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EIGHTH

AEC AIR CLEANING CONFERENCE

Held at
Oak Ridge
National Laboratory

Oct. 22-25, 1963

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EIGHTH

AEC
AIR CLEANING CONFERENCE

Held at
Oak Ridge National Laboratory

Oct. 22-25, 1963

Sponsored
by

Harvard Air Cleaning Laboratory, Harvard University

Oak Ridge National Laboratory, Oak Ridge, Tennessee

Division of Reactor Development, U S Atomic Energy Commission

EDITED

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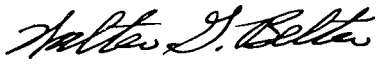
PREFACE

As the nuclear power industry continues to grow and develop, certain limiting aspects of this development are integrally related to improved air and gas cleaning technology. In assessing engineered safeguards for reactor siting and confinement or containment, the degree of reliability which can be placed on gaseous and particulate clean-up systems is of prime importance. This area along with increased emphasis on fission product release and behavior highlighted the holding of the Eighth Air Cleaning Conference at the Oak Ridge National Laboratory from October 22-25, 1963.

The largest meeting of this series, which dates back to June, 1951, numbered approximately 225, including representatives from Canada, France, and the United Kingdom. The program was developed as a joint effort between the Harvard Air Cleaning Laboratory and the Environmental and Sanitary Engineering Branch of the Division of Reactor Development.

While the first two days of the conference were devoted to formalized papers, the entire third day was taken up by four, informal panel discussions. The importance of meteorology to air and gas cleaning operations was emphasized in one afternoon session.

A special note of thanks is extended to the many Oak Ridge National Laboratory and Atomic Energy Commission-Oak Ridge Operations Office personnel who made this meeting a success. The required last minute change in meeting room location and the several guided tours to K-25 and ORNL were handled in a most efficient and congenial manner. It was a pleasure holding this conference at Oak Ridge.



Walter G. Belter, Chief
Environmental & Sanitary Engineering Branch,
Division of Reactor Development

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The 8th AEC Air Cleaning Conference was a joint effort on the part of the following organizations; the individuals named planned and coordinated the program:

Dr Leslie Silverman
Harvard Air Cleaning Laboratory
Harvard University

Dr C. S. Shoup
Research and Development Division
United States Atomic Energy Commission
Oak Ridge, Tennessee

Mr D.C.Costello
Environmental and Sanitary Engineering Branch
Division of Reactor Development
United States Atomic Energy Commission

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OPENING SESSION

22 October 1963

INTRODUCTORY REMARKS

D. C. COSTELLO
U. S. Atomic Energy Commission
Washington, D. C.

I will call the meeting to order, now, if you please.

For all of you who have not attended the last few Conferences, I am Dave Costello from the Environmental and Sanitary Engineering Branch of the Division of Reactor Development, Headquarters, AEC.

First I would just like to mention a change that has come up. At zero hour we were required to change our Conference location. There was nothing we could do about it. You probably have heard about the strike that is going on now at Oak Ridge.

The Management of the Operations Office obtained this alternate location and we certainly do appreciate it. Everything is going to work out all right.

There have been some inconveniences but hope you will bear with us. It is just one of those things that happened almost over night.

I want to welcome all of you here this morning, and would list a few of the representatives. We have groups from AEC Headquarters in Washington; our AEC Operations Office; Oak Ridge National Laboratory; contractors -- that is, the AEC contractors -- other Government agencies; universities, and private industry.

I would like to extend a special welcome to our foreign visitors. We have representatives from Canada, the United Kingdom and France; we just received a wire that our representatives from West Germany will not come, unfortunately.

As far as the program is concerned, we have 31 papers, and there are a few changes on the Agenda that are very minor. We will make corrections as we go along.

There has been a tremendous increase in interest in this field. I believe the Oak Ridge papers alone could have run this Conference for us, so you can see how the thing has expanded to this stage of the game.

I would like to say we will try to hold strictly to the time schedule. We have a heavy program, and we are going to give a five-minute bell warning. We would like each paper to end on time, about 15 minutes each, and leave a few minutes for pressing questions. If some speaker wants the audience to break in and ask questions, it's up to you to raise your hand and be recognized. Give your name and affiliation.

We are, of course, very sorry we could not accommodate all submitted papers. We had over two times the number we actually could accommodate. We certainly want to thank all you for preparing them. They will go in the Conference Proceedings.

As far as announcements are concerned, tomorrow morning we would like to start at 8:30 A.M. We will stick to the schedule as far as today is concerned, but tomorrow morning we would like to start the meeting at 8:30 A.M. That would mean we would break for lunch at quarter of 12:00 Noon for roughly a half hour sooner than we had originally planned.

Before finishing I would like to thank those who have greatly assisted us here: Sam Shoup; Ray Hervin and secretaries; Frank Bruce; Don Cowen; Steve Sinichak; Bob Schneider; Walt Stockdale from the Oak Ridge National Laboratory; and, John Arendt from the K-25 group. Many others that assisted us in setting up this program, and we certainly appreciate their effort.

I would next like to have the pleasure of introducing our first speaker this morning. He is a man well known in the Atomic Energy Field. He has held top management positions in this program since 1946. He has been in this present position since 1951. It gives me great pleasure to introduce to you this morning the Manager of the Oak Ridge Operations of the Atomic Energy Commission at Oak Ridge. Mr. S. R. Sapirie.

S. R. SAPIRIE
Manager
Oak Ridge Operations

Gentlemen, it is a real pleasure for me to be able to welcome you to Oak Ridge on behalf of Oak Ridge Operations of the Atomic Energy Commission. The Oak Ridge National Laboratory, your host, and the Division of Reactor Development, the sponsor for this meeting, have developed an extremely interesting and full agenda for your meeting, so my remarks will be extremely brief.

I understand that this is the first Conference of this type to be held in Oak Ridge, although before the numbered Conferences were scheduled, there were several meetings of the Stack Gas Working Group, and I think the meeting immediately preceding the first Conference was held in Oak Ridge, but since this is the first numbered Conference held here, there may be a number of you that have not visited Oak Ridge before. Particularly for those who have not been here before, I am sure that you will find a visit to the Oak Ridge National Laboratory, and the adjacent community here, to be both interesting and enjoyable.

This Conference, as I understand it, will have an attendance of between 200 and 250. This is almost twice the number of 125 that attended the last Conference at Brookhaven, two years ago. I think this alone indicates the increase in interest in the air-cleaning problems.

The problems are extremely important to the Atomic Energy Commission, but the Commission alone is not unique in recognizing air-cleaning problems. All of industry has similar problems. So I am sure that there will be a lot of technological spin-off from your meeting, and from the related research that is being recorded here that will be of interest to industry as a whole. This fact is also reflected by the increase in number of articles and various technical journals on your problems, and the increase in attention being given to air-cleaning problems by the popular press.

I am sure that your meeting here will be extremely productive. I hope it is also enjoyable. If there is anything that our staff can do to help you, do not hesitate to call upon us. Thank you.

D. C. COSTELLO
U. S. Atomic Energy Commission
Washington, D. C.

Thank you very much, Mr. Sapirie.

Next I have the pleasure of introducing my own supervisor, Mr. Walter Belter, of the Environmental and Sanitary Engineering Branch. This Branch is under the Director of Nuclear Safety of the Division of Reactor Development.

Mr. Belter plans to give us some more details on the Conference here this morning. It is a pleasure for me to introduce Mr. Walter Belter.

W. G. BELTER
U. S. Atomic Energy Commission
Washington, D. C.

Thank you Mr. Costello. Also, thank you, Mr. Sapirie, for the most cordial welcome to the Oak Ridge National Laboratory. We are really pleased to be able to hold the Eighth Air Cleaning Conference at the Lab.

As many of you know, the Division of Reactor Development has been sponsoring and organizing air-cleaning conferences for approximately the past 12 years, with the first meeting having been held at Harvard University in June of 1951.

In developing a program for a meeting of this type, one will look back at the Proceedings of the previous meetings to see what the problems were five, six, or seven years ago. Who were some of the people who were involved in those meetings at that time? How, possibly, do the problems in air and gas cleaning compare with the operations and activities of those days? It is interesting to note the number of familiar faces who attend these conferences time after time in addition to the many newcomers that we see each year. As Les Silverman has remarked from time to time, we always have approximately 50% newcomers for each meeting.

As Mr. Sapirie indicated, the attendance at these conferences get larger and larger each time, which tends to make the development of a program somewhat more difficult.

If you recall the last Conference at Brookhaven two years ago, we had a total of something like 37 formal papers presented in about 2 1/2-day period. We could have used easily another half-day for questions and further discussions.

This year we are going to try a somewhat different approach. We are planning only a two-day session, with formal papers, with ample time for discussion after each of these sessions. On Thursday, we are then planning to hold four round-table panel discussions, which are going to be highly informal, and which should provide ample time and opportunity for active discussion and participation by everyone in the audience.

In looking at our program agenda for the next two days, one cannot but help notice the tremendous difference in the program content when compared with the Conference that we held six years ago at Harvard. This, you will recall, was the last time that we held a laboratory training session, which was conducted for two days prior to the formal meeting by Dr. Silverman and his Harvard Air Cleaning Laboratory staff.

The formal meeting itself, you recall, was primarily a review and summarizing of air-cleaning operating activities at the various AEC sites, with the exception of the last day which was essentially devoted to the laboratory research work at Harvard.

During the past six years the Power Reactor Development program has really come to the fore: the problems of reactor siting; the location of power reactors near large cities; problems of reactor confinement or containment; fission product release in case of a reactor incident; the types of gaseous and particulate clean-up systems which can be used; how effective are they for radio-iodine removal under various conditions of pressures, temperatures, steam, et cetera; what type of meteorologic control is required for routine or accidental releases of gaseous effluents. These are only a few of the questions which are related to air and gas cleaning, and which are plaguing many of the people in the reactor development program at the present time.

Other reactor development programs such as the SNAP and ROVER programs, have associated air-cleaning problems, and also meteorological problems which are of interest and possible concern.

High temperature filters which will function satisfactorily above 1,000°F may be required in the not too distant future for applications at test stands for nuclear rockets, and ram jet engines.

In terms of some other problems, we still have the potential noble gas-release problem associated with chemical reprocessing, and, of course, the rare gas problem associated with reactor operation. As you perhaps know, the first commercial chemical reprocessing plant is now under construction in the State of New York. With future high burn-up fuels, the release of Krypton-85 could possibly be controlling, and might affect the future operations of this plant. The release of noble gases could also be the controlling factor in the building of large power reactors in populated areas, as well as being the most restrictive factor in bringing some of our nuclear-powered ships into populated ports. We believe that much work still remains to be done in developing larger scale noble gas-removal equipment.

In looking at the program for this morning I note that one of the problem areas mentioned, that is, the quantifying, or description of fission products release or behavior under certain operating or accident conditions, is the subject of actually the first several papers.

Another interesting session tomorrow morning is the confinement and containment approaches, which are being investigated.

We are quite pleased to welcome several of our meteorologist friends, who will participate in this meeting. The session on Wednesday afternoon, on the meteorological aspects of air cleaning, shows the increased emphasis that we are placing on this part of the gaseous effluent problem.

We are always glad to have our counterparts from foreign countries, such as the United Kingdom, France and Canada join with us in any of our waste-management meetings.

For those of you from foreign countries who are not already on the program, we have allotted some time at the end of Wednesday afternoon in order that we may have the opportunity to hear some of your experiences, and also the results of your research and development activities in the air-cleaning field.

It is again a pleasure to have Dr. Morgan and Mr. Jamison and Mr. Kornegay from our Johns Hopkins Contract, who will be responsible for our recording and handling the Proceedings of this Conference.

We would like to think that the information which is presented at the Air Cleaning Conferences, and published in the Proceedings, is being widely used in the design and operation of the AEC contractor and licensee air and gas-cleaning systems. We are quite hopeful that we will be able to publish this report quicker than any of the others to date.

We sponsored an air-cleaning laboratory training session at Harvard in June 1957. We might be thinking about this in the next several days so that at the end of the meeting we could decide whether it would be desirable to repeat this training type of session in conjunction, possibly, with the next air-cleaning conference. The holding of any session of this type obviously depends on your general interests and requirements.

We are again pleased that many of you could turn out for this meeting, and I am particularly pleased at this meeting room facility. Certainly, from the standpoint of transportation, being close to our living facilities here, and the meeting room itself, I am sure we could not have done as well in the 4500 Building.

So, we are hoping that the presentations and informal discussions which will follow will be of interest, and certainly useful to you in your work.

As we glance at this morning's session, it is my pleasure to introduce to you your morning Session Chairman, Mr. Frank Bruce, of the Oak Ridge National Laboratory. I am sure that many of you know him from his association with the Nuclear Safety Research and Development work which is being conducted here at Oak Ridge National Laboratory, and for which he has direct responsibility.

Also, Mr. Bruce is responsible for all of the Safety activities within the ORNL operations. Prior to that he was very much involved in the Chemical Technology Division at the Laboratory, in the chemical reprocessing work, and also was responsible for much of our waste treatment research development work here. Right now he is responsible for the Nuclear Safety work, which includes much of the fission product release work being conducted for the Commission. There are several papers on that subject in this session.

It is with great deal of pleasure that I introduce to you now Frank Bruce of the Oak Ridge National Laboratory.

F. R. BRUCE
Assistant Deputy Director
Oak Ridge National Laboratory

Thank you, Mr. Belter. The safety and operating of the reactors in populated areas is a matter of primary importance to the nuclear-energy industry today. In addressing himself to this question, Dr. Beck of the Division of Licensing and Regulations recently expressed cautious optimism concerning the location of reactors near populated areas.

In support of his position he referenced two facts: first, the recent accumulation of knowledge on the release and behavior of accident-released fission products; and, secondly, developments in engineered safeguards, such as water sprays, filters, foam encapsulation, and other techniques, which may be used to remove fission product aerosols from containment vessel atmospheres.

It is, therefore, very appropriate, I think, that the first session of this Conference concern itself with the matter of fission product release and behavior, and with methods for removing the hazard controlling radioisotope Iodine-131 from gaseous effluents.

In later sessions of the Conference there will be further discussions of containment, and engineered safeguards.

SESSION I - PARTICLE AND GAS RELEASES AND THEIR BEHAVIOR

Morning - 22 October 1963

F. R. Bruce, ORNL, Chairman

The first paper of Session I is entitled, "Release of Fission Products on In-Pile Melting or Burning of Reactor Fuels," the authors being C. E. Miller, W. E. Browning, Jr., B. F. Roberts, and R. P. Shields, of the Oak Ridge National Laboratory. The paper will be given by R. P. Shields.

RELEASE OF FISSION PRODUCTS ON THE IN-PILE MELTING OR BURNING OF REACTOR FUELS

R. P. Shields
W. E. Browning, Jr.
C. E. Miller, Jr.
B. F. Roberts

Reactor Chemistry Division, Oak Ridge National Laboratory , Oak Ridge, Tennessee

In-pile experiments are being conducted to study the release of fission products during simulated reactor accidents. Two types of experiments have been performed in the Oak Ridge Research Reactor to simulate reactor accidents in which fuel elements are destroyed by melting or burning. One type consisted of melting or vaporizing a miniature stainless-steel-clad UO_2 fuel element in a helium atmosphere. In the other type, a miniature fuel element composed of spheroidal particles of uranium carbide coated with pyrolytic carbon and embedded in a graphite matrix was burned in air. In each case, fission and gamma heat raised the temperature of the fuel element high enough to cause destruction. The details of design and operation of these experiments have been described previously.[1,2]

UO_2 Melting Experiments

In a typical in-pile meltdown experiment a miniature UO_2 fuel element clad in stainless steel is placed in a helium filled container of stainless steel, Fig. 1 which is lined with ceramic thermal insulation. This assembly is moved to a position close to the top of the lattice of the Oak Ridge Research Reactor to build up traces of fission products in the UO_2 specimen. At the end of irradiation period the assembly is lowered into a position where fission and gamma heat cause the specimen to melt. Helium gas sweeping over the specimen carries gas-borne fission products to suitable filters and traps where they are separated and collected. After the specimen is withdrawn from the flux, the furnace, filters, traps, and associated tubing are removed from the reactor. These parts are then cut up in a hot cell, examined, and analyzed for fission products.

Eleven experiments have been run, the first two of which were mainly for testing equipment although fission product release information was gained. The conditions for the next seven were identical, that is, 6% enriched UO_2, 400 cm^3 per min helium flow and the same time at the melting position. The inherent variation in the reactor neutron flux, however, caused a spread in the maximum temperature and resulted in partial melting in some cases and complete melting in others. The flow of helium sweep gas was increased from 400 to 800 cm^3/min for Experiment 10 and 4000 cm^3/min for Experiment 11; otherwise, the conditions were the same as in the preceding UO_2 meltdowns.

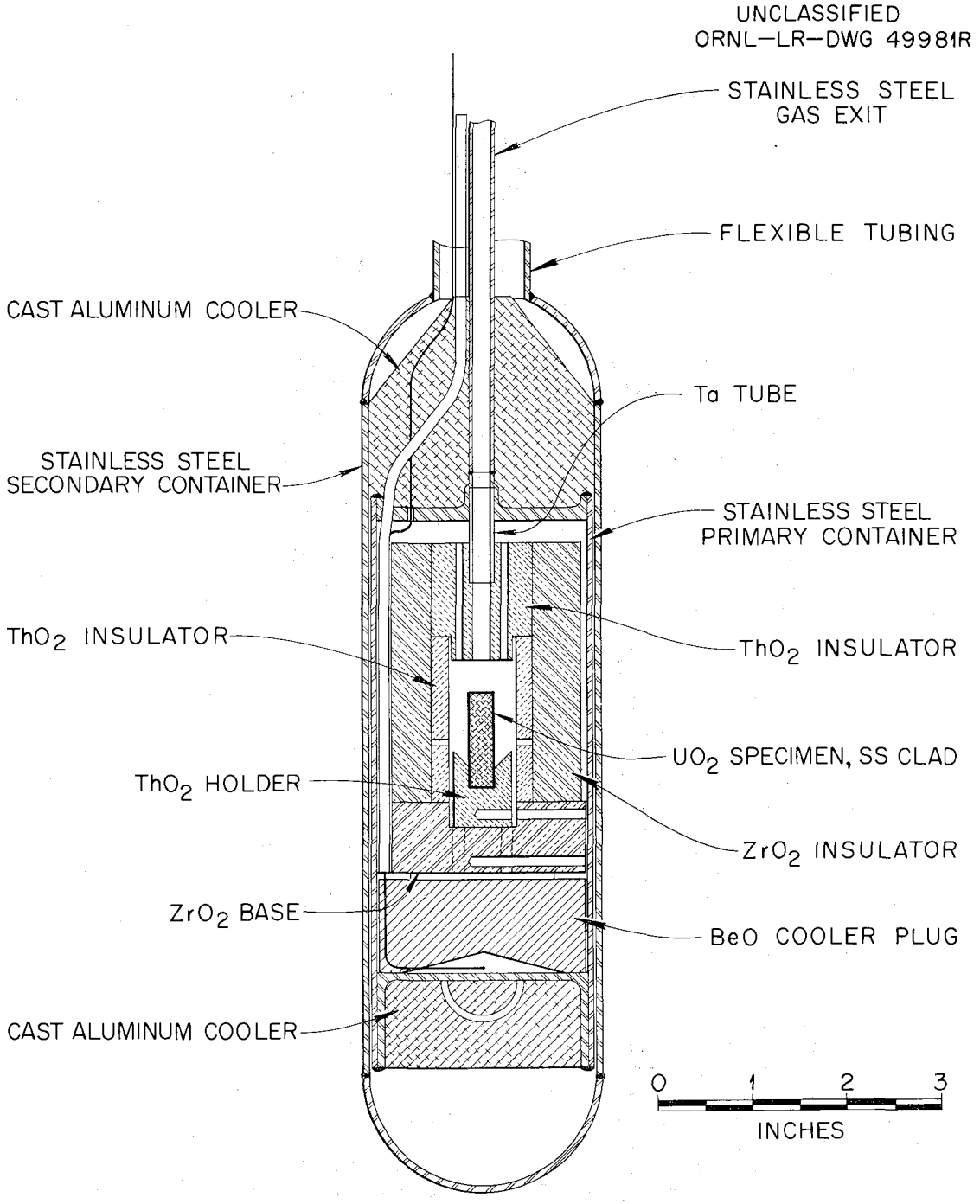


FIGURE 1

Reactor Furnace; for Fuel Element Meltdown Experiments.

The analytical results of the experiments through Number 10 have been discussed in detail[3,4] and the physical appearance of the UO_2 after the melting is described in references (1, 5). The results summarized in Tables 1 and 2 show the percentages of the various fission products released from the fuel residues and holder and the percentages of the isotopes which escaped from the high temperature zone of the furnace. Each value is based on the total amount of that fission product found throughout the experimental assembly. The data in Table 1 except for Experiment 7, show, in general, that nearly all of the I, Te, and Cs and more than half of the Sr, Zr, Ru, Ba, and Ce were released from the fuel. One-third to one-half of the UO_2 was released and the fission products contained in this UO_2 were considered to be released from the fuel. Fission product release was generally greater in Experiment 2 which had apparently reached a higher maximum temperature and which was irradiated unclad.

The values given in Table 2 are release values from the high temperature zone of the furnace. This zone consists of the volume enclosed by and including the ZrO_2 thermal insulation. The temperature of this zone during the period in which the UO_2 was molten was 1000°C or greater. In Experiment 2 strontium and barium were swept out of the furnace in the form of gaseous krypton and xenon by the helium during irradiation of the unclad fuel. The Ba^{140}, for example, was found in the charcoal trap where it would be expected if it had been carried as Xe^{140}. Comparing the release of fission products from the high temperature zone (Table 2) with that released from the fuel (Table 1), there was a slight decrease in the release of I, Te, and Cs, and a considerable decrease in the release of Sr, Zr, Ru, Ba, Ce, and U. Release of these latter fission products and uranium from the high temperature zone was generally less than 3%. This decrease in release values from fuel to high temperature zone is considered significant since during an actual reactor accident temperatures corresponding to those of the high temperature zone would probably occur only within the reactor containment.

The consequences of the increased helium flow in Experiments 10 and 11 appear to be a reduction in the release of the less volatile fission products caused by a reduction in temperature, and an increase in the release of these products from the high temperature zone because of the higher velocity of the sweep gas.

Characterization Studies of Released Fission Products

The distribution of fission products and uranium among the various regions in each experiment is being analyzed and interpreted in terms of the fractionation processes which govern the behavior of these materials. Fractionation refers to any alterations of the radionuclide composition occurring during the experiment which results in a sample composition different from that predicted for normal fission yields. Similar fractionation studies have been reported by Freiling in the study of debris from nuclear detonations.[6] Fractionation occurs because of differences in characteristics of the fission products leading to differences in release or deposition mechanisms. A study of fractionation, then, should lead to a better understanding of both the mechanisms and the characteristics. As an example of the type of data analysis which is being used in the fractionation studies, the ratio of Ba^{140}/Zr^{95} vs Sr^{89}/Zr^{95} is plotted in Fig. 2 for Experiment 7. The equation of the line empirically determined is shown. In this plot the abscissa may be regarded as a measure of the intensity of the volatilization conditions to which each sample, represented by a point on the plot, has been exposed. Since Sr^{89} is more volatile than Zr^{95}, points to the right represent samples with increasing amounts of volatilized Sr^{89}, for example, samples from cooler regions, while points to the left represent samples progressively depleted in Sr^{89}. The ordinate is a measure of the degree to which Ba^{140} volatilized for each volatilization condition on the abscissa.

Table 1. Material Released from the Fuel in UO_2 Melting Experiments (%)

Sample length, 1. in; diameter, 0.210 in; sample molten 5 min except Experiment 2, 10 min; helium flow, 400 cc/min, except Experiments 10 and 11, 800 and 4000 cc/min

Expt.	Sr^{89}	Zr^{95}	Ru^{106}	I^{131}	Te^{132}	Cs^{137}	Ba^{140}	Ce^{144}	UO_2
2	99.8	87.3	88.0				99.7	93.0	50.0
3	93.0	86.9	51.2				96.1	85.2	42.7
4	76.6	55.5	82.8	99.6			94.1	58.9	44.5
5	57.3	42.9	90.8	99.4	98.4	97.2	55.4	44.6	34.5
6	54.6	60.1	59.8	99.0	91.4	98.6	51.7	48.7	46.8
7	5.21	0.908	10.9	96.0		96.5	14.0	2.50	0.710
8	43.7	58.1	57.4	98.7	97.6	98.0	70.0	43.4	36.0
9	71.3	71.5	93.1	99.7	99.1	98.8	71.2	70.3	70.5
10	68.8	57.7		97.3	95.9	94.9	72.5	59.3	55.8
11	18.3	12.2	48.4	97.7	99.4	96.3	26.3	7.58	5.08

Table 2. Material Released from High Temperature Zone[a] of the Furnace in UO_2 Melting Experiments (%)

Expt.	Sr^{89}	Zr^{95}	Ru^{106}	I^{131}	Te^{132}	Cs^{137}	Ba^{140}	Ce^{144}	UO_2
2	20.1	0,115	2.84				14.5	0.508	4.08
3	1.24	0.110	0.614				0.732	1.78	0.0520
4	2.90	0.0465	6.60	94.5			0.941	0.651	0.773
5	1.44	0.0200	5.22	87.0	79.2	79.0	2.30	0.328	0.233
6	0.911	0.0896	1.32	94.3	48.8	81.9	0.547	0.0675	0.291
7	0.866	0.0370	2.15	49.7	11.5	74.1	0.576	0.322	0.00894
8	1.28	0.0508	1.73	95.4	81.4	87.5	0.824	0.244	0.0197
9	0.974	0.123	4.022	79.70	89.34	58.14	1.118	0.302	0.0128
10	2.119	2.819		89.46	71.45	79.73	2.837	1.003	0.289
11	2.93	0.568	0.198	89.0	69.5	86.4	8.01	1.24	1.64

[a]High-temperature zone includes fuel material and thermal insulation; minimum temperature, 1000°C.

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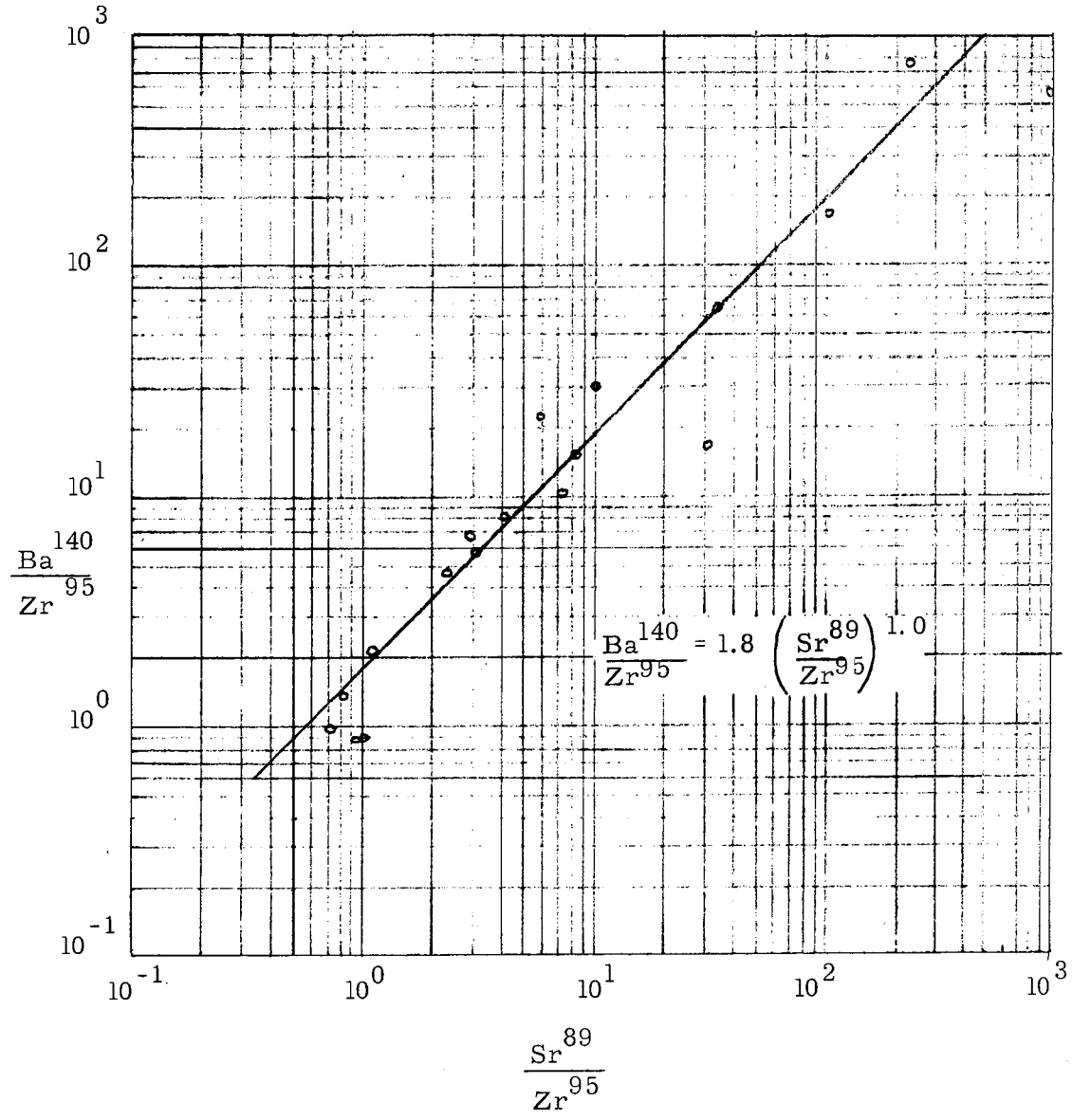


Figure 2 - Fractionation of Ba^{140} vs Sr^{89}

This plot indicates that Ba^{140} and Sr^{89} behave similarly and are both more volatile than the reference Zr^{95}. In a similar plot for Ru from Experiment 7, the slope is greater than unity, indicating that the Ru was more volatile than the Sr. In Experiment 8 the slope for Ru was unity indicating that its volatility was nearly the same as Ba^{140}. The difference in the slope probably represents a difference in the release mechanism since the fuel in Experiment 7 did not melt extensively while that in Experiment 8 did. One result of the fractionation studies is the conclusion that in several of these experiments, ruthenium follows the stainless steel cladding as the cladding melts into a puddle and subsequently vaporizes to other areas of the assembly. The mechanism for this is not yet known. However, it is anticipated that this work should lead to the formulation of models which explain the observed distributions and which may provide a basis for predicting the behavior, especially that in a controlled system of accident released fission products under various conditions. A knowledge of fractionation mechanisms will aid in the recognition of the relative importance of the various factors which define a reactor accident.

The characterization of released fission products by the diffusion tube method is being continued. Early results of this method were previously reported.[3]

In-Pile Burning of UC_2-Graphite Fuel

Three experiments have been conducted in the Oak Ridge Research Reactor at ORNL in which fuel specimens consisting of pyrolytic-carbon-coated uranium carbide particles embedded in a graphite matrix were burned at temperatures up to approximately 1400°C. In two of these experiments, fission and gamma heat produced a sufficiently high temperature for a large portion of the fuel to burn during the 15-min. period in which air was supplied as the sweep gas. The method of running the experiment and the results of the first experiment were described previously.[3] The specifications for the specimen and pertinent experimental conditions are listed below:

Fuel Specimen

Particles	Uranium Carbide spheres 175-250μ Laminar pyrolytic-carbon coating 75-100μ thick
Matrix	Graphite
Manufacturer	Minnesota Mining and Manufacturing Company
Dimensions	0.6-in. bushing, 0.5 in. long with 0.25-in. axial hole
Uranium content	8 to 10 wt. % natural uranium

Burning Conditions

Initial temperature	890°C
Combustion temperature	Up to 1400°C
Air flow rate	400 cm^3/min
Burning duration	15 min

As the graphite matrix burned, some of the fuel particles fell away from the unburned fuel. Metallographic examination of these particles and those in the unburned fuel showed that the damage to particles ranged from none to complete destruction of the coating and oxidation of the uranium carbide; however, it was not possible to determine the percentage of particles which belong in these categories. Some of the particles which remained in the unburned fuel also showed cracks. In Experiment 1, a count of the damaged and undamaged particles in the exposed surface of the fuel showed that about 45% of the particles had at least one crack in the coating. Experiment 2 was discarded without obtaining radiochemical analyses because the low uranium

content of the specimen made a comparison with the other burning experiment impossible.

The results of Experiment 3, for the most part, confirmed the conclusions from Experiment 1. In the first experiment, 3,7 58% of the specimen burned as compared with 41% in the third. In the third experiment, most of the uranium carbide in the specimen was concentrated on one side, and this side burned very little; 93% of the uranium found by analyses was in the unburned fuel.

The release of Sr, Zr, Ba, Ce, and U from the high-temperature zone of the furnace was very low, but large fractions of I, Te, and Cs were released. Forty percent of the Ru was released from the furnace in Experiment 1 and 5.7% in Experiment 3. The loss of ruthenium in the first experiment was probably due to the formation of volatile oxides. A large fraction of some of the fission products was probably retained inside those particles with undamaged pyrolytic-carbon coatings, especially those in the unburned fuel. Determination of the release of krypton and xenon was omitted to avoid collecting oxygen in liquid-nitrogen cooled charcoal absorbers. The following conclusions, based on Experiments 1 and 3, can be made:

1. Strontium, barium, zirconium, and cerium were retained where they are formed.

2. The unburned fuel retained 88 to 97% of the iodine associated with the uranium of the unburned fuel.

3. The following were released from the high temperature zone of the furnace: 15 to 25% of the I, 15 to 25% of the Te, and 35 to 40% of the Cs.

4. The release of ruthenium varied between 5 and 40%.

5. An appreciable amount of Cs (10% of total), Ru (1%), and I (1.5%) penetrated the filter, but Te was retained by the filter.

6. The fragments which fell away from the specimen during burning contained the same percent of carbon as the unburned fuel.

7. The side of the specimen with the least amount of uranium carbide burned more rapidly than other portions.

The results of both melting and burning in-pile experiments show that, although large fractions of the fission products were released from the fuel, they were almost entirely retained inside the high temperature zone of the furnace with the exception of iodine, cesium, and tellurium; if oxygen is present, ruthenium is also released. The noble gases appear to be released completely. These results suggest that for the conditions tested, effective retention of many fission products may be expected by high temperature surfaces near the hot zone in reactor accidents. Of the fission products released from the high temperature zone, significant fractions were carried as particles as small as 20 to 30A$^{\circ}$ in diameter. This work is being continued with emphasis being placed on the effects of the conditions of reactor accidents on the amounts and forms of released fission products.

Table 3. Fission Products and Uranium from In-Pile Burning Experiments

	Material Found (Percentage of Total in Assembly)								
	Sr^{89}	Zr^{95}	Ru^{106}	I^{131}	Te^{132}	Cs^{137}	Ba^{140}	Ce^{144}	U
Unburned fuel[a]									
Experiment 1	50.6	58.2	27.0	59.7	47.6	38.1	51.7	54.8	61.9
Experiment 3[b]	75.4	83.9	87.0	82.4	76.1	39.1	84.9	85.3	93.9
Outside of fuel residue[c]									
Experiment 1	13.8	3.7	48.2	28.9	42.7	51.3	14.5	9.05	2.12
Experiment 3	13.1	5.04	8.81	16.5	23.2	54.5	6.96	6.98	0.877
Retained in furnace									
Experiment 1	98.8	99.5	59.3	73.2	64.9	63.0	99.5	93.8	99.6
Experiment 3	98.7	98.7	94.3	85.6	85.7	58.4	99.3	97.1	99.8

[a] 58.6% of the sample was burned in Experiment 1 and 41% in Experiment 3.

[b] Experiment 2 was not analyzed because of low uranium content in the specimen.

[c] Fuel residues include the unburned portion of the specimen, fuel particles and powder, and the floor of the combustion furnace.

References

1. W. E. Browning, Jr., et al., Nuclear Safety Program Semiannual Progress Report June 30, 1962, ORNL-3319, pp. 29-38.

2. W. E. Browning, Jr., et al., Reactor Chemistry Division Annual Progress Report January 31, 1962, ORNL-3262, pp. 172-76.

3. W. E. Browning, Jr., et al., Nuclear Safety Program Semiannual Progress Report December 31, 1962, ORNL-3401, pp. 27-35.

4. W. E. Browning, Jr., et al., Nuclear Safety Program Semiannual Progress Report June 30, 1963, ORNL-3483, pp. 22-26.

5. W. E. Browning, Jr., et al., Reactor Chemistry Division Annual Progress Report January 31, 1963, ORNL-3417, pp. 236-243.

6. E. C. Freiling, Science 3, 1991-8 (1961).

7. W. E. Browning, Jr., et al., Gas-Cooled Reactor Monthly Progress Report September 1962, ORNL-3372, pp. 256-59.

DISCUSSION AND COMMENT

Variations of release in steam atmosphere would be expected. The variations in release mechanisms and particle sizes would probably occur when oxygen would be introduced. There are no future plans for carbide fuels. A later paper will describe diffusion tube separation of particles produced by melting fuels. Release in a water environment will be studied at a later date.

Session Chairman: The paper "Current Studies of Fission Product Behavior at BNL," by A. W. Castleman, Jr., and F. J. Salzano will be delivered by Mr. Lee Gemmell of that Laboratory's Health Physics Division. We regret that neither of the authors can be present; however, Mr. Gemmell is an able proxy.

CURRENT STUDIES OF FISSION PRODUCT BEHAVIOR AT BNL

by

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Brookhaven National Laboratory
Upton, New York

INTRODUCTION

Programs are under way at Brookhaven National Laboratory to study the behavior of fission products released from reactor fuel materials. Major emphasis has been placed on fission-product iodine because of the physiological hazard associated with the I^{131} isotope.

A complete reactor safety analysis, considering either a slow or rapid release of fission products, requires a knowledge of the chemical and physical states of the fission products during release, the extent of their release, and an understanding of their chemical interactions with the reactor environment.

RELEASE OF FISSION PRODUCTS FROM URANIUM AT HIGH TEMPERATURES

An extensive research effort has been carried out at BNL and other laboratories in the last few years for the purpose of studying fission product release rates from fuel elements. However, the subject is complex and not yet sufficiently understood. The purpose of the BNL work is, first, to develop a fundamental understanding of the fission product release mechanism; and second, to investigate the various factors which govern their physical and chemical behavior during and after release. It is expected that a detailed study of release from various reactor fuels under inert, oxidizing, and reducing conditions will provide data which can be used to predict fission product behavior in systems which have not been experimentally investigated.

The studies reported here are concerned with fission product release from metallic U and a U -3.5% Mo alloy into inert (He), oxidizing (air), and reducing environments. The experimental techniques have been previously described.[1,2] The fission products released into He and air were separated by condensing them (or their compounds) at different temperatures in a quartz tube, whose temperature decreased with length. The release of iodine into He and air from samples heated to temperatures between 1150° and 1250°C was studied in detail. Recently, preliminary results were obtained at temperatures up to 1800°C. These results are reported herein.

Most of the iodine released from U into He at temperatures between 1150° and 1250°C was in some combined form as evident from its deposition temperature zone shown in Fig. 1. (The condensation zone of other fission products is shown for com-

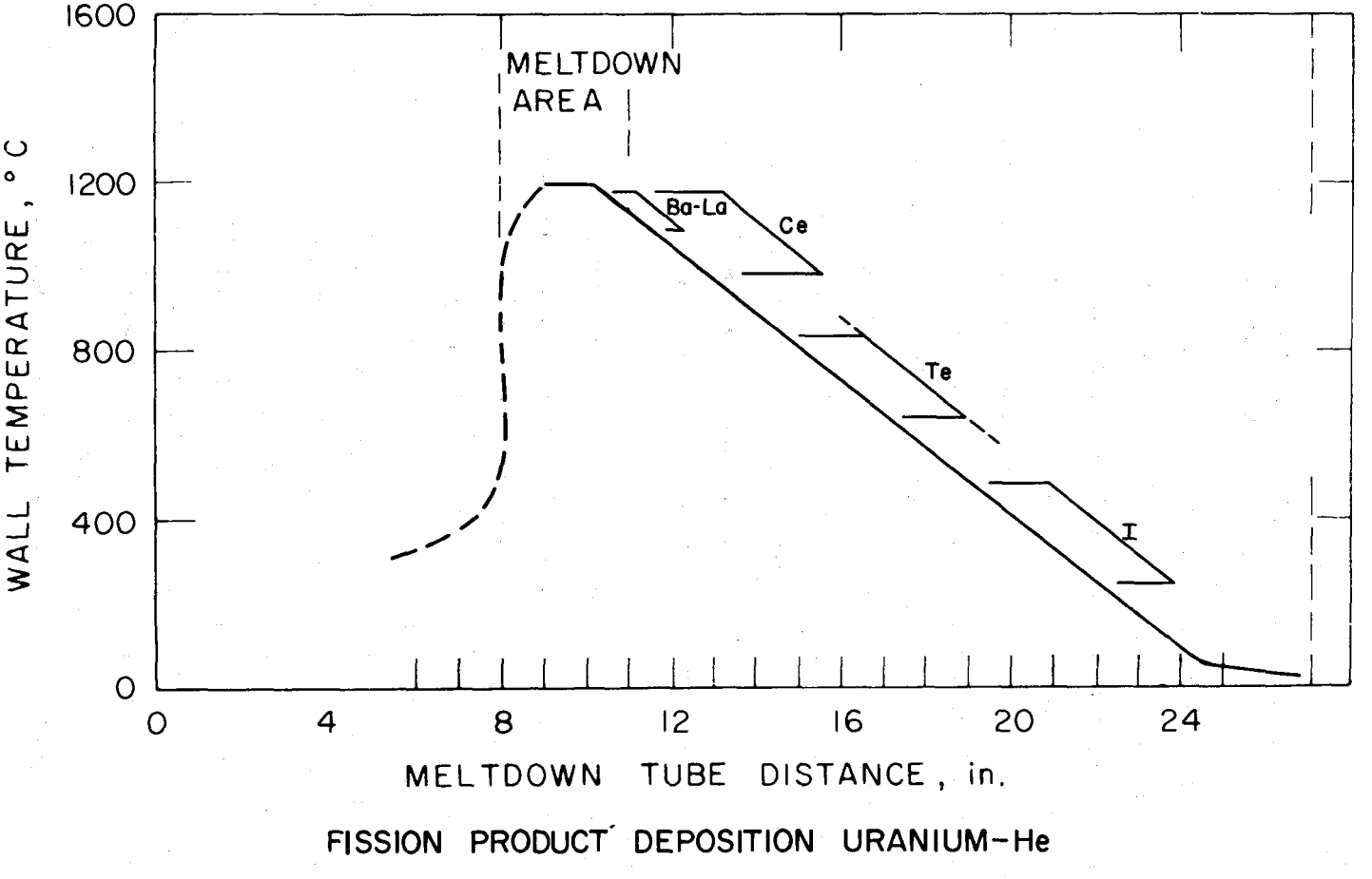

1600
1200
800
400
0
WALL TEMPERATURE, °C
MELTDOWN
AREA
Ba-La
Ce
Te
I
0
4
8
12
16
20
24
MELTDOWN TUBE DISTANCE, in.
FISSION PRODUCT DEPOSITION URANIUM-He

Figure 1

parison.) Elemental iodine is quite volatile and would not condense at such high temperatures (250° to 350°C). This is also borne out by the work of Hölemann and Braun[3] who studied the adsorption of microgram quantities of iodine on quartz surfaces in the temperature range 150° to 1000°C. Using their values, less than 3% of the iodine which deposited at 300°C could be attributed to adsorption, even assuming rapid equilibrium with the quartz surface. The iodine condensation was found to depend only on temperature, as evidenced by the fact that quartz, gold, and stainless steel surfaces behaved the same.

The released iodine from both metallic U and a U -3.5% Mo alloy was found to be identical in nature. This is consistent with thermodynamic estimates which show that molybdenum iodides are unstable under the conditions of a fuel meltdown. The above iodine release results were the same for fuels irradiated over the range of 3.0×10^{14} to 5.4×10^{19} nvt, showing that within this range there was no concentration dependence.

Two possible explanations could be offered for the observed iodine behavior:

1. Chemical combination with uranium.
2. Chemical combination with another fission product.

Considering the second, no other fission product was consistently associated with the iodine in its deposition zone. If the released iodine had formed a compound with some other fission products, CsI would be the most likely possibility, on the basis of free energy of formation values and on relative concentrations. The chemical activity of the Cs, however, is so low compared to that of the uranium, that the iodine is converted almost quantitatively to a uranium iodide. About 90% of the released Cs deposited in the temperature range 600° tc 800°C, while the quantity deposited in the iodine zone was a function of run-time and gas-flow rate. Undoubtedly, some reaction between the iodine compound and Cs occurs in the cell after release from the fuels with the higher burnups. The

iodine deposit was found to be unstable in air at 250° to 350°C, elemental iodine being slowly released. CsI is quite stable in air at these temperatures; uranium iodides, however, are unstable in air and would release elemental iodine to a flowing air stream as observed.

On the basis of these results, as well as thermodynamic and kinetic considerations, the released species is uranium iodide, probably UI_2. Approximately the right concentration of U was found in the deposition zones, but a definite ratio of U/I has not yet been established.

Preliminary results at 1800°C show that considerably more elemental iodine is released than at 1250°C. This would be expected, since the uranium iodides are less stable at the higher temperature.

The deposition behavior of fission products released into air is shown in Fig. 2. In contrast to the He results, elemental iodine rather than a uranium iodide is released from U heated to 1200°C in air. These results are summarized in Table I.

Iodine Reactions

Atmosphere	Reaction	Temperature
He	$U + 2I \longrightarrow UI_2$	1200°C
	$UI_x(ads.) + O_2 \longrightarrow UO_2I_2 + I_2$ $UO_2I_2 \longrightarrow UO_2 + I_2$	ambient
Air	$3U(I) + 4O_2 \longrightarrow U_3O_8 + I$	1200°C

Table I

Another series of experiments was undertaken to study the chemical state of iodine released from U into steam at temperatures between 1000° and 1320°C. Since hydrogen is evolved during the oxidation of the U, the fission products are re-

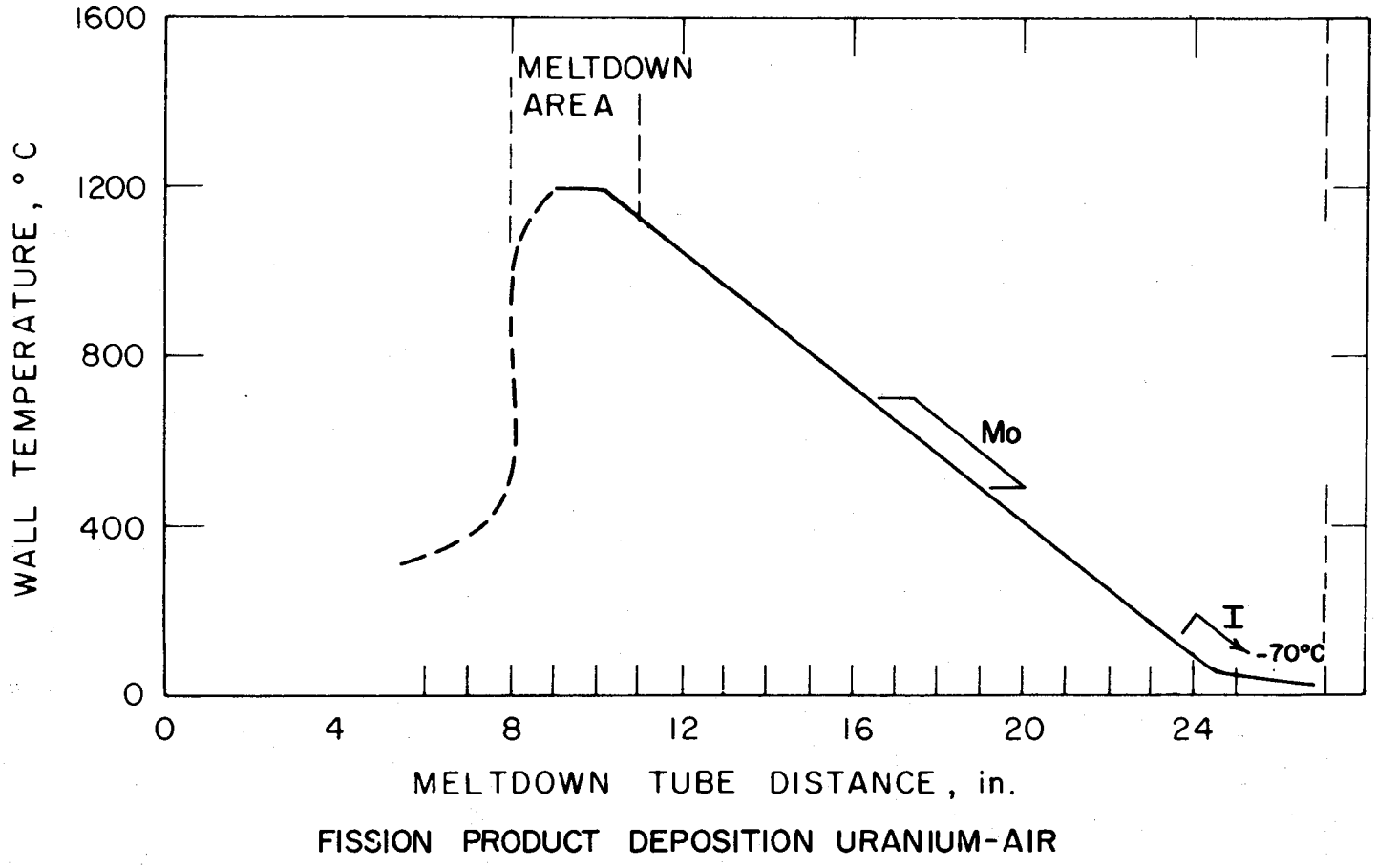

1600
1200
800
400
0
WALL TEMPERATURE, °C
MELTDOWN
AREA
Mo
I
-70°C
0
4
8
12
16
20
24
MELTDOWN TUBE DISTANCE, in.
FISSION PRODUCT DEPOSITION URANIUM-AIR

Figure 2

leased into a reducing medium. Some of the competing reactions associated with the iodine release are shown below.

(1) $U(F.P.) + 2H_2O \rightarrow UO_2 + 2H_2 + F.P.$

(2) $H_2 + 2I \rightleftarrows 2HI$ (Vapor phase)

(3) $I_2 + H_2O \rightleftarrows HIO + I^- + H^+$ (Aqueous phase)

(4) $3IO^- \xrightarrow{\Delta} IO_3^- + 2I^-$ (Aqueous phase)

Reaction (1) is the over-all reaction which liberates H_2 and fission products. The reaction between H_2 and iodine is shown in reaction (2). Although HI is relatively unstable with respect to molecular iodine and hydrogen, it is quite stable with respect to atomic iodine which is released from the U in steam. HI is very soluble in water and readily dissolves upon formation. Some elemental iodine dissolves in water according to reaction (3), but this is separated as elemental iodine and not collected as iodide ions in the analytical procedure.

Typical results of the release from metallic U at 1200°C are shown in Table II. Greater than 90% of the released iodine was collected as iodide ions. Essentially no difference in the iodine chemical state was found by varying the fuel temperature within the range 1000° to 1320°C. The pH of the water initially charged to the release cell was varied between 5.9 and 6.8; however, this had no apparent effect on the chemical state of the released iodine. The chemical state of the iodine is evidently a function of residence time after release, and depends primarily on subsequent chemical reactions, i.e., the

Table II

Iodine Release - Steam, Uranium System (1200°C)

Species	Average Percent
I°	8.7
I^-	90.9
IO_3^-, IO_4^-	0.4

hydrogen-iodine reaction kinetics. Less than 1/2% of the iodine was collected as IO_3^-, which is formed by the high temperature disproportionation of IO^- [reactions (3) and (4)].

BEHAVIOR OF IODINE ON GRAPHITE

Graphite is used as a moderator and fuel-matrix material in power reactors. In advanced types of high-temperature gas-cooled reactors it performs both functions. In such reactors, certain fission products, including iodine, will be released even during normal operation. These will be, to a certain extent, adsorbed on the fuel and any other graphite components. Therefore, it is important to understand and be able to predict the behavior of iodine in contact with graphite, i.e., the adsorption behavior and possible reactions with the bulk graphite.

Some preliminary results of the behavior of iodine on a reimpregnated graphite have been reported.[4] The adsorption of iodine was studied by using I^{131} tracer with a scintillation scanning probe. The techniques and procedure used in the present study are the same as those previously described.[4] The purpose of this report is to present a summary of the final results and conclusions.

The object of the study was to measure the adsorption of iodine on TSX graphite, a high-purity material. Initial studies[5] indicated considerable variation in the adsorption behavior of iodine on what was thought to be similar graphites. The adsorption behavior of iodine on this pure polycrystalline graphite was investigated over the temperature range of interest (100° to 800°C) in reactor systems. Moreover, certain variables, in addition to temperature and pressure, which could affect the adsorption behavior of iodine were studied. The other variables were (a) outgassing temperature, (b) heat treatment, and (c) contact with water vapor at 900°C. Since it has been established by several investigators[6-9] that there is no reaction of pure iodine and bulk graphite at temperatures up to 1000°C, one is only concerned with adsorption phenomena. Iso-

Table III

TABLE OF EXPERIMENTS

BEHAVIOR OF IODINE ON TSX GRAPHITE

1	2	3	4	5	6
Sample	Surface Area by Nitrogen M^2/g	Surface Area by Iodine Adsorption at 100°C M^2/g	Outgassing Temperature °C	Treatment	Experimental Procedure
C	0.38	0.24	2000	Outgassed at 2000°C. Exposed to air and reoutgassed in the equilibration capsule at 900°C	800°C Isotherm measured 500°C One point obtained at 1 mm Hg 100°C Isotherm measured
D	0.33	0.36	2000	Outgassed at 2000°C. Exposed to air and reoutgassed in the equilibration capsule at 900°C	800°C Isotherm measured 500°C Isotherm measured 100°C Isotherm measured
E	0.28	0.22	900	Outgassed in the equilibration capsule at 900°C	800°C Isotherm measured 500°C Isotherm measured 100°C Isotherm measured 200°C Isotherm measured
F	0.31	0.24	900°C	Equilibrated with 23 mm Hg H_2O vapor at 900°C, then outgassed at 900°C	800°C Isotherm measured 500°C Isotherm measured 200°C Isotherm measured 100°C Isotherm measured
G	Not measured	0.23	200°C	Outgassed in the equilibration capsule at 200°C	100°C Isotherm measured 200°C Isotherm measured

therms were measured at 100°, 200°, 500°, and 800°C over the pressure range 0.010 to 15 mm Hg.

RESULTS

A series of five graphite samples was studied. For the purpose of discussion they are given the letter designations C, D, E, F, and G. The surface area of each sample, as measured with nitrogen at -195°C, is given in Table III, along with the outgassing temperature and sample treatment.

The data obtained on iodine adsorption at 800°C for samples C, D, E, and F are shown in Fig. 3. The largest adsorption took place on sample C which was heated to the highest temperature, 2000°C (2150°C maximum), while the least adsorption took place on sample E which was heated to the lowest temperature, 900°C. The results from samples D and F, which were outgassed at 2000°C (2030°C maximum) and treated with water vapor at 900°C, respectively, fell between those from C and E.

The data obtained at 800°C can be adequately expressed by the Freundlich equation

$$Q = Kp^n$$

where Q is the quantity of iodine adsorbed in ppm, p is the pressure in mm Hg, and K and n are constants which depend on temperature and the nature of the adsorbing surface. In the table shown in Fig. 4, are listed the values of K and n obtained. As K decreases the value of n increases.

The data obtained on the adsorption of iodine at 500° and 200°C are shown in Fig. 4 and 5. The same co-ordinates are plotted as in Fig. 3. At these temperatures, the data no longer give a linear relationship. The isotherms are not similar in shape and show abrupt changes in slope. A consistent feature of the data is the relative positions of the adsorption isotherms, i.e., that sample which gave the highest adsorption at 800°C also showed the highest adsorption at 500° and 200°C. Neither the 500° nor the 200° data can be fitted by any of the common isotherm equations. From Table III, it can be seen that

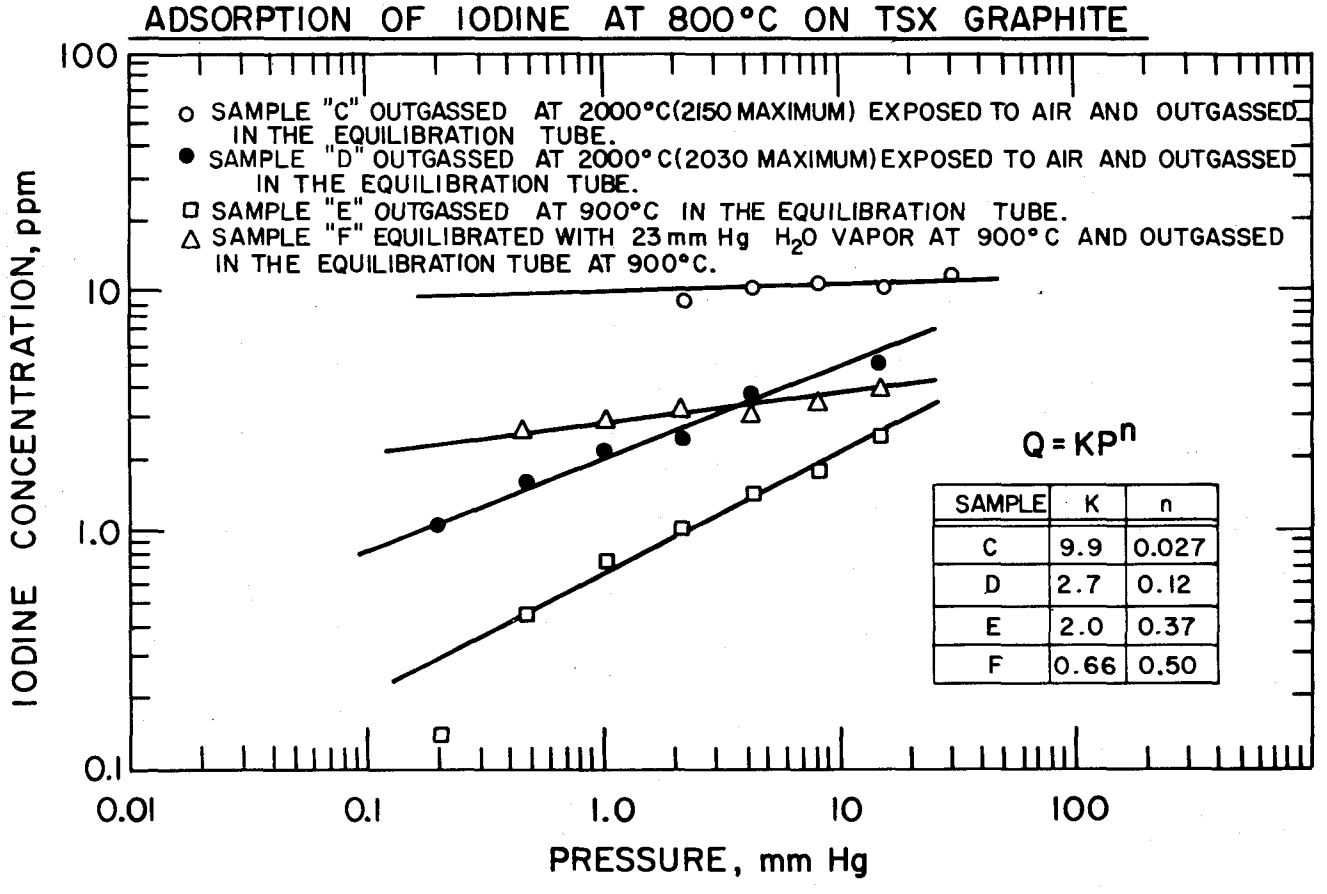

ADSORPTION OF IODINE AT 800°C ON TSX GRAPHITE
o SAMPLE "C" OUTGASSED AT 2000°C(2150 MAXIMUM) EXPOSED TO AIR AND OUTGASSED IN THE EQUILIBRATION TUBE.
● SAMPLE "D" OUTGASSED AT 2000°C(2030 MAXIMUM) EXPOSED TO AIR AND OUTGASSED IN THE EQUILIBRATION TUBE.
□ SAMPLE "E" OUTGASSED AT 900°C IN THE EQUILIBRATION TUBE.
△ SAMPLE "F" EQUILIBRATED WITH 23 mm Hg H_2O VAPOR AT 900°C AND OUTGASSED IN THE EQUILIBRATION TUBE AT 900°C.
$Q = KP^n$
SAMPLE K n
C 9.9 0.027
D 2.7 0.12
E 2.0 0.37
F 0.66 0.50
IODINE CONCENTRATION, ppm
100
10
1.0
0.1
0.01
0.1
1.0
10
100
PRESSURE, mm Hg

Figure 3

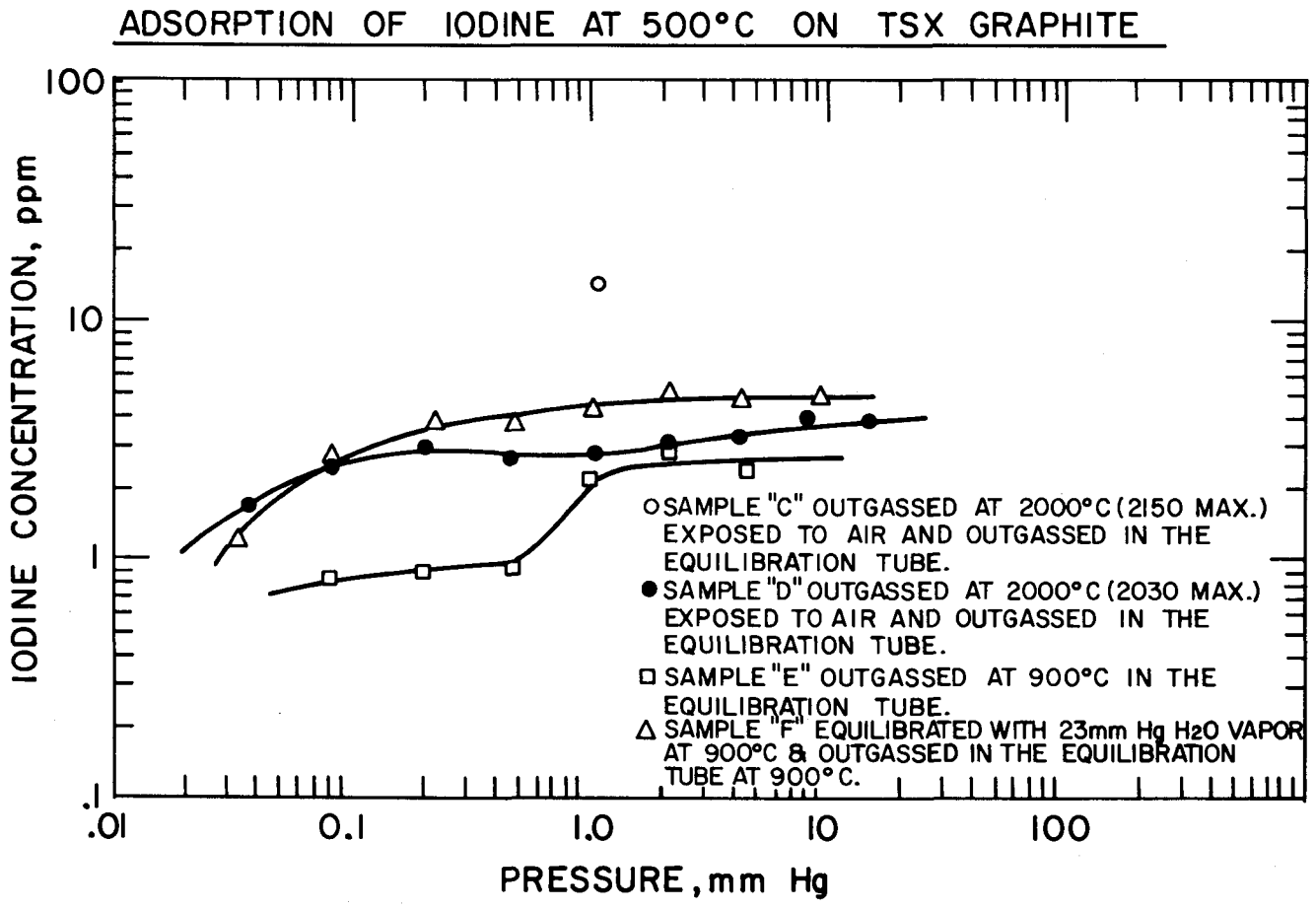

ADSORPTION OF IODINE AT 500°C ON TSX GRAPHITE
IODINE CONCENTRATION, ppm
100
10
1
.1
.01
0.1
1.0
10
100
PRESSURE, mm Hg
○ SAMPLE "C" OUTGASSED AT 2000°C (2150 MAX.) EXPOSED TO AIR AND OUTGASSED IN THE EQUILIBRATION TUBE.
● SAMPLE "D" OUTGASSED AT 2000°C (2030 MAX.) EXPOSED TO AIR AND OUTGASSED IN THE EQUILIBRATION TUBE.
□ SAMPLE "E" OUTGASSED AT 900°C IN THE EQUILIBRATION TUBE.
△ SAMPLE "F" EQUILIBRATED WITH 23mm Hg H2O VAPOR AT 900°C & OUTGASSED IN THE EQUILIBRATION TUBE AT 900°C.

Figure 4

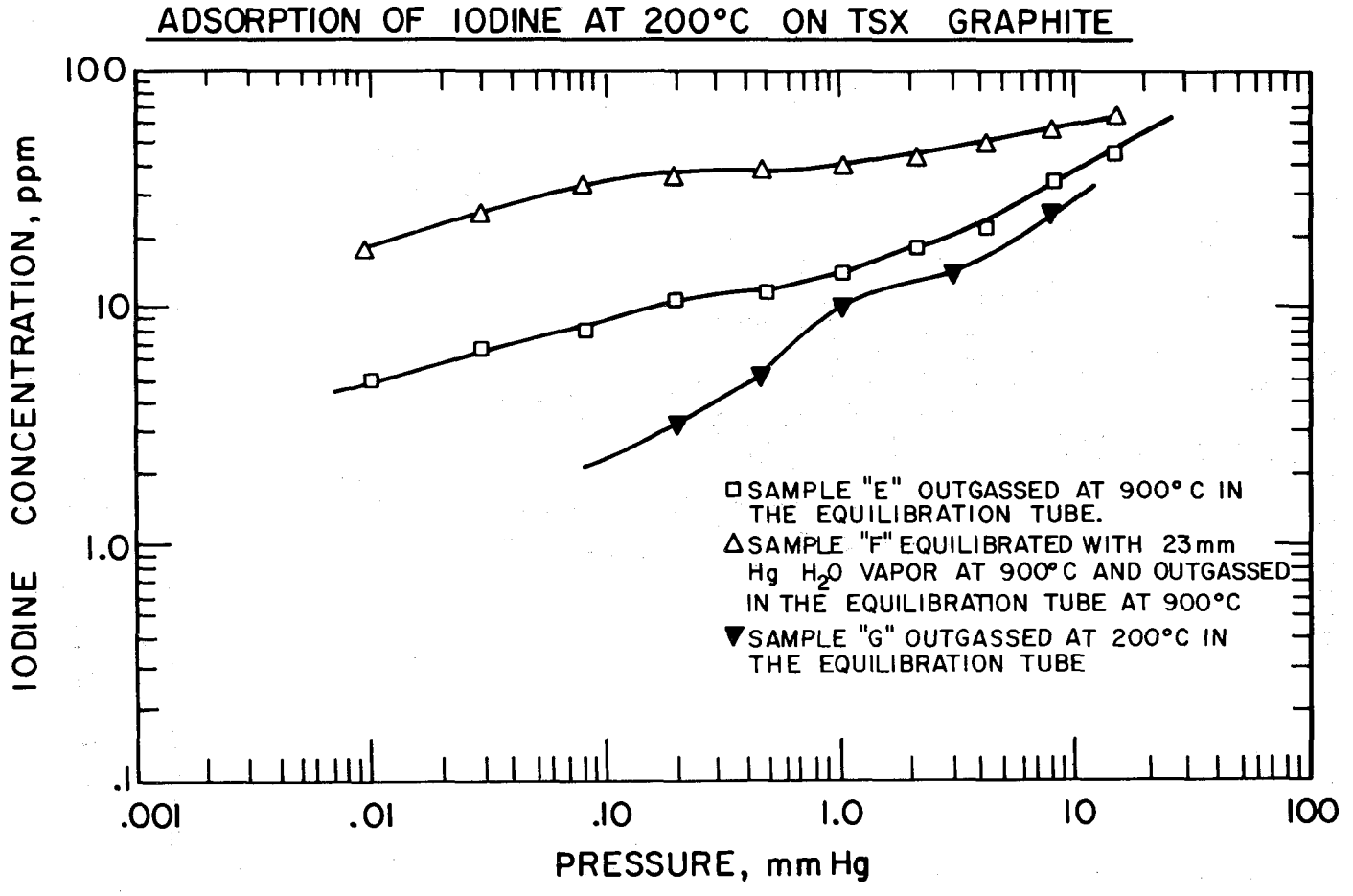

ADSORPTION OF IODINE AT 200°C ON TSX GRAPHITE
IODINE CONCENTRATION, ppm
100
10
1.0
.1
.001
.01
.10
1.0
10
100
PRESSURE, mm Hg
□ SAMPLE "E" OUTGASSED AT 900° C IN THE EQUILIBRATION TUBE.
△ SAMPLE "F" EQUILIBRATED WITH 23mm Hg H_2O VAPOR AT 900°C AND OUTGASSED IN THE EQUILIBRATION TUBE AT 900°C
▼ SAMPLE "G" OUTGASSED AT 200°C IN THE EQUILIBRATION TUBE

Figure 5

there is no relation between surface area and iodine adsorption, since the surface areas of the samples were similar.

The data obtained at 100°C are shown in Fig. 6. They fall into two distinct isotherm groups, which appear to merge at about a pressure of 2 mm Hg. At low pressures, the isotherms differ by an order of magnitude. The samples outgassed at 2000°C and the sample treated with the water vapor are included in the higher isotherm, while the samples outgassed at 200° and 900°C are included in the lower isotherm.

Utilizing B.E.T. theory,[10] it is possible to calculate the monolayer coverage on the graphite and therefore its surface area. The surface area values obtained for all the samples are shown in the third column of Table III and show excellent agreement with each other, and with the exception of sample D, are within 5% of the mean. These values compare well with the surface area values obtained with nitrogen at -195°C which are listed in the second column of the table.

DISCUSSION

The adsorption of iodine on graphite at 200°, 500°, and 800°C was found to vary with outgassing temperature, heat treatment, and contact with water vapor at 23 mm Hg. None of the above treatments was found to affect appreciably the surface area of the graphite. There was no relation between surface area and the quantities of iodine adsorbed. These facts, and the fact that the iodine could not be completely removed by reducing the partial pressure to zero, indicate that iodine is wholly or partially chemisorbed at these temperatures. P. Connor et al.[11] have investigated the adsorption of iodine on a graphite powder up to 400°C and found evidence for at least partial chemisorption in the fact that adsorption of hydrogen reduces the subsequent adsorption of iodine by approximately a stoichiometric amount.

More direct evidence for chemisorption would be the magnitude of the heat of adsorption. Calculated values of the

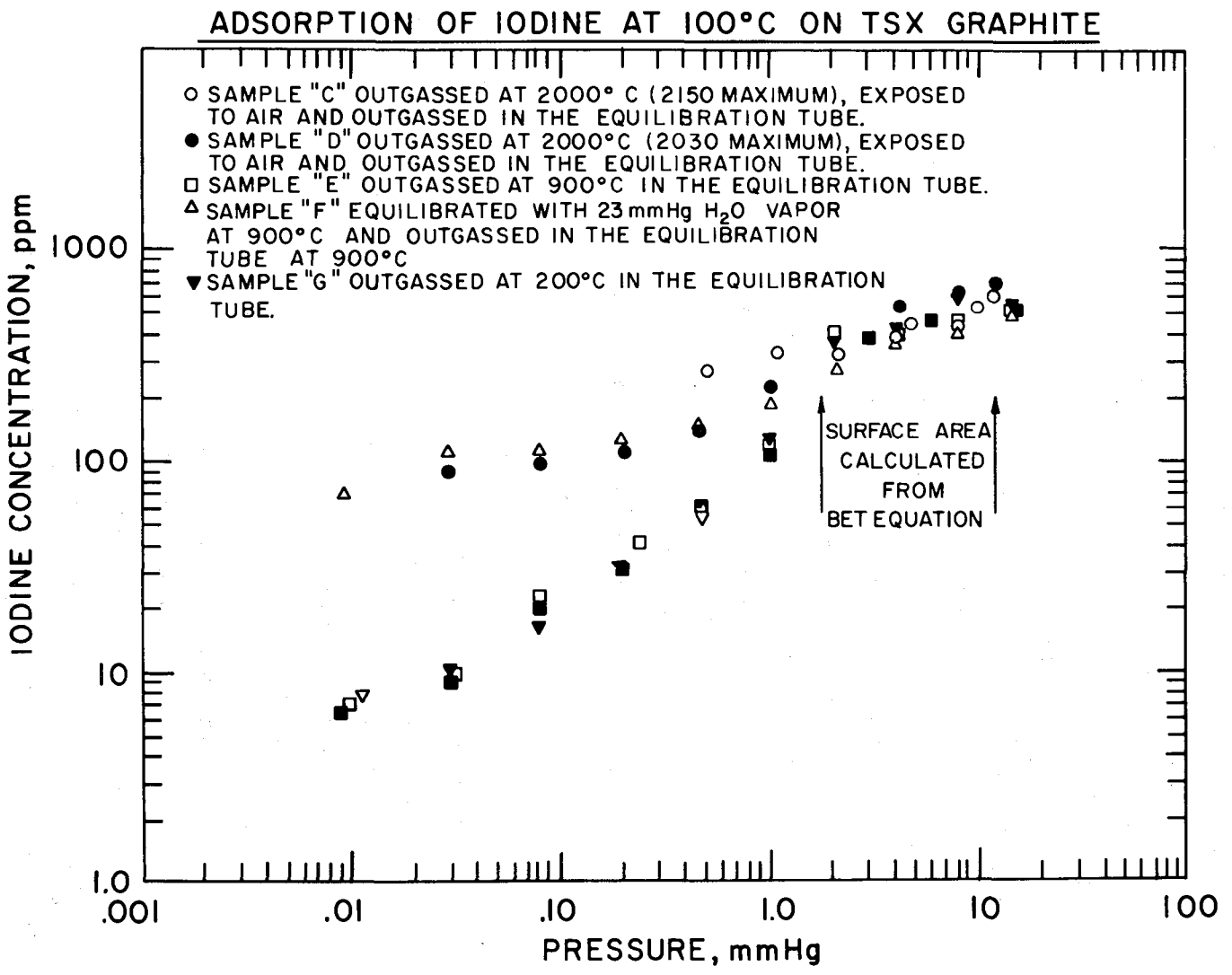

ADSORPTION OF IODINE AT 100°C ON TSX GRAPHITE
○ SAMPLE "C" OUTGASSED AT 2000° C (2150 MAXIMUM), EXPOSED TO AIR AND OUTGASSED IN THE EQUILIBRATION TUBE.
● SAMPLE "D" OUTGASSED AT 2000°C (2030 MAXIMUM), EXPOSED TO AIR AND OUTGASSED IN THE EQUILIBRATION TUBE.
□ SAMPLE "E" OUTGASSED AT 900°C IN THE EQUILIBRATION TUBE.
△ SAMPLE "F" EQUILIBRATED WITH 23 mmHg H_2O VAPOR AT 900°C AND OUTGASSED IN THE EQUILIBRATION TUBE AT 900°C
▼ SAMPLE "G" OUTGASSED AT 200°C IN THE EQUILIBRATION TUBE.
SURFACE AREA CALCULATED FROM BET EQUATION
IODINE CONCENTRATION, ppm
1000
100
10
1.0
.001
.01
.10
1.0
10
100
PRESSURE, mmHg

Figure 6

heat of adsorption from the measured data are not significant, owing to the flatness of the isotherms. Calculation of the isosteric heat of adsorption from isotherm data previously reported,[4] in the temperature range 200° to 450°C,* indicates that at low surface coverage the isosteric heat of adsorption was as high as 40 kilocalories per gram mole and decreased and approached the heat of vaporization (10.6 kilocalories per gram mole) at high surface coverage. Estimates of the heat of chemisorption of iodine on graphite, based on the strength of the carbon-iodine bond, indicate the heat of adsorption to be in the order of 44 kilocalories per gram mole when the iodine is chemisorbed as monoatomic iodine. Therefore, the value of 40 kilocalories per gram mole obtained in this study indicates the iodine to be chemisorbed at low surface coverages.

In the case of the 100°C isotherms there are no significant differences between the samples outgassed at 200° and 800°C. However, there is a considerable difference between these and samples outgassed at 2000°C and that treated with water vapor, though the surface areas of the samples are similar. The fact that the isotherms converge at 2 mm Hg and the fact that the surface areas calculated from the iodine adsorption are similar to the values obtained with nitrogen at -195°C over the same relative pressure range, indicate that at 100°C, above 2 mm Hg, iodine is held on the graphite by physical multimolecular adsorption.

In general, the difference between the high iodine adsorption on samples C, D, and F relative to sample E and G is due to the production of new chemisorption sites during the 2000°C outgassing and the treatment with water vapor. These sites are created by removal of surface carbon atoms, without altering appreciably the original surface area. These treatments apparently change the nature and number of the adsorption sites, as well as the distribution of energies among the sites.

Information which could be used to predict iodine adsorp-

*Graphite Specialties Company, R-4 graphite

tion on graphite in a reactor core, either during normal operation or after accidental release of fission products, would be of value to those concerned with reactor safety. Such information can enable one to estimate the extent of iodine adsorption in the core, if its partial pressure were known. Because of the variable nature of the graphite surface and its sensitivity to various environmental conditions, this becomes, however, a very uncertain prediction. However, since a good estimate is better than none at all, it is suggested that the following relation be used to estimate iodine adsorption in a graphite reactor core:

$$Q = 3.2 \times 10^{-4} \frac{e^{20,000/RT} P^{1/2}}{T^{1/4}},$$

where Q is the quantity adsorbed in ppm, T is the absolute temperature, R is the gas constant, and P is the partial pressure of the iodine in mm Hg. The above is the low-pressure form of the Langmuir equation for adsorption of a diatomic gas which dissociates on a uniform adsorbing surface.[12] The constants in the equation are derived from the 800°C isotherm data obtained on the untreated TSX graphite (E), outgassed at 900°C. It should only be applied above the critical temperature of the iodine (553°C) and at pressures below 10^{-3} mm Hg.

REFERENCES

1. Castleman, A. W., Jr., "The Chemical and Physical Behavior of Released Fission Products," TID 7641, 3rd Conference on Nuclear Reactor Chemistry, October 1962.
2. Progress Report of Nuclear Engineering Department, BNL 799, Brookhaven National Laboratory, Jan. 1 - April 30, 1963.
3. Hölemann, P., Braun, A., Z. Physik Chem. 34, 5, 381-95 (1936).
4. Salzano, F. J., "Summary of Fission Product Adsorption Work at BNL," Seventh AEC Air Cleaning Conference, held at BNL, Oct. 10-12, 1961, TID 7627 (March 1962).
5. Progress Report of Nuclear Engineering Department, BNL 696, Brookhaven National Laboratory, May 1 - August 31, 1961.
6. Hennig, G. R., J. Chem. Phys. 20, 1443 (1952).
7. Juza, R., Schmeckenbecker, A., Z. Anorg. u. Allgen Chem. 292, 46 (1957).
8. Herold, A., Bull Soc. Chem. France, 999, (1955).
9. Salzano, F. J., Prog. Rept. Nuclear Eng. Dept., BNL 659, p. 14, Sept. - Dec. 1960.
10. Young, D. M., Crowell, A. D., Physical Adsorption of Gases, Butterworths and Co., London, 1962.
11. Connor, P., Lewis, J. B., Thomas, W. J., The Adsorption of Iodine by Graphite, Proceedings of the Fifth Conference on Carbon 1962, Pergammon Press.
12. Trapnell, B. M. W., Chemisorption, London, Butterworths and Co., 1955.

DISCUSSION AND COMMENT

Session Chairman: Thank you, Mr. Gemmell. We realize that you are not prepared to enter into detailed discussion since you have not been associated with the fission product behavior study. We appreciate the fact that although you were primed to present the paper from the platform that you may not feel qualified to answer detailed questions.

Dr. Silverman: I am not certain this is going to be a fair question since you are filling in as a proxy, but the conclusions that Salzano drew that the iodines can absorb, and so on, are not new to us, but the data that he presented showing the measurement of surface area with nitrogen correlating so well with the measurement of surface area with iodine treatment has me puzzled, because we thought we had an excellent way to measure surface area using iodine adsorption, and yet when we tried to do this we found not monomolecular adsorption, but multiple molecular layers, and the correlation he showed us would contradict that conclusion. In fact I hope we were wrong and he is right!

Mr. Gemmell: Dr. Silverman's comments and question have been recorded. I regret very much that I am not sufficiently acquainted with the work to answer your problem. When I return to Brookhaven, I'll get in touch with Mr. Salzano and ask him to write a reply which will be included in the proceedings of the conference. In the meantime, we will contact Dr. Silverman by telephone and arrive at a mutually satisfactory answer. The authors of this paper have asked me to express their regrets for not being able to be here today.

Mr. Salzano: (Reply to Dr. Silverman's Question) The surface areas I measured were obtained from the 100°C isotherms. They were calculated from B.E.T. plots over the relative pressure range 0.04 to 0.30. If the temperature or relative pressure range were different than the above values the results might not agree with the nitrogen surface areas. I have not determined if this method works with other materials or at different temperatures.

Session Chairman: The last speaker during Session I is Mr. J. D. McCormack, of Hanford Atomic Products Operations, who has prepared a paper entitled, "Some Observations on Iodine Removal from Plant Steams with Charcoal."

SOME OBSERVATIONS ON IODINE REMOVAL FROM PLANT STREAMS WITH CHARCOAL

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ABSTRACT

The performance of several large scale charcoal beds in radioiodine removal service is discussed. The efficiency of the beds was measured after service times of months to years, and appears to be related to the quality of the air being treated. Efficiencies of 99.9 per cent to nearly zero per cent were noted.

INTRODUCTION

Radioactive iodine must be effectively removed from air streams, which, through design or accident, may contain quantities of this isotope. Exhaust from fuel processing plants, reactor halls, and radiochemical laboratories must be treated to insure that iodine releases are minimal. The Federal Radiation Council recommended in 1961 that permissible concentrations for I^{131} in air be significantly lowered.(1) This ruling prompted even more restrictive limits to the quantity of I^{131} which could be safely released from large nuclear installations, and led to additional evaluations of existing and new iodine removal facilities.

Among the more common I^{131} removal systems are liquid scrubbers, silver reactors, and charcoal beds. While the scrubbers and silver reactors can be efficient iodine removers, charcoal beds are often favored because of their simplicity, compactness and efficiency.

Although very high I^{131} removal efficiencies may be demonstrated in the laboratory for fresh charcoal under a rather wide range of operating conditions, the proof of sustained efficiency must come through observations of the actual bed installation. Reduction in efficiency with time is a real possibility due to mechanical blinding of active centers with inert material, and to the eventual saturation of active centers by minute traces of unsuspected chemicals present, such as oil fumes and organic solvents. Another consideration which must be given attention is the potential that the iodine present in the stream may not be wholly molecular iodine. A charcoal showing 99.99 per cent removal of molecular iodine in controlled laboratory tests may conceivably be much less efficient on a plant stream. Less reactive species of I^{131} have been cited in the literature, but the physical and chemical nature of these forms have not been clearly revealed.(2,3)

Ten large scale charcoal beds have been operated at Hanford for periods ranging from a few months to several years. From 6000 to 100,000 cfm of air pass through these beds. Eight are part of the reactor confinement system, one is installed in a high level radiometallurgy laboratory, and one was more recently installed at a chemical separation plant (Redox) downstream from a high efficiency filter.

OBJECTIVE

It is the objective of this paper to present certain observations of the performance of these charcoal beds in service relative to I^{131} removal efficiency.

TESTING OF CHARCOAL SYSTEMS

Reactor Confinement Beds

The charcoal beds which treat the reactor building ventilation air are preceded by absolute filters. Their design was discussed in detail at the Seventh Air Cleaning Conference.(4) Perforated metal envelopes, containing test charcoal hung on the upstream face of the main 1-inch thick convoluted bed, were provided in the initial design to permit periodic checking of charcoal efficiency during service. The charcoal from these envelopes after a period in service is removed and repacked in 1-1/4-inch long by 7/16-inch-diameter beds. Filtered air containing I^{131} liberated by the evaporation of a carbon tetrachloride solution of iodine is drawn through the test coconut shell charcoal bed at a face velocity of 60 fpm. The test charcoal is followed with a similar cartridge of Pittsburgh BPL type activated carbon. This charcoal has been shown in previous tests to be a very efficient adsorber of molecular iodine. The I^{131} activity is determined by measurement of the 0.36 Mev gamma ray under conditions of constant counting efficiency. The iodine retention is then calculated as the ratio of the activity on the test cartridge to the sum of the activity on the test and the back-up cartridge. Table I shows the results of the laboratory retention measurement. The test charcoals had been exposed to the air stream for about one year. The "unexposed" charcoal standard, a sample of the original charcoal used in the installation, had been stored in a sealed glass jar.

TABLE I

IODINE RETENTION OF REACTOR CONFINEMENT CHARCOAL AFTER 1 YEAR OF EXPOSURE

Sample Location	% I^{131} Retained
B	99.8
C	99.7
D	99.8
DR	99.7
F	99.9
H	99.7
KE	99.6
KW	99.7
"unexposed"	100.0

The standard deviation of the tests, based upon the counting data, is about 0.07 per cent; hence, it can be seen that the deterioration of the charcoal is not highly significant.

Radiometallurgy Building Beds

The iodine removal charcoal beds used to treat 6000 cfm of hot cell exhaust air are quite similar to those just described and the testing was identical except that in this case one of the 2' × 2' modular beds was opened and the charcoal sample removed from the bed itself. Testing of this charcoal, which had been in service for over two years, showed a poor retention of molecular iodine. Because the grain size was larger than the previous charcoals which had been tested, and relatively large in relation to the 7/16-inch-diameter test cartridge, additional measurements were made with larger diameter test cartridges to check for wall effects. These results, and others, are shown in Table II, below.

TABLE II

RESULTS OF RADIOMETALLURGY BUILDING CHARCOAL TESTS

Test No.	Charcoal	% I^{131}* Retained	Comments
1	Exposed	58	As sampled.
2	Exposed	57	100 fpm; 7/8"-diameter.
3	Exposed	94	Abraded and washed.
4	Exposed	99.7	100 fpm; crushed to 14/20 mesh.
5	New	99.9	As sampled.

* Test bed was 7/16-inch-diameter × 1-1/4-inch long, with air flow of 60 fpm, unless otherwise noted under comments.

The sample of exposed charcoal definitely shows a low retention of the I^{131} vapors, as can be seen from test one, above. As noted, test two was made to check for wall effects. The results, similar to test one, show that wall effects were not important in the testing.

The loss of adsorptive capacity seems to be restricted to the surface of the charcoal grains, as shown by the increased retention on tests three and four. Indeed, the charcoal had a dull, dusty appearance. The presence of Sb^{125} activity could indicate some particle penetration of the high efficiency filters upstream of the charcoal. Either removal of the surface layer by mild abrasion and washing, or creation of new surfaces by crushing restores the efficiency of the charcoal to nearly that of new charcoal, shown in test five.

Separations Plant Bed

Earlier this year a charcoal bed was installed in the ventilation exhaust stream from the Redox plutonium separations plant. The location chosen was just downstream from the deep bed sand filter, through which pass all of the process building ventilating air and vessel vent air. Exhaust gases from the fuel dissolvers do not pass through the sand filter. Iodine appearing in the air entering the sand filter comes from tanks, columns, and process vessels at many points in the process and might be suspected of being associated with or in combination with other materials. An earlier study of charcoal capsules for measuring I^{131} in the total stack exhaust, which is made up of the sand filter stream and the treated dissolver off gases, showed that from 90 to 95 per cent of the iodine present would be trapped on charcoal during a 24-hour sampling period.(5) Although not as efficient as for wholly elemental iodine, the indicated efficiency was high enough to warrant the use of charcoal on the stream downstream from the sand filter.

The observed efficiency of the charcoal trap installed downstream of the sand filter has been very low. The sustained exposure to traces of organic vapors of hexone and degradation products appears to effectively block the I^{131} from adsorption sites although detailed causes are not known. As contrasted to the 95 to 99 per cent I^{131} efficiency for a 24-hour long sample drawn from the total exhaust through small charcoal capsules, the installed bed has a current efficiency of practically zero.

Some experiments were conducted to measure the loss of efficiency with time for a charcoal cartridge through which was drawn a long term sample of air taken upstream from the sand filter at Redox. An identical cartridge was operated in parallel on the same volume of air and replaced daily with a fresh charcoal cartridge. Results of these tests are shown in Figure 1. A face velocity of about 100 fpm was used.

These data show the progressive and rather complete loss of efficiency with time. The materials present in the stream explicitly responsible for this "poisoning" effect are not known at present.

Sampling of this stream does show that approximately one-half of the gaseous iodine is in a form not readily removed by caustic scrubbers, but is retained by fresh charcoal; that is, some form other than molecular iodine. This is in agreement with the finding of others.(6) The iodine which is retained by the charcoal seems firmly fixed and is not eluted through the bed by air and fluctuating concentrations of hexone vapors at room temperature. In addition, vacuum degassing of the charcoal at 100 to 200 C removed the hexone, but only a small amount of I^{131} -- say 10 per cent -- was removed. It seems, then, that the radioiodine is not chemically associated with the hexone vapors in the air stream. In our laboratory tests charcoal could be made inefficient when oil vapor was present. Hexone present did not materially reduce the initial efficiency. Long exposure studies were not conducted, however.

The efficiency of both new and exposed samples of the charcoal has been measured with molecular I^{131}. The efficiency of the exposed charcoal has also been measured in the Redox air stream with generated I^{131}. These results are shown in Table III.

TABLE III

RESULTS OF REDOX BUILDING CHARCOAL TESTS

Test No.	Charcoal	% I^{131} Retention*	Comments
1	Unexposed	99.9	Filtered laboratory air.
2	Exposed	99.5	Exposed 15 days, eluted 23 days with air and 20 ppm hexone.
3	Exposed	86	Exposed 37 days, tested with generated I^{131} in process air.

* Charcoal beds were 7/16-inch diameter by 1-inch long with a linear flow of 100 fpm.

While the specific cause of the loss of efficiency has not yet been determined, the loss has been demonstrated to increase with time of exposure to the air stream.

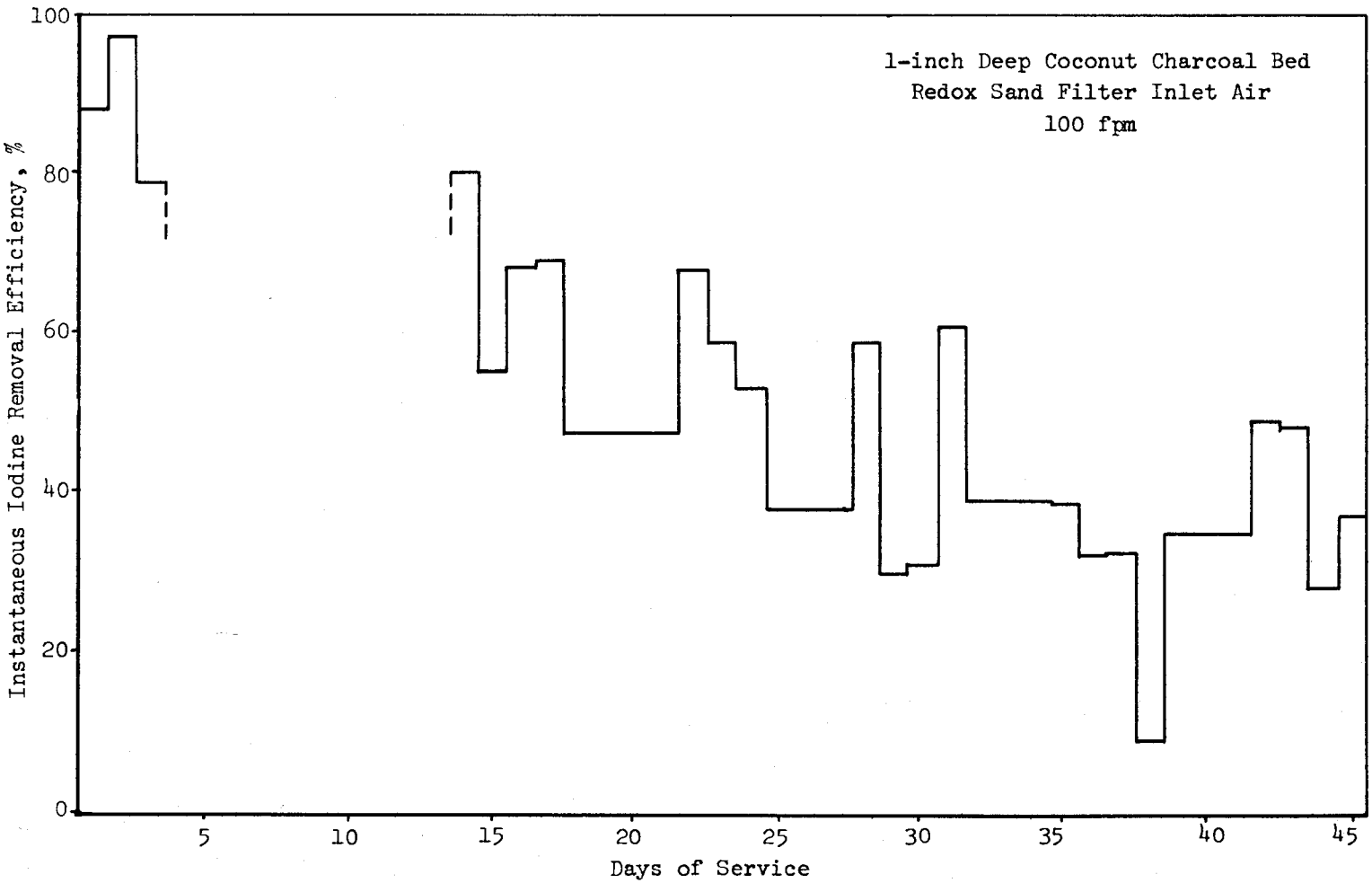


FIGURE 1

IODINE REMOVAL EFFICIENCY

CONCLUSIONS

The efficiency of charcoal beds for iodine removal from air has been discussed as a function of length of service and complexity of the air composition. Beds in three types of installations were investigated. There seems to be a correlation between the retention of iodine removal efficiency and the quality of the air stream. Charcoal in the reactor building ventilation air, which can be thought of as clean air from a building which includes no chemical processing activities, showed no significant deterioration during one year exposure. Charcoal in service for over two years in a radiometallurgy lab showed loss of iodine retention, being only 58 per cent efficient under the test conditions. The air from the hot cell exhaust contains impurities generated from physical testing of irradiated fuel elements and from a small amount of chemical treatment of the specimens.

In the third application, in the process building ventilation air and vessel off-gas streams, charcoal lost its iodine removal efficiency during a period of a few weeks. This air stream contains organic and inorganic components arising from the routine processing of irradiated fuel elements.

The varying response of the charcoal behavior of these three filtered gas streams is some indication of the complex nature of iodine and the care that should be used in applying iodine adsorbing systems in real gas streams. In addition, the possible "poisoning" potential of trace components in the air being treated must be recognized. Because of this potential the performance of charcoal beds should be periodically monitored.

REFERENCES

(1) Federal Radiation Council. Protection Guidance for Federal Agencies; Memo for the President, Federal Register, September 26, 1961.

(2) C.W. Sill, J.K. Flygare, Jr. Iodine Monitoring at the National Reactor Testing Station. Health Physics, 2:261-268, February 1960.

(3) J.B. Morris, C.H. Romary. Tests on Absorbers for Iodine at Low Concentrations. AERE-R-4219. 1963.

(4) H.W. Heacock, C.E. Jones. The Hanford Reactor Confinement Program. Seventh AEC Air Cleaning Conference, Brookhaven, October 10-12, 1961. TID-7627, p. 284-308, March 1962.

(5) D. McConnon. Radioiodine Sampling with Activated Charcoal Cartridges. HW-77126. April 1963.

(6) G.K. Cederberg, D.K. MacQueen. Containment of Iodine-131 Released by the RALA Process. IDO-14566. October 1961.

DISCUSSION AND COMMENT

Although a caustic scrubber is not efficient for removal of iodine, remember that it has been treated in the plant with boost-over reactors. Silver reactors in the steam will remove some additional iodine. A charcoal bed behind the caustic scrubber will always pick up additional iodine, whereas a caustic scrubber behind a fresh charcoal bed will pick up essentially no additional iodine.

In the radio-metallurgical application upstream absolute filters preceded the charcoal. It was felt that in this series of results there was mechanical blockage of the carbon.

In the performance of a charcoal cleanup filter where primary coolant is released in steam into the containment, Savannah River has run numerous tests with activated carbon exposed to steam-air mixtures, as well as to steam. With new carbon it was found that the steam or steam-air mixtures, as long as they entrain water or a large fraction of it, is removed up-stream of the carbon filter, there is no adverse effect on the removal efficiency. Beds that are exposed to steam-air conditions until the carbon is essentially in equilibrium with the water vapor shows no adverse effects on iodine-removal efficiency. With exposure to normal rural air for as long as five months no adverse effects on the iodine-removal efficiency in steam-air mixtures. These results were reported in DP-778.

The UKAEA has been examining the performance of charcoal against iodine emissions from irradiated fuel under a variety of conditions and one of the species of iodine identified was methyl iodide. The performance of charcoal against methyl iodide appears to be somewhat complex but the salient point so far resolved is that up to a certain loading of methyl iodide, which is rather low, of the order of a few μg/g charcoal there is virtually complete retention; beyond this penetration increases and reaches high percentages.

There was no specific information regarding HAPO iodine concentrations in off-gas streams in respective loadings when decreasing efficiencies were observed; however, the iodine concentrate streams were low.

SESSION CHAIRMAN: These three papers we have heard are, of course, related to determining the extraction or release of fission products from fuel in the case of a reactor accident, characterizing the properties and behavior of these materials, and doing something about ameliorating the consequences of the accident. The motivation here, of course, is to assess the consequences of reactor accidents, and hopefully with the view to take steps that would allow one to relax siting criteria.

This raises an interesting question, I think; namely, to what extent have we been successful, through research and development, in doing something useful and constructive towards solving the reactor safety problem. We have an expert in the audience, Dr. Silverman of Harvard University. I wonder if he would care to say a few words about the impact this research has had on evaluating the consequences of reactor accidents, and to what extent it has been useful in relaxing siting criteria.

COMMENT BY DR. SILVERMAN:

First, let me say that we have enough confidence in what we think carbon can do, notwithstanding fires, and have recommended and have seen carried out multi-million dollar programs in reactor confinement at both Hanford and Savannah River, and you will hear about these in some detail. You probably heard at the Idaho Conference some of the orderly and positive planning.

I think those of you who are familiar with the reactor siting problem will get the notion, if we can be sure of the source for its strength and its chemical characteristics, that we ought to be able now, on the basis of our research and development, to design safeguards and feel a degree of confidence in their performance.

I might say, speaking entirely without regard to my regulatory status, that the Nuclear Ship Savannah has such safeguards aboard, and that these safeguards are being routinely tested and retested, because of the problems in entering ports throughout the world, and has shown the kind of performance that would permit one to make reliable estimates of the safety of its operation.

The results of our research and development are being put into effect. As you will see from some of the later discussion in regard to research and development, we still have some problems with charcoal that ignites. Activity may be lost, but there are ways to protect against that. Either substitute another adsorbent, or another technique.

All things considered, I think reactor safeguarding is coming closer and closer to the point when we can accept engineered safeguards, primary engineered safeguards, with a third degree of reliability, and I think what we are now arguing about essentially is whether or not the DF should be 10^0, 10^1, 10^2, et cetera. In other words, the release is zero. I am the only one who might raise some alarm as to how positive can you be that it is zero; we haven't got efficiencies of 100%, even though we are pretty close.

With that in mind I still think we have some objectives to achieve in engineered safeguards, but certainly we have come a long way.

What can we expect from the mechanical behavior of a system, because we test and retest? We have vibration and compaction taking place in charcoal beds, and I would take the attitude that if somebody can show me 99.5% efficiency after repeated retests, with both vibration and mechanical stress, then I would accept the 99.5%. I don't know how to give me an assurance that I will feel better. In other words should I say: "O.K. my safety factor is going to be 99.5% or reduce it to 99%." In other words I half believe that I should take 90%, because I think that somebody is going to become careless in routine surveillance, and so on.

If you have a system that is operating all the time that tests 99.5% before you enter a port, I think you have a pretty good feeling that it is going to be 99.5% all the time you are at dock-side, if we are talking about a nuclear-powered ship.

If we are talking about a power reactor in the center of Pittsburgh, or something of that nature, I think the frequency of your checking is going to give you the confidence in what numbers you can use.

So I don't think it is any different than taking out a coupon and checking it for irradiation characteristics, tensile strengths, and so on. It is the same basic philosophy. Our engineering safeguards for cleanup and protection of the public still, we hope, are never called on to act; but nevertheless, we have to have that area with some positive degree of assurance, in case all other things go wrong.

Sessions Chairman: Thank you. If there are no other comments this will conclude Session I.

SESSION II - TRANSPORT AND VENTILATION OF RADIOACTIVE AEROSOLS AND GASES

Morning - 22 October 1963

D. J. Keigher, RLO, Chairman

Session Chairman: Gentlemen, Session II concerns the transport and ventilation of radioactive aerosols and gases. The first paper has been prepared and will be delivered by Mr. T. W. Pickel of the Oak Ridge National Laboratory. The title of thisinteresting presentation has been announced as, "The Analog Computer as an Aid in Critical Ventilation System Evaluation."

THE ANALOG COMPUTER AS AN AID IN CRITICAL VENTILATION SYSTEM EVALUATION

T. W. Pickel
Oak Ridge National Laboratory

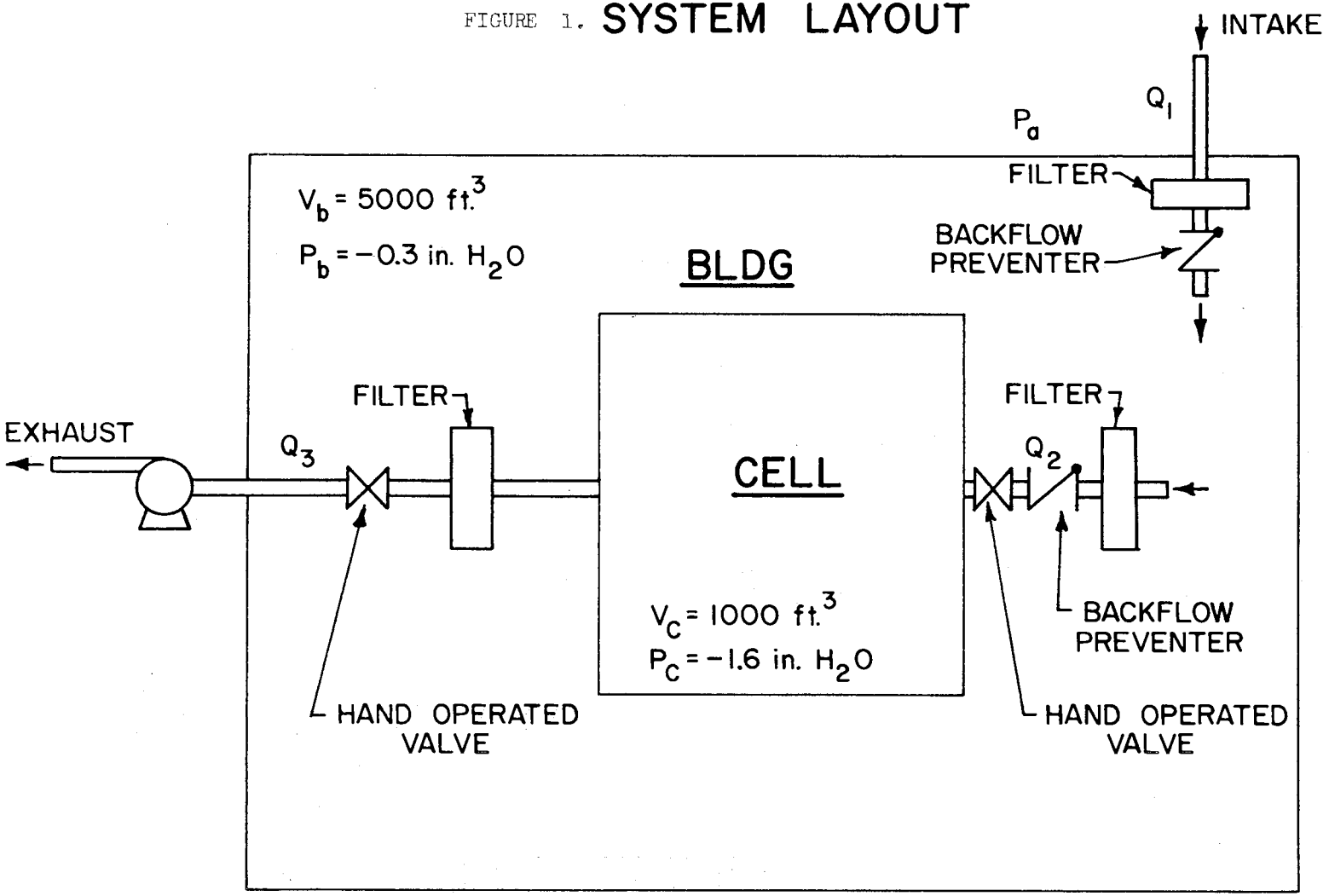
The purpose of this report is to indicate some advantages of using analog computers in the analysis of air handling systems and to present an illustration of an analysis of a simple system.

The analog computer can be of assistance in evaluating several areas of a ventilation system. First, simulation of the system on the computer can help the designer select the proper components and test their compatibility with the rest of the system. This would involve a study of static flow conditions over a range of the operating variables such as filter resistance. Second, it can help in the operation of the system. This is particularly true for the start-up of a complicated system in which a proper balance of air flows is difficult to obtain and maintain. It is also true of operation after startup when increases in filter resistance will cause a shift in the air balance. Third, the computer can be used to evaluate upset or transient conditions. The ability of the analog computer to handle differential equations makes it an extremely valuable tool in this type of analysis. Items of interest here may include the stability and response time of the system and the effect of dynamic changes on component performance. The length of time to recover from such disturbances as explosions, fires, accidental release of fire extinguishing systems, and opening of air locks is of interest in a hazards evaluation.

The complexity of the system that can be analyzed is limited only by the computer equipment available and the ingenuity of the analyst. The accuracy of simulation may be limited by the data available on the performance characteristics of the components. For this discussion, I am considering a rather simple system. The layout is shown in Figure I. The system consists of a building containing a single cell. Air enters the building through a filter and backflow preventer. Air from the building enters the cell through a filter, backflow preventer, and hand-operated valve. The exhaust system consists of a filter, hand-operated valve, and a fan. Flow resistance in the filters is considered to be proportional to the flow rate. Resistance in valves, ducts, and backflow preventers is assumed to be proportional to the square of the flow rate. In this illustration, it is assumed that the fan curve is linear over the range of flow rates to be covered. In many problems this assumption would not be adequate. In these cases the complete pump curve could be simulated by a function generator.

Figure 2 shows the equations used. The first three equations give the static pressure drop in building intake, cell intake, and cell exhaust systems respectively. The symbols C_1, C_3, and C_6 represent the filter resistances, and C_2, C_4, and C_7 represent the duct, valve, and backflow preventer resistances. The symbols C_5 and f represent the intercept and slope of the fan curve respectively. The last two equations relate the rate of change of the building and cell pressures to the flow rates. K_b and K_c may be considered to be the

FIGURE 1. SYSTEM LAYOUT



NORMAL FLOW: $Q_1 = Q_2 = Q_3 = 300$ CFM

FIGURE 2. EQUATIONS

(1) $P_a - P_b = C_1 Q_1 + C_2 Q_1^2$

(2) $P_b - P_c = C_3 Q_2 + C_4 Q_2^2$

(3) $P_a - P_c = C_5 - f Q_3 - C_6 Q_3 - C_7 Q_3^2$

(4) $\frac{dP_b}{dt} = K_b (Q_1 - Q_2)$

(5) $\frac{dP_c}{dt} = K_c (Q_2 - Q_3)$

reciprocals of the capacitances of the building and cell respectively. For this model these values are considered constant. A more accurate representation would be to express them as functions of pressure. However, for this illustration the maximum error introduced by this assumption is two per cent.

The computer diagram is shown in Figure 3. The diagram is divided into areas that correspond to particular portions of the system. The area labeled "Building Intake" includes the computer components that relate the flow rate entering the building to the pressure drop across the intake duct and associated equipment. A similar correspondence exists for the areas marked "Cell Intake" and "Cell Exhaust". Since we are interested in cases in which the cell pressure is higher than building pressure, it is necessary to simulate the action of the backflow preventer in the cell intake line. This is done with a comparator. When the building pressure is greater than cell pressure, the switches are closed and the circuit calculates the cell intake flow rate. When the cell pressure is equal to or greater than building pressure, the switches are open, giving a zero flow rate. The areas indicated as "Building" and "Cell" represent the buildup or decay of pressure due to transient conditions.

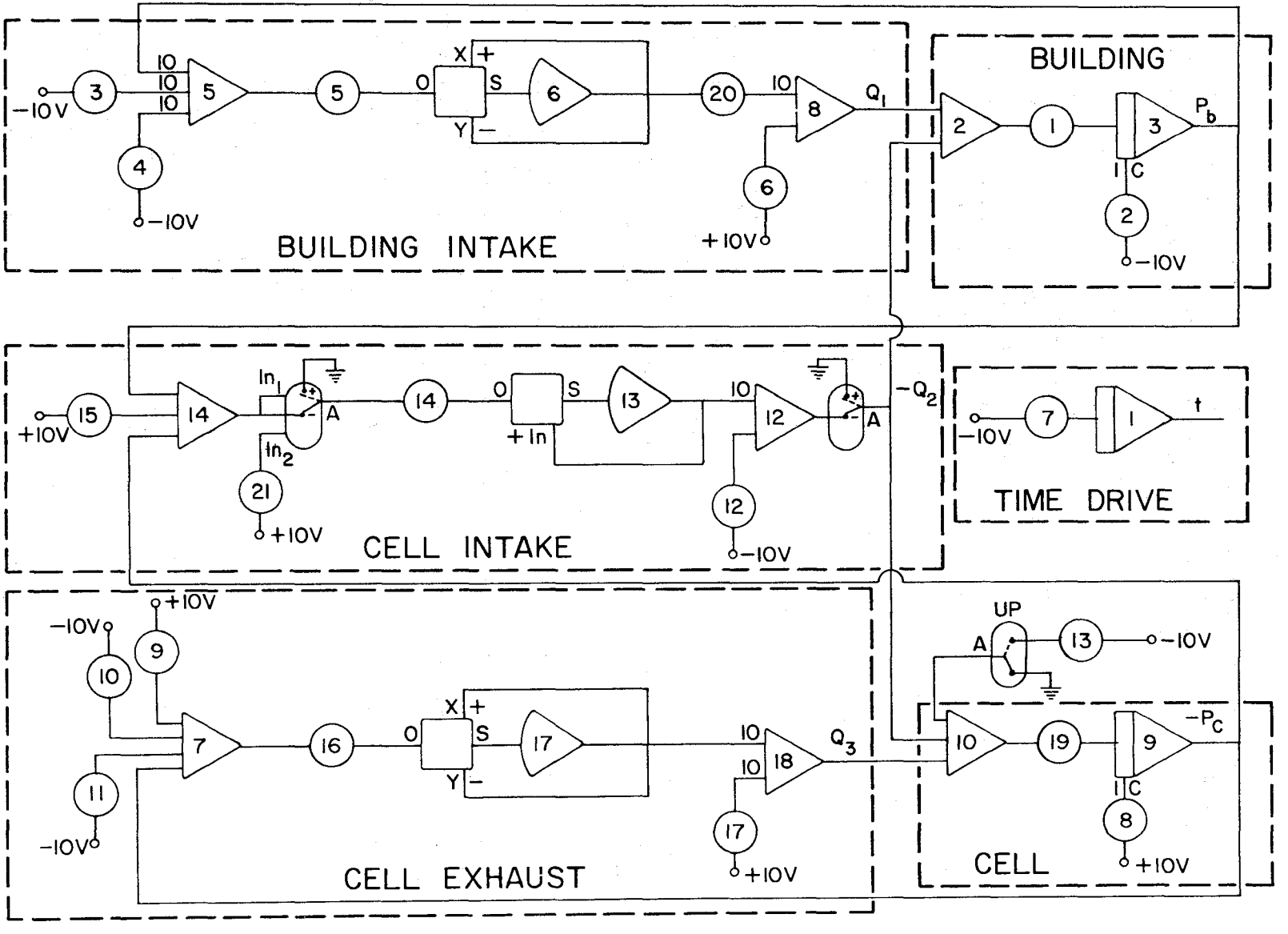
The computer being used for this problem is an Electronic Associates, Inc., Model TR-10. This unit has twenty high-gain (10^7) amplifiers, two quarter-square multipliers, one x^2-function generator, twenty-four potentiometers, one comparator, and two manual switches. For this problem we have used fourteen amplifiers, both multipliers, the x^2-function generator, twenty potentiometers, the comparator, and one manual switch. Additional cells, separate building exhausts, automatic control equipment, and multiple fans can be added to this model. However, more computer equipment would be needed than is available on the TR-10.

Four possible upset conditions are considered. First, Figure 4 shows the response of this system to a sudden opening of a door to the cell. The building and cell pressure quickly equalize at a value between the two initial pressures. The flow of air into the cell increases rapidly, then decreases to a new equilibrium value. The flow rate into the building also increases to a peak, then decreases slowly to the new equilibrium position. The change is not as abrupt for the building intake as for the cell intake. The exhaust flow rate increases to the equilibrium quantity at a slower rate. The pressures equalize in less than one second, but the flow rates take approximately five seconds to reach a new static condition.

The second condition considered is an explosion in the cell. The system response is shown in Figure 5. The cell pressure is assumed to suddenly increase and then decay. The building pressure increases and then returns slowly to its initial value. As the building pressure increases the flow rate into the building decreases. After the building pressure reaches its peak value and starts to decrease, the flow into the building starts increasing and returns to its initial value. The cell intake flow rate drops to zero and remains there until the cell pressures drop below the building pressure. The cell exhaust rate increases with the cell pressure, then decreases to the equilibrium value. Approximately six seconds are required for the system to reach steady-state conditions after the explosion.

The third condition considered is an accidental release of compressed CO_2 into the cell. This is shown in Figure 6. It is assumed that this causes a reduction in cell temperature which results in a reduction in cell pressure. Since the model has no backflow preventer in the exhaust system, the flow of air in the exhaust system is into the cell rather than out of the cell for a short period of time. About five seconds are required for the system to recover.

FIGURE 3. COMPUTER DIAGRAM



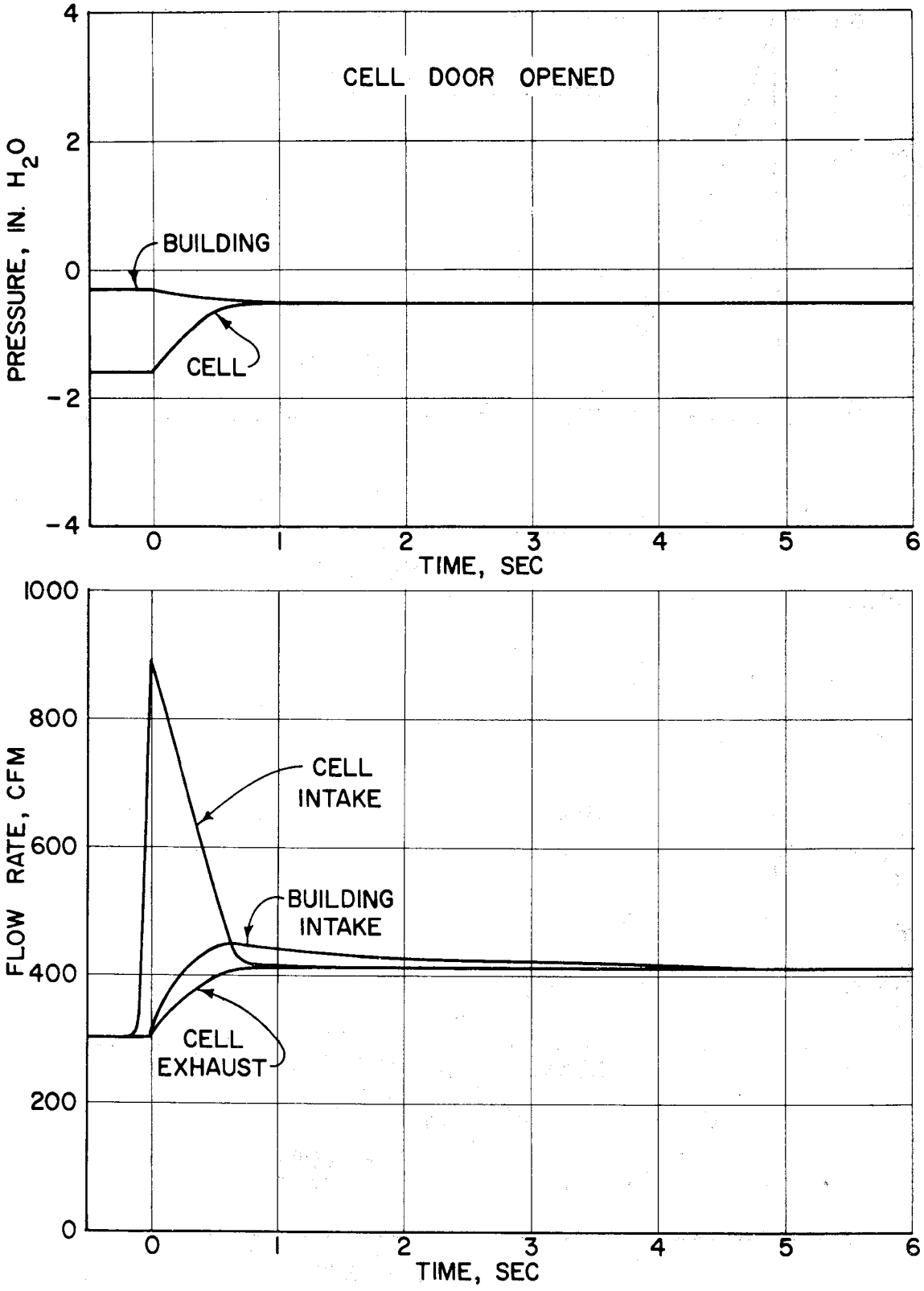


FIGURE 4. System Response to Sudden Opening of a Cell Door

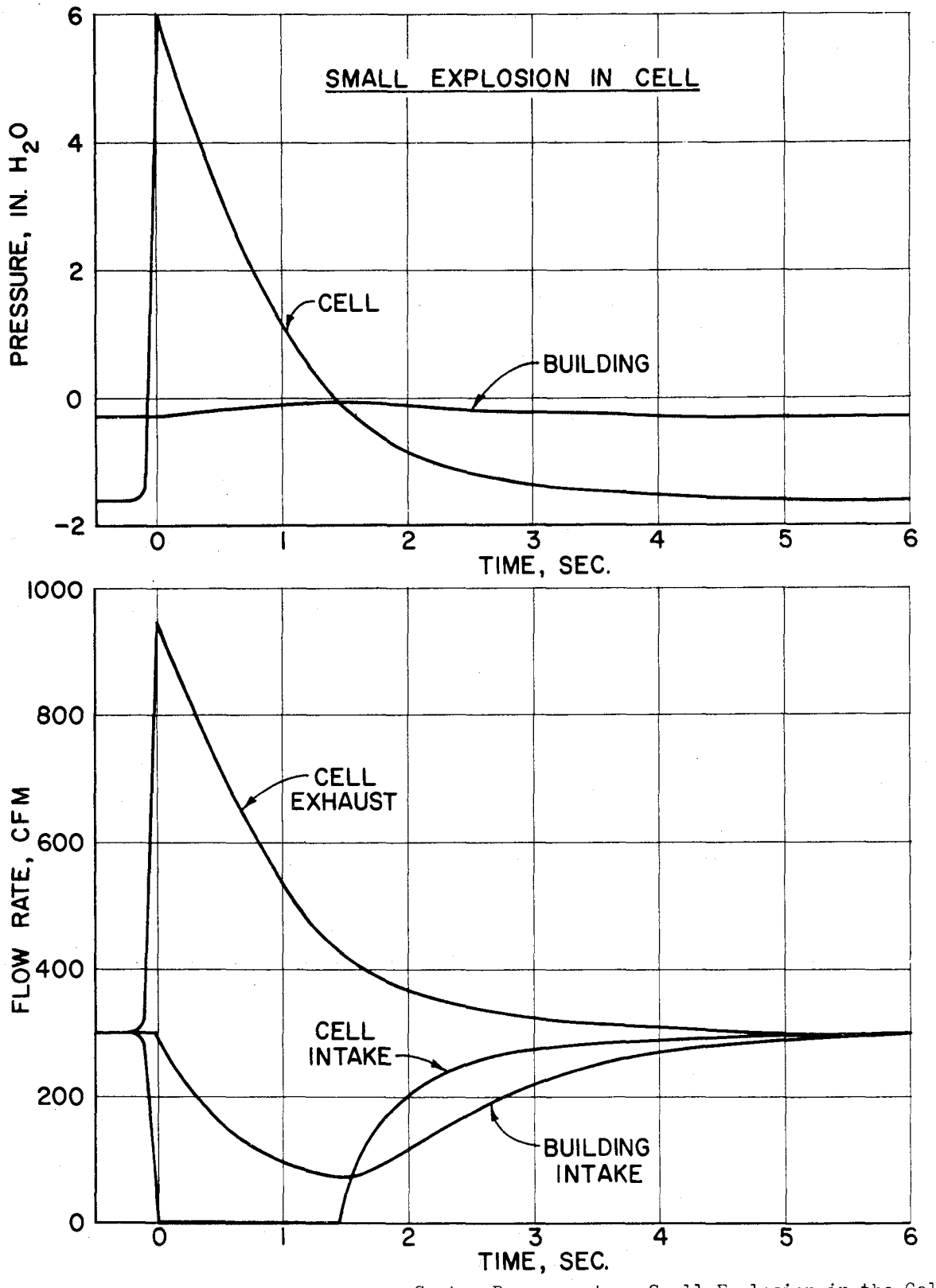


FIGURE 5. System Response to a Small Explosion in the Cell

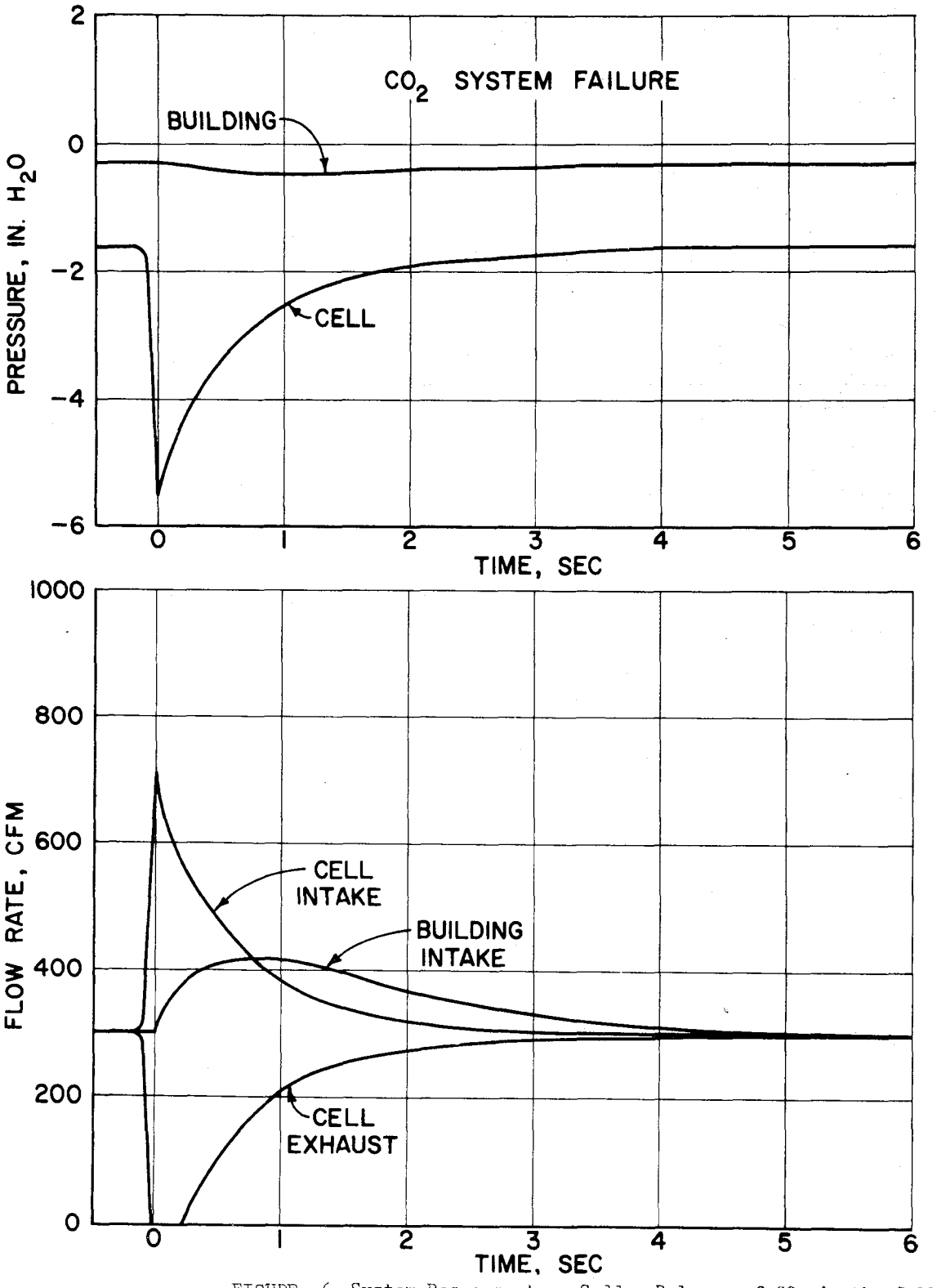


FIGURE . 6. System Response to a Sudden Release of CO_2 in the Cell

The fourth case, which is shown in Figure 7, is an example of a fire in the cell. This example assumes a constant rise in cell temperature. The fire is assumed to last for 3.5 seconds. After this, the system returns to equilibrium. About five seconds are required for the system to return to equilibrium after the fire is stopped.

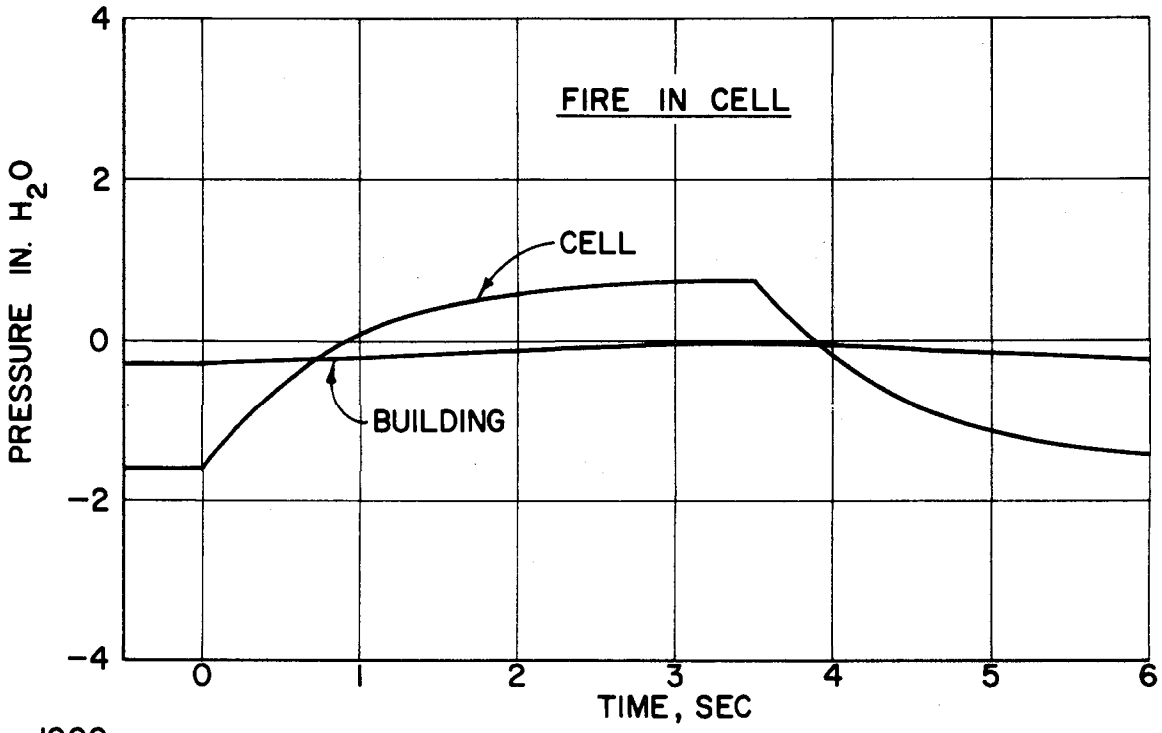
The model considered here is a cell. The same techniques can be used for glove boxes, building ventilation systems, exhaust systems, vessel off-gas systems, and other air handling problems. Although the examples shown are of drastic changes to the system, a study of less drastic changes may be of equal or greater importance in evaluating the system. The value of the computer as an aid in designing and operating a complex system applies to all air handling problems and not just to critical systems as the title of this paper implies. Several important features were excluded from this model for simplicity. Some of these are covered in a study by J. J. Perona, W. E. Dunn, and H. F. Johnson and reported in Calculated Transient Pressures Due to Impulse and Ramp Perturbations to Ventilating Systems in Buildings 3019, 3026, 3508, and 4507, ORNL-3086 (1961).

In summary, the analog computer can be a valuable aid in the design, operation, and hazards evaluation of all air handling systems. Although the system considered here is simple, complex problems can be analyzed with a modest amount of analog computer equipment.

TABLE I

Input Data for Steady-State Condition

Variable	Definition	Value
Q_1	Building Intake Flow Rate	300 cfm
Q_2	Cell Intake Flow Rate	300 cfm
Q_3	Cell Exhaust Flow Rate	300 cfm
V_b	Building Volume	5,000 ft^3
V_c	Cell Volume	1,000 ft^3
P_b	Building Pressure	-0.3 in. H_2O
P_c	Cell Pressure	-1.6 in. H_2O
P_a	Atmospheric Pressure	0 in. H_2O
C_1	Building Intake Filter Resistance	0.25 in. H_2O/300 cfm
C_2	Building Intake Line and Valve Resistance	0.05 in. H_2O/(300 cfm)^2
C_3	Cell Intake Filter Resistance	1.00 in. H_2O/300 cfm
C_4	Cell Intake Line and Valve Resistance	0.3 in. H_2O/(300 cfm)^2
C_5	Intercept of Pump Curve	4.0 in. H_2O
C_6	Cell Exhaust Filter Resistance	1.0 in. H_2O/300 cfm
C_7	Cell Exhaust Line and Valve Resistance	0.2 in. H_2O/(300 cfm)^2
f	Negative Slope of Pump Curve	0.004 in. H_2O/cfm



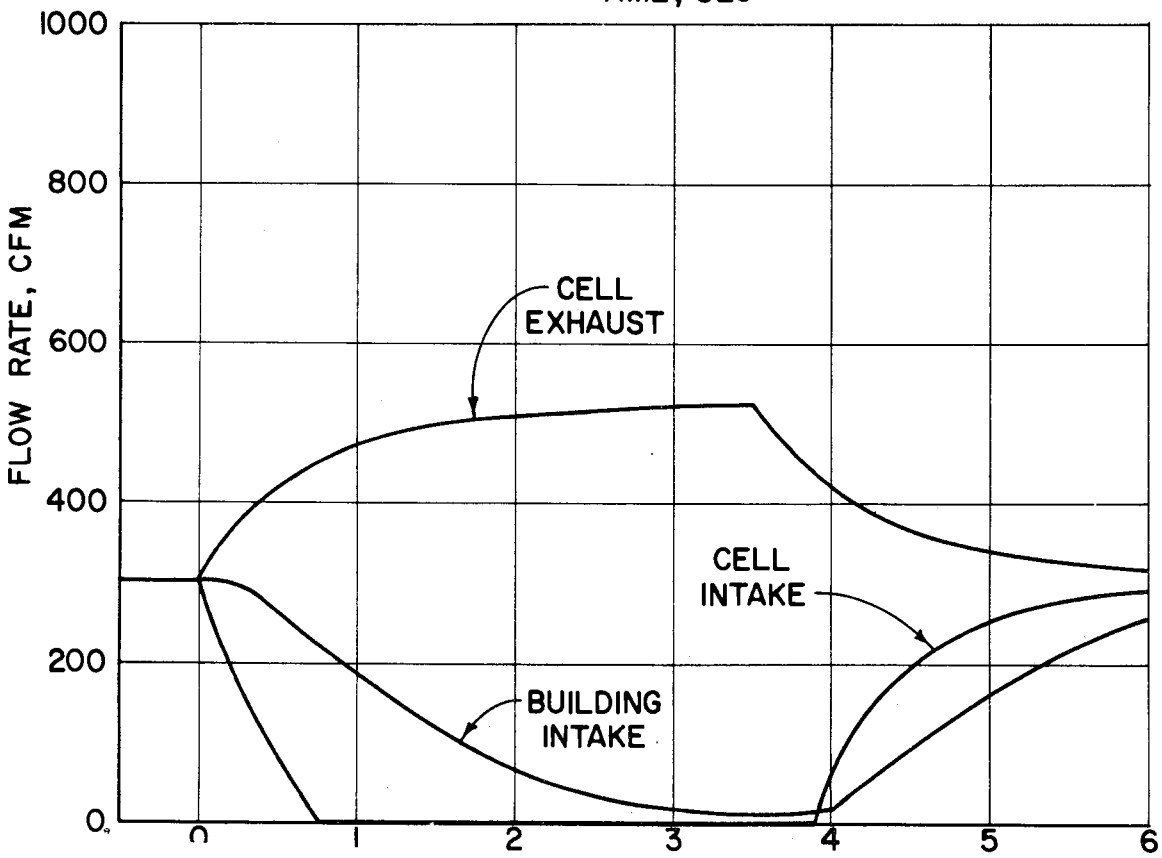


FIGURE 7. System Response to a Fire in the Cell

TABLE II

Potentiometer Settings

Potentiometer Number	Quantity	Setting
1	$K_b/2.4$	0.034
2	$P_{bO}/20$	0.485*
3	$P_a/20$	0.500*
4	$C_1^2/80\ C_2$	0.0156
5	$10^{-6}/5\ C_2$	0.360
6	$C_1/2000\ C_2$	0.750
7	K	0.100
8	$P_{cO}/20$	0.420*
9	$P_a/20$	0.500*
10	$C_5/20$	0.200
11	$(C_6 + f)^2/80\ C_7$	0.303
12	$C_3/2000\ C_4$	0.500
13	A	0.600
14	$10^{-6}/5\ C_4$	0.060
15	$C_3^2/80\ C_4$	0.0416
16	$10^{-6}/5\ C_7$	0.90
17	$(C_6 + f)/20,000\ C_7$	0.165
19	$K_c/2.4$	0.170
20	10/10	0.3162
21	$C_3^2/80\ C_4$	0.0416

*Five volts corresponds to a gage pressure of 0 in. H_2O.

DISCUSSION AND COMMENT

Analysis has not been performed on a real system to check computer results against actual measurements; therefore, no data is available to check a simulated system. We hope to do so in a few years, both cells and glove box facilities will be simulated.

Session Chairman: Thank you, Mr. Pickel.

The second paper, "Safety Aspects of the Design of Filter Ventilation Systems," has been prepared by S. E. Smith, F. J. Hall and W. E. Holmes, all of the UKAEA. The paper will be presented by S. E. Smith.

SAFETY ASPECTS OF THE DESIGN OF FILTERED VENTILATION SYSTEMS

by

S.E.Smith, F.J.Hall, W.E.Holmes

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

Atomic Weapons Research Establishment

Aldermaston

SYNOPSIS

A number of safety aspects of the design of filtered ventilation systems for radioactive and toxic buildings have been considered.

These include theoretical and experimental assessments of the heat release from fires of various kinds in workrooms, fume cupboards, glove boxes, and extract systems, the use of spark and flame arrestors, the ignitability of dust deposits in extract systems and filters, the cooling of hot gases in exhaust ducts.

As a result of this work, it is possible to formulate principles which should be followed in the layout and design of such systems, in the future; existing systems have been found not to require any serious modification apart from installation of glass paper filters.

1. INTRODUCTION

In the recent past, considerable attention has been paid at AWRE, as in other parts of the UKAEA, to the problem of fire protection in filtered ventilation systems of radioactive and toxic process buildings.

A major contribution to this has been the adoption of non-combustible filters based on the use of filter papers made from glass fibres, in place of the combustible filters, constructed either from cellulose-based paper, or from the resin-wool, asbestos-wool, and cotton-asbestos pad materials previously employed. At AWRE, glass-paper filters were first used experimentally in 1958, but were not accepted for general use until commercially available glass-paper filter units had undergone a number of modifications. These were due to AWRE insistence on a completely non-combustible construction, and on various other mechanical features, to avoid failure (refs. 1,2). At about this time, AERE (Harwell) tests had demonstrated that ordinary paper filters in wooden frames could not be satisfactorily fire-proofed.

The standard filter, now in use in all modern installations in the UKAEA consists of the 1000 cfm. 2' x 2' x 1' high-temperature absolute filter insert, which contains approximately 250 sq.ft. of thin (0.025"-.03") glass paper, pleated around spacers of corrugated aluminium and sealed with a fire-resistant cement into a steel frame. The metal spacers have beaded edges to avoid perforation of the paper at the folds. Such filter inserts are either used in a "honeycomb" wall pattern, bolted directly onto duct flanges, or, as at AWRE, sealed into an outer steel canister which is mounted in the ductwork headers. These canisters contain one or more inserts in series.

This paper is not concerned with the adoption of glass-paper filters, but with a number of safety aspects of the ventilation systems in which glass-paper filters are now used, which have also been investigated at AWRE in the last two to three years, and with the safety philosophy which has evolved as a result of these various investigations.

The safety aspects of filter installations which have been covered include:

(1) experimental work on spark and flame arrestors, and an examination of the need for flame and spark arrestors in filter systems

(2) experimental investigations, and theoretical calculations, of the possible temperatures which could arise in the extract air, and at adjacent filters, as a result of fires of various materials in (a) workrooms and process enclosures, etc. and (b) the extract ducts and filters

(3) experiments and calculations on the cooling of air in the ducts, to arrive at safe distances of separation of filters in ductwork in the absence of dilution effects

(4) isolation of ventilation systems in emergency, by the use of dampers and fan cut-outs, and the installation of fire detection equipment in filtered ventilation systems

(5) examination of the design of existing systems at AWRE, and of the condition of the systems with regard to dust deposits

(6) data on the ignitability of various dust deposits in the beryllium extract systems and filters at AWRE, as well as limited data from uranium and plutonium filter deposits, and on some synthetic dusts.

As a result of this work, it is possible to set out the principles which are now being followed at AWRE with regard to the safety aspects of the design of filtered ventilation systems of radioactive and toxic buildings.

In the following sections the work which has been carried out under each of these headings is summarised. Fuller details of the various investigations are available.

2. FIRE HAZARDS IN RELATION TO GLASS PAPER FILTERS

2.1 The fire resistance properties of glass paper filters may be stated to be as follows:-

(1) Although these filters are non-combustible, they are only fire-resistant up to approx. 500°C, (1000°F). Above this temperature failure occurs by melting of the glass paper, which is the weakest material present.

(2) They are not intended for routine or continual operation at elevated temperatures, but are expected to remain intact after accidental heating to a temperature not above 500°C. Most important is the fact that they do not themselves catch fire although burning material caught on the filter could cause a breach of the filter by melting the glass-paper medium.

(3) Under accident conditions such as a solvent fire in close proximity to the filter, when very high temperatures are involved, failure will occur quite rapidly.

(4) Hence where inflammable material, hot gases or incandescent sparks can reach it, some means of protecting the filter is essential if failure of the filter concerned cannot be tolerated.

2.2 In considering the effects of fires on filters it is necessary to distinguish between fires in which the material involved is solid, and gives rise to solid combustion products, and fires of solvents, etc., where the combustion products are gaseous. The important difference is that in the former case, heat transmission occurs by radiation and conduction, as well as by convection from the solid material to the gas stream, with an additional hazard of transport of solid debris, while in the latter case, heat evolved is mostly transferred directly to the gas stream with great rapidity.

3. SPARK AND FLAME ARRESTORS

At the time that the development of glass paper filters was taking place, investigations into the selection and performance of spark and flame arrestors were initiated at AWRE, and in early 1960, a working party was appointed to examine the necessity for flame and spark arrestors in the ventilation systems of radioactive and toxic buildings.

3.1 Spark Arrestors

An experimental programme carried out in the Chemical Engineering Branch at AWRE in 1960 led to the conclusions that, as far as spark arresting was concerned, glass-fibre was a satisfactory material to use, and that a coarse glass fibre pack, of quite low filtration efficiency, would adequately intercept any incandescent particles which were large enough for them to have a sufficiently long life to endanger filters within a few feet of the arrestor. It was concluded that a coarse loosely packed glass-fibre pad, 2" thick, operating at a face velocity of 300 ft./min., should be installed at the entrance to extract ducts, whever a spark hazard could be said to exist (e.g. machining boxes, welding booths, casting operations).

Suitable filter pads of this type are commercially available, are inexpensive, and have a low flow resistance. These pads could also be used as spark arrestors in the first stage of a composite filter to protect the main filters, although some economic advantage will normally accrue from the use of a more efficient prefilter of the pleated glass mat type, to extend the life of the main filter, and this will also serve a spark arresting function.

A prefilter of this type would acquire a heavy burden of any combustible material present in the extract gases and consideration was also given to the propagation of secondary fires in such filters and prevention of debris from these penetrating further downstream. For this purpose experiments were carried out to determine the duration of burning of different sized particles of various materials in a current of air so as to determine the mesh size of a debris arrestor in relation to the size of particle to be arrested, consistent with a low pressure drop contribution.

Carbonaceous materials, being slower burning, had a longer distance of travel than metal particles, but the temperature of carbonaceous particles is lower, and hence the ignition danger to a subsequent main filter is less.

For general use, a spark guard of stainless steel wire BS40 mesh has been adopted; this will give burning distances of 20 ft. for carbonaceous sparks and less than 5 ft. for magnesium; the location of the main filter should be decided accordingly.

3.2 Flame Arrestors

Flame arresting presented a much more difficult problem, and discussions which were held with the Group Safety Officer and the Fire Research Station at Boreham Wood, led to the general conclusion that commercially available flame arrestors were likely to be effective in only a limited range of conceivable conditions, and for only a very short period of time.

It was agreed that the most satisfactory approach in the light of the current state of knowledge of this subject was to restrict the use of highly inflammable materials (certain organic solvents, celluloid, etc.) in sensitive areas, and where their use was essential, to impose strict limits on the quantity of such solvents which might be introduced into ventilated boxes or fume cupboards and to provide sufficient air flow to reduce the concentration of vapour in the event of total spillage to below the inflammable limit (refs. 3, 4, 5).

4. THE TEMPERATURE OF AIR AND COMBUSTION GASES AS A RESULT OF VARIOUS TYPES OF FIRE

The effects of fire involving inflammable solvents, metals, whether massive or finely divided, and certain inflammable materials of construction (e.g. perspex) in raising the temperature of air extracted from open workrooms, fume cupboards or glove boxes, were considered, both by theoretical calculations and by practical experiments. Similar consideration was given to the effect of fires in the extract ducts and filters themselves.

4.1 Room extract

Solvent fires constitute the worst hazard in these circumstances; it was concluded that the temperature of air entering the main room extract duct is unlikely to exceed 500°C from this cause.

4.2 Fume cupboards

In fume cupboards where the volume of extract is normally in the region of 1000 cfm. solvent fires again constitute the principal hazard; the local extract temperature might reach 1000°C, in the event of a solvent fire although in general this would be reduced by dilution with air from other sources, further down the duct. Temperatures to be expected from metal (Pu, Be) fires, even when the metal is finely divided, are lower.

4.3 Glove boxes

Fires in air filled glove boxes, or inert gas boxes where a breach of containment has allowed some air to be drawn in, and where the emergency high velocity extract is in operation at 50 cfm., might give rise, in the case of burning beryllium swarf, to extract gas temperatures as high as 2000°C; for solvent fires the figure is about 1000°C, for massive beryllium it is below 1000°C and for massive or finely divided plutonium below 500°C.

The findings of separate investigations to consider certain aspects of box fire hazards (refs. 7,8) include recommendation for the cancellation in the event of a box fire, of high velocity extract (this is a system whereby air at high velocity is sucked in to preserve containment). With this precaution the probability of damage of main extract filters by fire arising in inert-gas-filled boxes is considered to be negligible. Local filters would however, be expected to fail rapidly.

4.4 Filters

(a) Where glass fibre filters (which having a comparatively loose structure, have a large surface area) are concerned, ignition of a deposit consisting essentially of all metallic dust, would raise the air passing through the filter to a very high temperature (1700°C), which could cause damage to another filter downstream, unless it were a considerable distance away, so that the air cooled before reaching it.

(b) For a dust of a more likely composition, i.e. partly organic, and partly inert inorganic, with only a small proportion of metal dust, providing the metal is not more than 80 gm. approximately and the rest is not more than 50% combustible organic material, the heat release is not enough to raise the air to a temperature sufficient to damage another filter, even though this is close to the filter containing the combustible dust.

It is possible that the materials would not burn readily if the total diluent were sufficient, i.e. a fully loaded filter but containing only this quantity of metal dust.

(c) In the case of a glass paper filter, owing to the lower surface area available for heat transfer purposes, calculations indicate that even if the dust accumulated were all metallic, the consequent increase in temperature of air passing through the filter would not exceed 500°C, although the filter itself would probably disintegrate eventually.

Where the fire is due to ignition by gases which are already at 500°C then the existing gas temperature could be raised beyond this, and might therefore approach 1000°C for the cases quoted.

5. RATES OF COOLING OF HOT GASES IN UNLAGGED DUCTS

5.1 Theoretical Assessment

Calculations based on conventional heat transfer data have been made, to determine the expected rate of heat loss from hot gases passing through unlagged mild steel ducts (see Fig. 1).

The initial maximum temperature was assumed to be 1000°C; the only condition under which any extract gases might conceivably exceed this figure is that of a major beryllium swarf fire in a glove box under high velocity extract at 50 cfm. and stringent operating precautions are taken to avoid such a condition.

A flow of 1000 cfm. of gas through a 1' diameter duct is one of the conditions considered, since this is the highest flow rate for which (in a solvent fire in a fume cupboard) a temperature of 1000°C might be attained; above this flow, dilution with cold air from other sources could be expected to reduce the temperature. Since the supply of gas at this temperature and flow rate would be of comparatively short duration, the unsteady states at up to 2 mins. were considered, and graphs were drawn of the temperature profiles along the duct, under unsteady and steady-state conditions. From this it could be seen that the duct lengths required to cool the combustion gases to 450°C for 1 and 2 mins. are 110' and 130' respectively, while the steady-state requirement for the same degree of cooling is 160'.

The other case considered is for a flow of 50 cfm. through a 4" duct, the condition for standard glove box high velocity extract. Since a fire involving a normal quantity of solvent might be expected to last for a longer period at this extract rate, the steady-state condition only is considered, and it is calculated that the direct length required under these conditions to reduce the temperature to 450°C is not more than 25' to 30'.

5.2 Experimental verification of cooling rates

It was considered advisable to carry out a practical check on heat transfer conditions approximating to those under review.

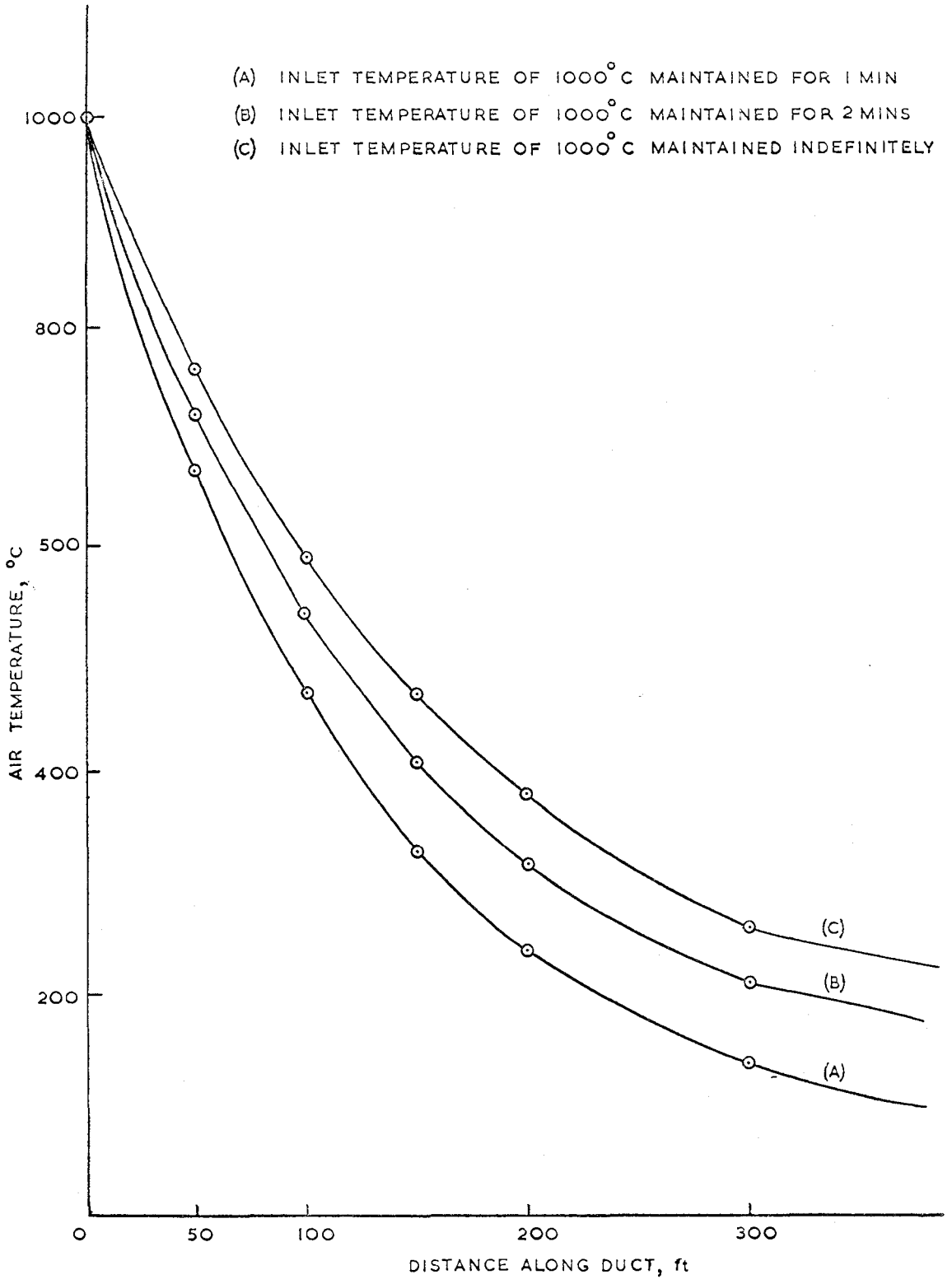


FIGURE 1. MAXIMUM AIR TEMPERATURES ATTAINED ALONG A 12 in DUCT WITH AIR FLOWING AT 1000 SCfm, AND INITIALLY AT 1000°C

A small research contract was therefore placed with the Chemical Engineering Branch, Department of Scientific and Industrial Research, Warren Spring Laboratory, who happened to have suitable equipment available to investigate this (ref. 10).

The air was heated by a paraffin burner, the maximum capacity of which was insufficient to heat 1000 cfm. of gas measured at STP. A reduced duct diameter of 8" was therefore adopted, and three flow rates were chosen to give about the same linear velocity as in our original calculations, the same Reynolds number and one value intermediate between the previous two. Gas temperatures were measured at 3', 32' and 61' and wall temperatures at 3' and 32', over a period of 5 mins.

Theoretical calculations of duct length versus temperature were made for these experimental conditions; the duct lengths, calculated for the three different flow rates as giving the temperatures observed at 61' from the entrance after 2 mins. were 70', 65' and 62.6' respectively, confirming our belief that the method of calculation used for the conditions in sections 3.1 and 3.2.1 was valid.

6. HEAT TRANSMISSION BY RADIATION AND CONDUCTION

The worst case which can be envisaged, i.e. that leading to the highest temperature and rate of heat release, is the case of a heavily loaded filter or prefilter containing essentially 100% beryllium dust, or a similar dust accumulation anywhere in the ductwork.

In this case, assuming a temperature of burning beryllium of over 2000°C, then a main filter located adjacent to it would suffer a severe temperature increase due to radiant heat. Aluminium spacers, if present, would constitute the main heat sink, but even so the temperature would reach at least 750°C, and whether aluminium were present or not, glass paper would certainly fail.

There would not be much heat loss by conduction to the ducting, until the filter collapsed. Then the temperature of the burning mass would rapidly cause the steel duct to melt through.

With a more likely filter dust deposit, as postulated in 3.1.4, if this ignited, then the heat release by radiation could still cause failure of a second glass paper filter, downstream, but it is doubtful whether with these compositions, combustion could be sustained, unless the metal content exceeded 80 gms.

Experiments to check this on the rig shown in Fig. 2 and 3 using filters loaded with atmospheric dust, with and without added magnesium powder in quantities up to 100 gms., and filters loaded with carbon and tarry matter from the rag-and graphite crucible-burning extract in a uranium building, showed that even when combustible matter ignited on the filter and the local temperature rose above 1000°C., the temperature of air passing through at 1000 cfm. rose only from 450°C. to 500°C.

A fire in the prefilter only damaged the main filter when burning debris was carried onto the latter.

7. THE USE OF ISOLATION DAMPERS AND FAN CUTOUTS IN AN EMERGENCY

7.1 Local Isolation

Whilst it might seem to be desirable to be able to isolate a part of an extract system in which a fire occurs from other parts of the system, if the system is designed so as to avoid the transmission of both burning debris and hot gas to the main or secondary filters then it is preferable to keep the extract going in such circumstances.

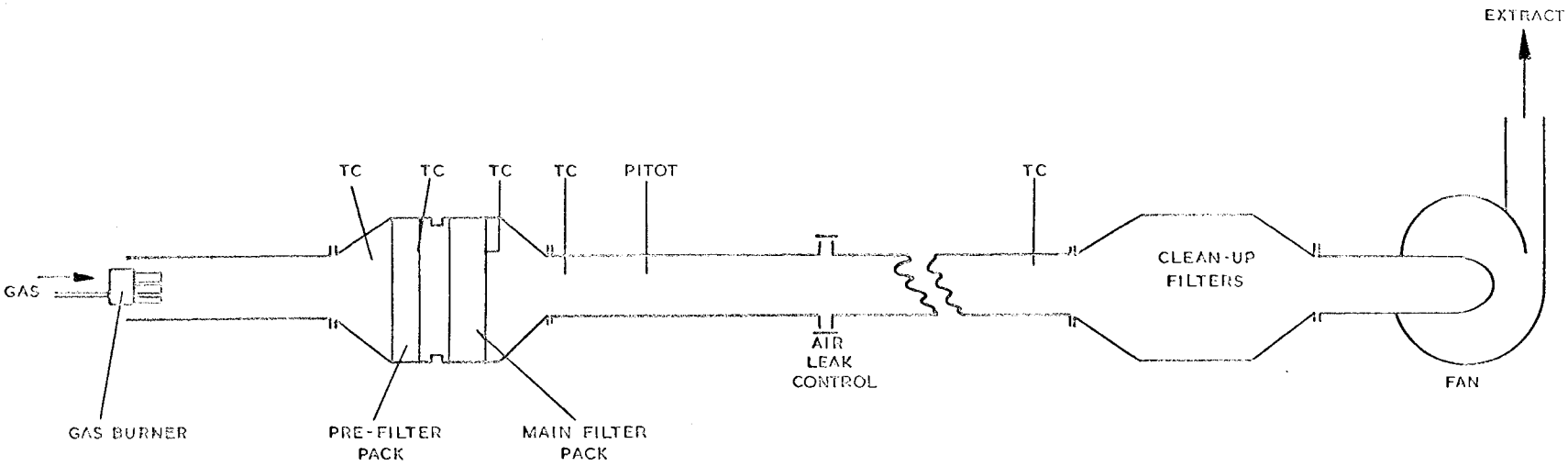
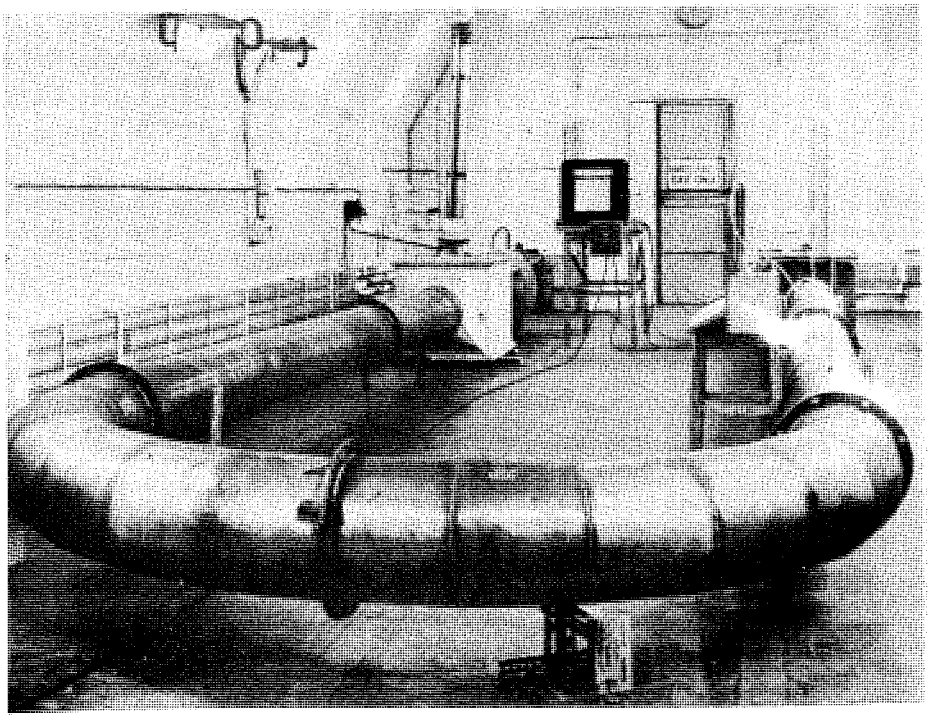
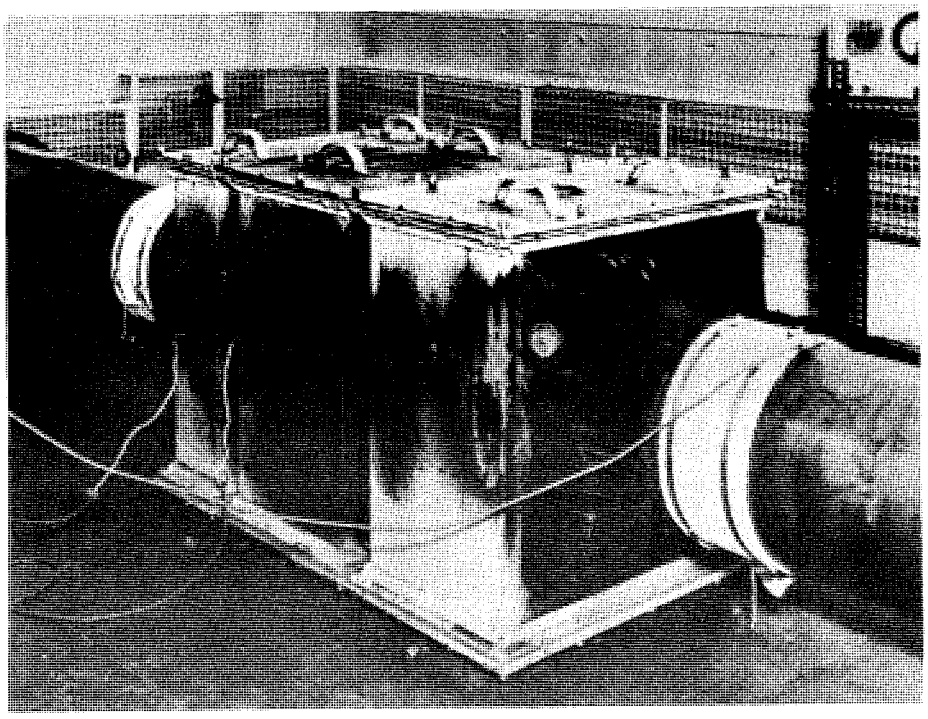


FIGURE 2. FILTER BURNING RIG



A. FILTER BURNING RIG



B. FILTER AFTER TEST

FIGURE 3

This however does not preclude the control of a fire by, for example, shutting down openings in fume cupboards.

Hence it is not necessary to fit special local isolation dampers in filter systems for this purpose.

7.2 Complete Isolation

It has always been possible at AWRE to shut down main fans without undue difficulty or delay. It is envisaged that this decision would be taken only after due deliberation and while adequate time remained for the necessary action to be carried out. Existing plant control rooms provide for this with sufficient accessibility.

Also as a last resort, the systems at AWRE have main isolation dampers at the stack which could also be operated as in 7.2 above.

8. FIRE PRECAUTIONS

Separate investigations were set up to cover fire detection in filters, in work boxes and in workspaces.

As far as filters and extract systems are concerned, recommendations for the fitting of certain types of fire detector were formulated so that in future all filter systems will have installed fire detectors of a recommended type.

9. BERYLLIUM EXTRACT SYSTEMS

9.1 Review of Beryllium Extract Systems at AWRE

In view of the high fire risk involved in handling beryllium powder, a special review was made of the operating and extract conditions in the beryllium metallurgy buildings at AWRE.

(a) Non-combustible prefilters and main filters are employed.

(b) Primary collectors are provided at extract points where beryllium dust concentrations are high, reducing the quantity of beryllium reaching the main extract system.

(c) No continuous collection system was provided for swarf arising in machining operations (this has since been provided).

(d) Production and handling of beryllium powder are carried out in argon-filled boxes.

(e) Machining boxes are provided with spark arrestors.

(f) Certain minor buildings still used combustible filters. These have been replaced by glass paper filters.

(g) Main filters are adequately protected by separation distances and dilution.

(h) Spark guards should be fitted after local filters on machine boxes.

9.2 Examination of Deposits in Extract Systems

A detailed examination was made of the extract systems in all beryllium buildings at AWRE; the total quantity of deposits present in the ducts was assessed and samples were taken for chemical analysis and determination of ignition temperatures. Ignition temperatures were determined by a differential thermal analysis technique, using the apparatus shown in Fig. 4.

In general the beryllium content of all deposits was low (0.01 to 1.5%), although isolated instances of high metal content in machine extract systems have occurred. These systems are being modified to confine contamination to the immediate vicinity of the boxes.

The deposits fell into three groups, those (consisting mainly of organic matter) which ignited at various temperatures below 500°C, those (containing metallic dusts) which ignited above 500°C, and those (consisting of inert inorganic dust) which failed to ignite up to 950°C.

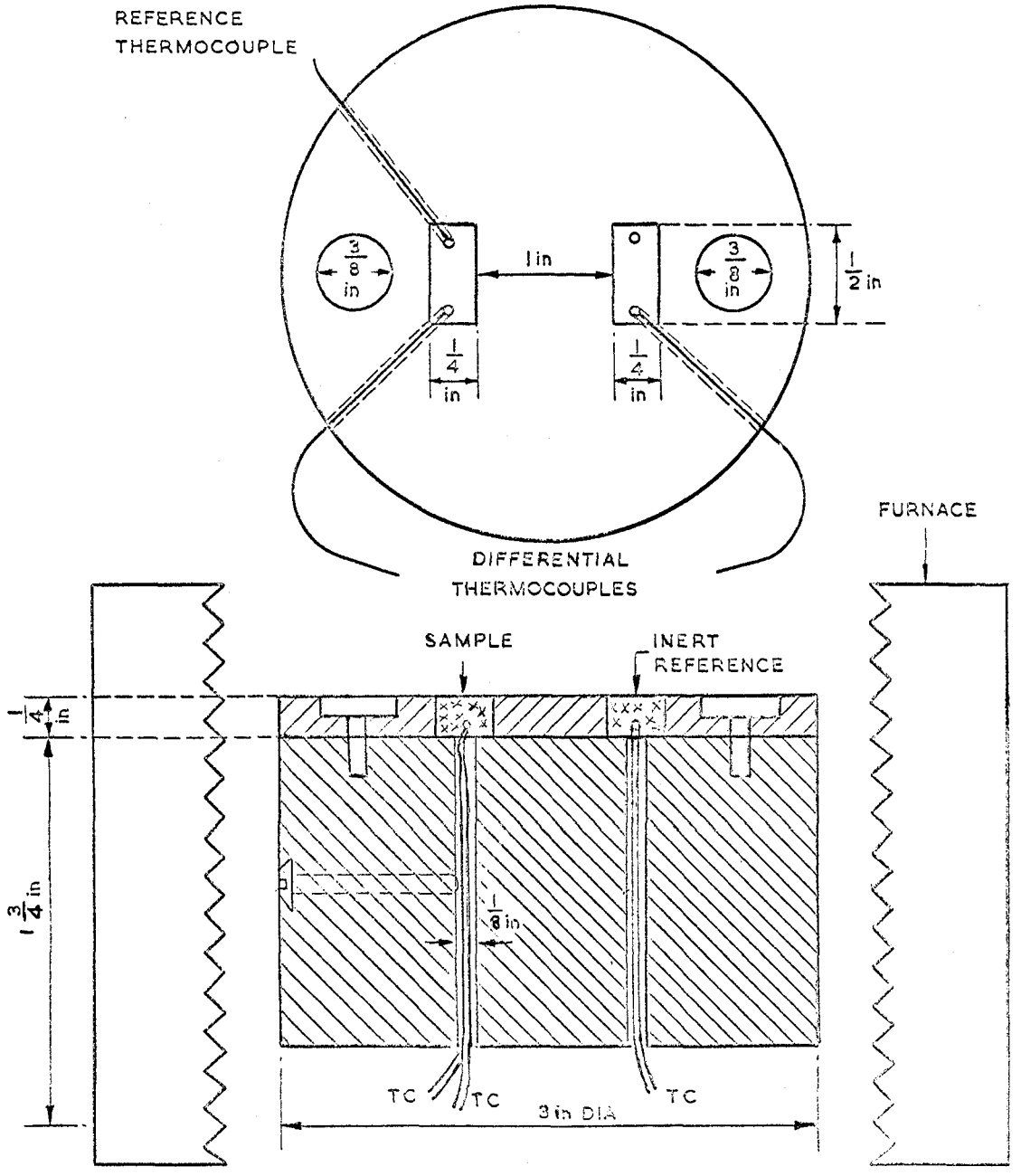


FIGURE 4. IGNITION BLOCK FOR DIFFERENTIAL THERMAL ANALYSIS

In none of the cases where ignition took place below 500°C was the heat released sufficient to raise the temperature of the burning mass above 500°C, although in a few instances, further external heating of the sample gave successive ignition points above 500°C. The inference drawn from this is, that dusts arising in the course of normal operation in beryllium buildings, which have these low ignition points, could not constitute a serious hazard to the integrity of glass paper filters, which are heat-resistant up to 500°C.

The samples showing ignition points above 500°C produced in most cases a very small temperature rise, indicating a low metal content, and the quantities of such deposits were so small that they are considered unlikely to constitute a serious hazard to the filters, unless in contact with them, in which case the filter would be expected to fail before ignition took place. The only possible exception to this was in the exhaust duct from the hot press, where the deposit contained 10% of beryllium, and ignited at 800°C with a considerable temperature rise. If deposits were allowed to accumulate in this duct a fire arising in the hot press might be transmitted to the filters. A local filter has now been fitted.

9.3 Synthetic Beryllium Dusts

Tests carried out on samples of beryllium powder showed ignition temperatures in the region of 750°C with a rapid temperature rise to well above 1000°C.

9.4 Effect of Glass Filter Material

Mixing beryllium with glass fibres from high efficiency glass paper, and from low efficiency glass fibre prefilters had no effect on ignition temperatures, although on ignition the coarse glass fibres fused round the dust and stopped the combustion. When actual dust deposits were combined with glass fibres they showed the same or higher ignition temperatures, and samples taken from fully loaded glass-fibre prefilters and glass-fibre main filters did not ignite below 950°C although another prefilter which was heavily loaded with oil ignited with a very small temperature rise at 360°C and again at 500 and 550°C.

It is concluded that glass fibres and glass paper do not affect the ignitability of dust arising in the course of beryllium metallurgy operations.

9.5 Possible Methods of Ignition

(a) Tests using Dewar flasks have established that spontaneous heating does not occur in dusts from the extract system, either alone or intermixed, or mixed with glass fibres.

(b) The possibility of build-up of static electricity when dry air passes through glass-paper filters with metal separators was also explored, but in all cases the static charge developed was found to be negligible.

9.6 Combustibility of Filter Material

Samples of cotton-asbestos and resin-wool filter materials from obsolete types of filter ignited at 240°C and 430°C respectively with low (~30°C) temperature increases, although these would be expected to be higher if a complete filter were ignited; this would, in any case, be completely destroyed, with consequent release of toxic material held on it.

10. URANIUM EXTRACT SYSTEMS

Samples were taken in 1958 from loaded 300 cfm. glass fibre filters in a uranium metallurgy building in order to find out whether there was enough uranium on them to be economically recoverable.

The total dust burden was estimated to be about 500 gms., and this included about 6 gms. of uranium in the filter from the foundry extract and about 1 gm. on the filter from the machine shop extract.

The dust deposits had low ignition temperatures (below 400°C) but produced a temperature rise of less than 50°C on the standard test. Attempts to produce sustained ignition of a complete filter in a current of air, by application of sparks or a flame were unsuccessful, even on a filter removed from the crucible and rag-burning system, which was heavily loaded with tarry and carbonaceous material (see 3.3 and Fig. 3).

It is concluded that deposits accumulating in extract systems from this type of building are unlikely to contribute seriously to a fire hazard.

11. PLUTONIUM EXTRACT SYSTEMS

Samples have been taken from a resin wool filter which has been in use in a plutonium metallurgy building for nearly 10 years on the extract from a high-activity area. These samples ignited at temperatures between 200 °C and 400 °C

Plutonium analyses on filter samples, and on material deposited in electrostatic precipitators, indicate that the total plutonium burden accumulating on main extract filters in 5 years is about 1 gram. Deposits in duct work and high velocity box extract filters probably total no more than this, and those in the filters on the argon box circulation system about the same.

12. DESIGN RECOMMENDATIONS

12.1 The UKAEA standard non-combustible high efficiency glass paper filter is sufficiently fire-resistant for use in all normal extract systems; although special consideration will need to be given to installation design to protect it from heating above its failure temperature (450-500°C). Some advantage may be obtained by elimination of the aluminium-foil spacers and this should be one aim of further development.

12.2 Glass-fibre spark arrestors should be used to protect the glass-paper filters from damage by incandescent sparks entering the system. Such spark arrestors should be located close to all extract points. A wire mesh spark guard should be fitted downstream of each pre-filter. A 2" thick low density coarse glass-fibre mat of the "Versil" or "Renuglas" type, operated at about 300' per min. face velocity, constitutes a satisfactory spark arrestor at a low cost and low pressure-drop. Considerations of economy in replacement of main filters may however dictate the use of a more efficient glass-fibre prefilter/spark arrestor, of the type shown in Fig. 5.

12.3 In certain cases (solvent fires, metal swarf fires), glass-paper or other filters installed locally to glove boxes, fume cupboards or room extracts will be breached.

12.4 The present use of spark arrestors in ventilated machine hoods is correct.

12.5 No known flame arrestor is likely to provide adequate protection from a major fire at the high flow rates involved in ventilation systems. Wherever possible the use of inflammable solvents, etc., should be restricted and the integrity of the main filter system should be ensured by providing a sufficient length of ducting to cool combustion gases below the temperature at which the filters will fail, unless adequate dilution with cool air is available.

12.6 Where the dust burden involved consists essentially of normal atmospheric dust the spark-arrestor and filter need be no more remote from the area extracted than is necessary to protect them from direct exposure to flames within the area.

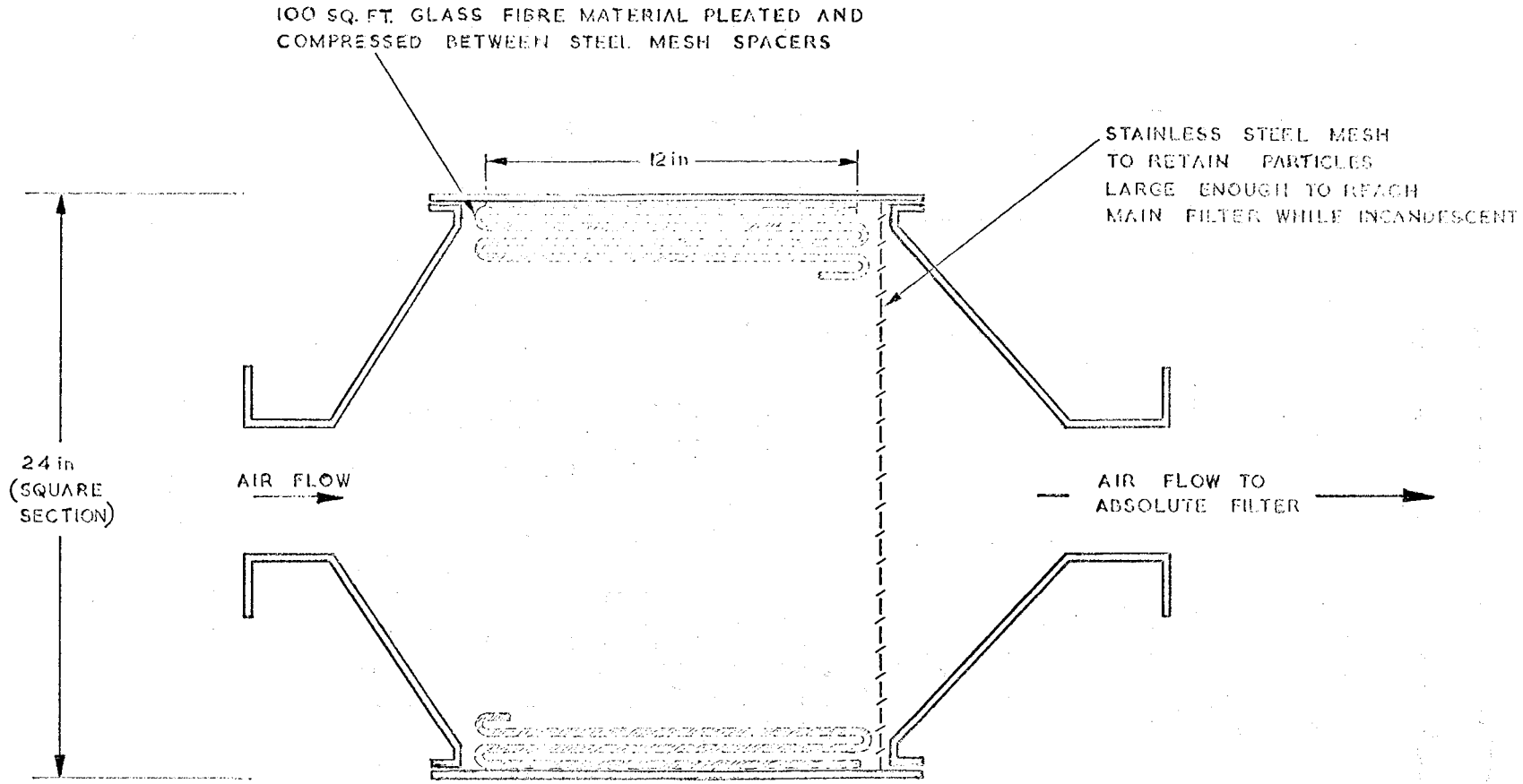


FIGURE 5. DIAGRAMATIC ARRANGEMENT OF PRE-FILTER FOR 1000 C.F.M

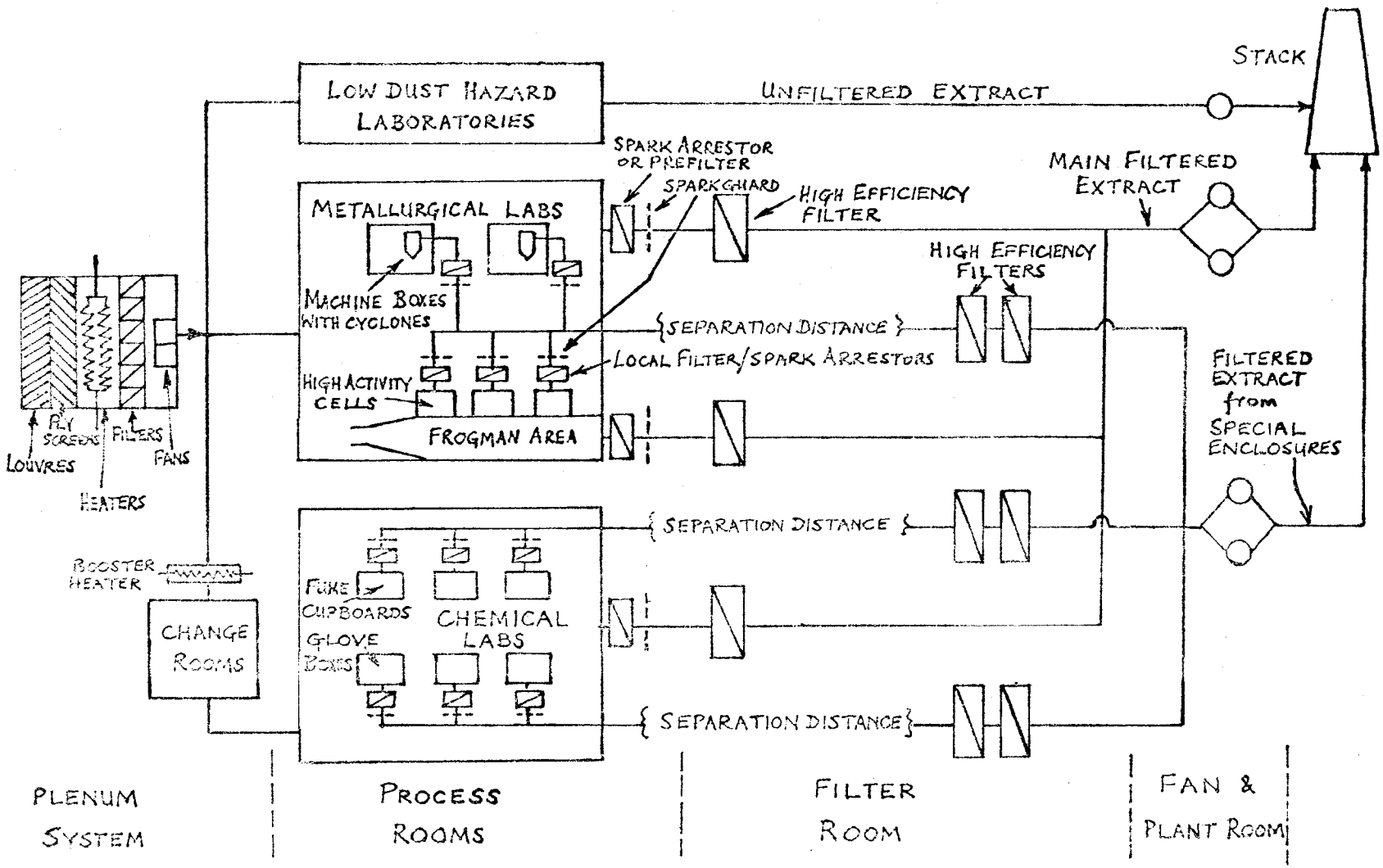


FIG. 6 : PROCESS BUILDING FILTERED VENTILATION SYSTEM

12.7 Where combustible dusts are involved, as in machining box extracts, a local dust removal system terminating in a filter should be employed, to keep the duct work and main extract system free from combustible matter.

Such a system is vulnerable to fire hazards and would itself add to the fire if material in it ignited, the main filters should therefore be protected

(a) by location where they cannot receive direct heat radiation from the local filters

(b) by installation of a spark arrestor between the local and main filters

(c) by providing either for a mixture of cool air from other sources, or for a sufficient length of duct, to cool the gases below 450°C in the worst credible conditions.

12.8 Where inflammable gases or liquids are handled in an extracted enclosure, the danger of damage to the main extract and filter system should be guarded against by ensuring that the air flow is sufficient to maintain the concentration of inflammable vapour below the lower explosive limit under all operating conditions. Provisions 12.7 (b) and (c) should also be followed.

12.9 Temperature sensitive elements should be fitted to main filters to give warning of high temperatures as an additional safeguard.

12.10 No special provision need be made for local isolation dampers to cut off parts of the system in an emergency.

A diagrammatic layout sketch of the type of extract system recommended is given in Fig. 6.

13. ACKNOWLEDGMENTS

The assistance of Mr. J. Dyment and Mr. A. F. George of the Chemical Engineering Branch and members of the Metallurgy, Safety and Maintenance Engineering Divisions in providing advice and information, is gratefully acknowledged. This paper is published by permission of the UKAEA.

14. REFERENCES

1) Dyment J., SSCTD Tech. Memo. 3/59 AWRE 1959.
2) White P. A. and Smith S. E., Paper to Board of Management, AWRE 1960.
3) AWRE Safety Instruction No. 2/60.
4) AWRE Safety Instruction No. 1/61.
5) AWRE Materials Department Safety Notice No. 1/62.
6) Addison R. A. et al. - Fire Detection in Ducts & Filters, AWRE March 1962.
7) Wilson E. et al., Report of Working Party on Fire-Fighting in Boxes, AWRE, 1961.
8) Smith S. E. et al. Report of Working Party on Extract Ventilation Safety, Part A - High Pressure Extract System, AWRE 1961.
10) Poll A., D.S.I.R. Report No. RR/CE/28, March 1962.
11) Addison R. A. et al. - Fire Detection in Room Spaces, AWRE Feb.1962.

DISCUSSION AND COMMENT

While you speak of a fire-resistant filter, we tend to use the term non-combustible in the sense that this construction would not contribute any heat itself. The construction was one which we arrived at in cooperation with the manufacturers. We did not accept the readily available units, and these underwent certain modifications to make them satisfactory to us. Essentially, the filter consists of a glossed paper filter medium, an all-steel case, not an impregnated, wooden case, and a suitable cement. I say that guardedly. There are alternative ways of achieving the cementing of the filter. There are at least two acceptable possibilities.

Session Chairman: Mr. Smith that was a most interesting paper and we are fortunate to have had the opportunity to hear your presentation.

The third paper in this Session is by A. B. Fuller of Oak Ridge National Laboratory and the title is, "Design Considerations for Exhaust Systems Involving Radioactive Particulates."

DESIGN CONSIDERATIONS FOR EXHAUST SYSTEMS INVOLVING RADIOACTIVE PARTICULATES

A. B. Fuller
Oak Ridge National Laboratory

ABSTRACT

The dependability required of exhaust ventilation systems handling radioactive particulates makes it essential that: (1) thorough investigations concerning needs be made, and (2) good engineering practices be applied. Many features peculiar to such systems are not clearly understood by inexperienced designers. A number of these "designer shortcomings" are discussed, with references listed, to enable designers to brief themselves prior to planning, reviewing, and designing such exhaust systems.

Just ten years ago the subject of air handling and air cleaning was a far step back of where we think it is today. Knowledge and know-how of twenty years ago concerning air handling and cleaning would now be termed primitive. Before World War II, few college-level courses were offered beyond elementary tutoring in heating, ventilation, and air conditioning. Many basic fundamentals were not stressed.

Things have changed--along came the nuclear age--the space age. Now everyone is, or should be to some degree, concerned about the air he breathes and how clean it is. Air is one of the few necessities of life that is plentiful and still free. This resource has been abused by mankind and still is being abused. We must learn better how to preserve and care for it. That knowledge should then be applied whenever the opportunity can be created. This is one reason we are here this week.

The engineer is the "doer" who is expected to apply his skills to design new air handling systems. These systems, then, will never be any better than the engineering knowledge he is capable of designing into them. Is your engineering designer sufficient for the job? Maybe he is the best man available, but is he experienced in this field? Do his designs accomplish their objectives? As in any field, there is no substitute for good experience.

The design of an exhaust system handling radioactive particulates demands good engineering judgment and experience to achieve safe, acceptable performance and needed dependability. It is necessary for an exhaust system to function as planned to ensure the proper operation of its air cleaning components. Good engineering judgment can only result from good factual conditions: complete and concise criteria, a clear understanding of design objectives, and the freedom to act.

We who are representatives of AEC contractors often find ourselves in the roll of preparing criteria and reviewing the design work of others. By our standards, we at the Oak Ridge National Laboratory have found most air handling designers employed by Architect-Engineer firms incapable of doing this type of job well. They lack know-how for this particular type of design assignment. Review effort therefore has been heavy; resubmission of review materials is frequently required, and confusion results. Much time is lost. It is also necessary that our own designers be sufficient for this job of reviewing, as well as doing direct design assignments. Experience is needed in all phases of design, construction, and operation; good experience, not just an exposure. This experience is difficult to find and, therefore, the price is high.

The design of exhaust systems involving radioactive particulates is a rather narrow field. Certain aspects are peculiar to this type system. This specific knowledge does not exist in one book. What little that is written is scattered, difficult to correlate, and very time-consuming to search out and evaluate. Therefore, it is difficult, near impossible, to know all the "best methods" of solving every problem that will arise.

The type and complexity of exhaust systems varies widely. I would like to point out some of the problem areas that we find need particular attention:

1. Many designers are short on the evaluation of maintenance needs and how to keep maintenance costs reasonable. This is very clearly reflected in their choice of equipment, space allowances, and access to items requiring routine attention.

2. Design calculations are poorly prepared, if prepared at all, for the final arrangement of the system. Operating and maintenance limitations are not given the users of the systems.

3. Designers are forever designing system components to meet the maximum demands and leave the lesser conditions to chance. These "less-than-maximum" conditions represent as much as 99 per cent of the operating time. Therefore, they too must be analyzed and designed for good operability.

4. The selection of fans and their application are areas often slighted, especially when space is limited. The needed compensation for a poor arrangement of ducting is frequently neglected, sometimes at a flow deficiency equal to 20 per cent of tabled ratings for fan performance.

5. Designers are found to be weak in the proper application of instrumentation and controls. The area of pressure control and monitoring is difficult to keep within practical limits of cost and good operability.

6. Filter selection and their proper application for the particular use is the pinnacle of the designers' problems. High efficiency filter applications are new to the inexperienced man; and having radioactive particulates further complicates the picture. It is here that designers need the greatest assistance and guidance. Too, it is here that much developmental work must yet be done to ensure installations of good dependability and reasonable maintenance.

These six categories seem to cover all the aspects in designing an exhaust system. Though this is near the truth, a particular designer is not necessarily weak on all counts. Having the services of competent designers is all important in getting the job done well.

I have compiled comments concerning design considerations for various aspects of this subject. These are attached.

These remarks do not cover all phases of design but attempt to offer guidance on the controversial items and those often causing trouble.

CODES GOVERNING DESIGNS (USAEC INSTALLATIONS)

All design effort for USAEC installations is governed by the AEC Design Manual, with its local interpretations. AEC instructions in this manual include compliance with local codes as well as certain other nationally recognized codes that are in the interest of constructing safe facilities and in providing for their safe operation.

Design References

See Ref. 11 and 13. State and local codes for the location under consideration.

Design Considerations

1. A designer must make himself thoroughly familiar with the AEC Design Manual, and applicable codes, during early planning of any work.

2. Radiation safety features and control do not always remain compatible with the usual interpretation of NFPA Fire Codes. Therefore, early establishment of the governing consideration must be ascertained from the jurisdictional authority. To this end the designer must arrange systems to maximize compliance with both considerations.

3. A basic guide to all ventilation work can be had in the ASHRAE Guide and Data Book. From this publication, and its referenced information, a designer can secure much of the written materials concerning exhaust systems.

ARRANGEMENT OF SYSTEM COMPONENTS

Planning the arrangement of components can provide advantages that are paramount to the success of a system. The order, or sequence, of components may vary for different types of exhaust systems. Therefore, considerations of features such as shielding, containment of contaminants, and access must be studied and evaluated.

Design References

See Ref. 1, 3, and 5.

Design Considerations

1. It is desirable to have all ductwork and other components under a negative pressure during all operations of a system(s). This means the fan power is situated near the terminus of the system; i.e., before release to the atmosphere or stack.

2. TID 7023 (Ref. 3) suggests the physical separation of roughing filters from high efficiency filters to minimize the spread of fire. See "Filtration" for other considerations.

3. Ductwork under negative pressure is subject to collapse. The arrangement of components must be considered for their pressure loading. The nearer the filter component(s) can be situated to the fan, the less heavy ductwork is required. Filter resistances most frequently constitute a major portion of total systems flow resistance.

4. The exposure to weather of system ductwork, housings, etc., can create problems of condensation. Such surfaces should be minimized to lessen the expense of items such as insulation, weather painting, and internal drainage apparatus. Where drainage can be tolerated and handled, condensation need not be a serious problem and can be the cheapest approach.

5. Convenience of access must be carefully studied and arranged. Shielding, if required, must be given preferential treatment to minimize cost and maximize operational convenience. Maintenance provisions must be planned; good conditions do not happen by accident.

6. Systems that will include alpha particle contamination must consider needed containment of components to allow maintenance by an acceptable method. Cleanup provisions are needed to prevent the spread of loosed contamination. Features required of this type system must be designed to prevent the release of intolerable amounts of radioactivity, not just to allow for the cleanup of materials that may be released. Penetration of the system at points where negative pressure conditions will be encountered is a prime consideration. Penetrations downstream of filtration, where feasible for the particular need, is another preference.

7. The atmosphere is not a dump for radioactive particulates. Maximum allowable concentrations and rates of release are closely regulated by the USAEC. Advice from the AEC must be obtained.

FILTRATION

Where chemically neutral exhaust gases are to be handled, particulate filtration is best achieved by a method that does not entail secondary wastes such as washing solutions, water, or oil additives. Dry type filter units serve this requirement better than other type devices. Where particulate loading in the air stream is low (i.e., <0.05 grains per 1000 cubic feet), high efficiency filter life can be expected to last well beyond twelve months' continuous usage. Prefilters are desirable for long filter life when a significant part of particulates is over one micron. Where atmospheric air is being handled (not previously filtered on intake systems), prefiltering is mandatory.

Exhaust streams containing chemically active ingredients present a formidable hazard to filtration equipment, both framing and medium. It is essential that investigations predetermine all the constituents to be encountered by the filtering devices. Systems arranged to serve multiple sources of effluent, from perhaps unrelated operations, present an even more difficult filtration problem to solve. Costs soar as a result of attempting to meet complex criteria of incompatible effluents. It is advisable to provide separate filtration facilities for each basic need and, if necessary, combine effluents downstream from filtering points in the system. This permits filtration to be best suited to the particular needs of each exhaust source.

The delicate construction of most filters, especially high efficiency of the absolute type, requires that precautions be taken in their application and use that guarantees the integrity of the installation throughout the filter life.

Special consideration must be given to ensure dependability commensurate with the hazards involved. Particulate filtration facilities in radioactive exhaust streams must serve as defense against release of air-borne activity, both to downstream portions of the system as well as against the release to the atmosphere.

Design References

See Ref. 1, 3, 4, 9, and 12.

Design Considerations

1. Investigate the nature of the intended effluent very carefully to allow a proper selection of medium and dust-holding capacity for each component.

2. Physically separate prefilters from final filters where combustibles are involved. Consider whether or not the system flow can be stopped in case of fire within, or near, the filter section. Does a radiological air-borne release have a greater potential of hazard than a contained filter fire? If yes, the fans should be stopped upon the detection of a fire and the fire contained insofar as possible. If the fans are stopped, what effect does this deficiency have upon the area that was being exhausted?

3. What safeguards are to be considered for fire prevention and control? Use of: (1) equipment that is noncombustible wherever possible, (2) separation of combustibles, (3) a fire extinguishment system consistent with size and application of combustibles, (4) smoke and/or heat detection equipment for early warning and preaction, flow diversion, and isolation--all are measures worthy of consideration by the designer. The potential hazard involved in having a fire and the results from a fire must be the paramount concern upon which a decision is reached and costs are justified.

4. During initial investigation, determine the method of handling and replacement that must be applied to filters and removable framing. If direct contact is to be allowed, the designer must stay within physical limits of an individual to carry and maneuver filter and frame units during changes. Filter bank heights over 6 feet should be avoided unless access is included as part of the designed facility. Steps must be minimized. Weights over 50 pounds become very tiring when lifting is involved. If the use of protective clothing, respirator (or mask), etc., is to be necessary, areas of abnormal heat, lifting, and handling weighty objects can become very acute to the problem of filter change or replacement. Where radiation fields and/or high contamination levels preclude direct contact for maintenance, many additional considerations must be made. The requirements for containing highly contaminated components will involve the need for good closures and sealing. Preplanning must establish an acceptable handling procedure to afford the designer criteria with which to work. Filter handling and replacement facilities must afford the worker and the surrounding area ample protection against excessive radiation exposure and the accidental spread of radioactive contamination. Positive means for effective cleanup must be evaluated.

5. Provide for drainage from each compartment of a filter section. The method of decontaminating inside surfaces could involve washdown using water or other agents needing drainage of appreciable amounts of liquids. If surfaces are exposed to outside winter temperatures, condensation may occur. Any entrapment of moisture droplets that loads a high efficiency filter will cause an air flow blockage that can result in sudden failure of the filter bank. A fire protection scheme involving liquid sprinklers

must be limited to a system that has air flow stopped in the event the sprinklers are applied.

6. In the absence of exact data concerning the gradation of particulates by size and weight to be expected in exhaust streams, the following is suggested for initial design:

   Prefilter (up to 35 per cent NBS efficiency, or equivalent): Provide for pressure drops, at normal flow, that are at least three times the initial resistance (clean), or 0.5" wg, whichever is the greater value.

   High Efficiency (from 35 to 95 per cent NBS): Provide for pressure drops, at normal flow, that are at least three times the initial resistance (clean). Never exceed the manufacturer's recommended limit for pressure drop, or as framing strength may limit the loading, at any flow rate that will be produced.

   High Efficiency--Absolute Type (99.95 per cent, or better, per DOP testing): Provide for pressure drops, at normal flow, that are at least three times the initial resistance (clean), except where preceded by a filter bank of equal efficiency. In such event, a resistance allowance of 1.25 times the initial resistance for the second stage of filters will afford reasonable life, insofar as particulate pickup is concerned. Maximum resistance for high efficiency units of the corrugated separator type unit should seldom exceed 4" wg, except where the application approaches the "ideal conditions" of dryness, chemical neutrality, filter position, temperature, and smoothness of air flow. From a practical viewpoint, such an ideal situation will never exist. Where resistances exceed 3" wg, particular care must be taken concerning the conditions under all phases of operation, more from the consideration of filter deterioration than from dirt pickup. It should be remembered the 24" x 24" x 5 7/8" and 24" x 30" x 11 1/2" size units are weaker construction than are other standard size units such as the 24" x 24" x 11 1/2"; therefore, their application can become more critical in achieving satisfactory performance. Gaskets will present problems where loading is applied to extremes and filter life is maximized.

7. Sealing faces for filter gaskets must be prepared initially as flat, smooth surfaces that are accessible for cleaning and inspection. It is essential that crack leakage be eliminated at the sealing face; this is done best by welding all joints with continuous seal welds. After welding the sealing face must be ground smooth, flat, and free from weld spatter. Then the surface must be prepared with a coating to preserve its smoothness. Tolerances not to exceed $\pm 1/16$" from a true, flat plane should be required of seal faces prepared for high efficiency absolute type 24" x 24" size filter units. Smoothness of surfaces before coating should be comparable to 250 P (microfinish) or better at all contact faces. While calking can be termed acceptable for prefilter frame sealing, it is unacceptable for high efficiency absolute type filter banks. Welded joints (ground at seal faces) are best and are reasonable in cost.

8. Provisions for in situ testing should be made for all high efficiency filter installations of the absolute type. If DOP smoke penetration tests are applied for routine system quality assurance, it is necessary that appropriate openings be provided to introduce DOP smoke ahead of the filters, sample upstream, and sample downstream. ORNL-3442 gives the requirements for such testing, along with other test experiences.

9. Filter unit hold-down must provide uniform gasket pressures. Individual filter unit mounting is preferred where contact maintenance is to be applied, with liberal spacing to provide easy handling. Hold-down attachments must be kept simple to operate and require a minimum of time to perform. Small pieces requiring positioning or alignment are to be avoided. Filter unit framing should be provided aligning guides and weight rests that minimize the chance of poor positioning. The hold-down pressure to compress gaskets must be spread sufficiently to prevent damage to the filter framing that may later release pressure by fatigue or breakage. Initial gasket pressures will vary by the type of material used. Approximate value for 5-10 durometer neoprene sponge (1/4 inch thick) would be 2 psi for 50 per cent depression (i.e., to 1/8-inch thickness). Clamping and framing strength must account for a safety factor of at least 4. No deflection of framing can be tolerated that would shift or shear gaskets or filter frames.

10. Good lighting is an absolute must for contact maintenance filter change areas. It is essential that operators be able to clearly see how to position filters, align clamping, and inspect framing and medium.

11. When conditions of maintenance will allow physical contact, filters should be considered for upstream mounting, thus taking full advantage of increased gasket sealing as filter resistance increases. This means gaskets are to be limited to the downstream edges of filter unit framing. Should contamination levels prevent direct contact with the filter units and framing, other mounting schemes are necessary. Mounting filters on downstream faces of seal framing will mean gasket pressures are lessened as filter resistance increases. Also, as gaskets loosen, their "blow out" is more likely to occur. Therefore, in applications involving heavy filter resistance, such as high efficiency absolute types, greater dependability and longer life expectancy can be achieved with filters arranged upstream of the seal framing.

12. High efficiency filters of the absolute type must be mounted in a particular way to maximize strength and life. A strong preference is given for their having framing in a vertical plane (or near so) with the air flowing horizontally. Filter pleating must be vertical. Filter mounting should install the marked test flow arrow correctly to match the system's flow. Filter installations of this absolute type which have vertical air flows increase the chance of bulging and breaking the medium.

13. Provide pressure drop indicators across filter banks, individually. Provide means to correlate this pressure drop data with the flow rate through the bank. Good evaluations of filter dirtiness can only be made by having pressure drop and corresponding flow rates.

FAN SELECTION

The heart of the system is the fan, or fans, that provide for the movement of air. Good operation is dependent chiefly on the fan and its installation matching the flow characteristics of the system. A fan that is oversized can be as critical to good system performance as one that is undersized. Designers must respect the importance of a proper selection to suit both normal and maximum system demands. Fan selection must be finalized after all other features of the system are designed and are carefully analyzed to anticipate system characteristics.

Design References

See Ref. 1, 2, 7, and 10.

Design Considerations

1. Make a final selection of a fan only after the system is designed and its characteristics are calculated and analyzed. If a system is being designed or modified to suit an existing fan unit, be certain its performance is known. Use certified data from the manufacturer.

2. Remember--seldom, if ever, is a fan applied to a system in a manner equal to AMCA test conditions. Therefore, the fan performance to be expected in a system application is different from the catalog data given by a manufacturer. The variation must be compensated for in the selection of the fan and its drive. Conditions in a practical application are always more adverse to good performance than those for AMCA test conditions. Factors such as temperature variations, inlet configuration, inlet approach, discharge configuration, voltage variations, and belt slippage are to be considered.

3. Select fans having non-overloading characteristics for systems having major variations in static pressure due to filters, automatic, or manual adjustments. Fan performance must be stable during any condition of the system, meaning the selection of the operating point must always be well beyond the peak of static pressure for the speed being used. For an application of a fan with a backwardly inclined wheel, flow will increase as static resistance of the system decreases in a predictable manner, and vice versa. Where operating points are selected too near the peak of maximum static pressure, operation is unstable; a slight variation in system characteristics can easily upset the flow level.

4. Dependability of system flow must be considered in fan selection. The arrangement of a fan unit is a prime part in providing dependability. A unit having a direct drive is more dependable than a V-belt-driven unit. Arrangements 4 and 8 can be termed more dependable, but less versatile, in an application than arrangements 1, 2, and 9.

DAMPERS

To regulate and control flow and pressure in an exhaust system, a means of varying the system's characteristics is required. Dampers can offer this type of performance. They function as orifices, having variable restriction, that produce pressure drop, thus regulating flow. Many types exist having various identifications, such as: multi-blade, parallel blade, opposed blade, butterfly, single blade, etc. Some names are synonymous with others; no standardized identification is complete for all the types in use.

Design References

See Ref. 1.

Design Considerations

1. The most common fault with damper applications is in oversizing them. This means added costs and less effectiveness as an adjustment to system characteristics. To be a control, a damper must provide resistance to the flowing stream.

2. A damper may be applied only for shutoff uses, thereby limiting its control to two positions only, open and shut.

3. Damper construction for exhaust systems must provide for: (1) needed strength to suit maximum suction or pressure conditions to be experienced; (2) minimum leakage, both through the blade cracks and from the outside; (3) reliability and ease of movement; and (4) desired characteristics.

4. Metal bladed dampers of multi-blade construction are preferred to be metal-to-metal, free of edge gaskets, when access is limited. Maintenance costs for edge gaskets can be intolerable in corrosive and contaminated locations.

5. Clear, concise information must be established in the specification of dampers concerning strength, leakage, and operability during operation. Static water tests are suggested to prove strength. A stipulation of maximum crack area (by percentage of the net free area) is necessary to establish leakage parameters. Operability must be controlled by stating torque limits for required operating conditions. All dampers do not require a complete listing of all these features. However, when a feature is critical to the needs of the system's operation and safety, such features must be formulated into detailed requirements.

6. Where damper operation is planned, as two-position action, employ spring power to make the device fail in the safer position of operation.

7. Be certain there is a position indicator on all dampers where blades are obstructed from view.

8. Supply all dampers with setting and locking quadrants. Provide means for marking damper positions after the balancing of system flows and pressures.

9. Dampers for heavy vacuum or pressure service (-8" wg to -60" wg, and +8" wg to +60" wg), having low leakage features, are difficult to obtain as standard items of manufacture. Construction more common for these levels of pressures is the butterfly type. This type can be found for pressure limits of 5 psi, or above, but not readily available for the 2-psi limit. Therefore, many applications will, of necessity, include values having heavy weight and pressure capabilities far beyond the other features, such as the ductwork that connects to the damper.

DUCTWORK CONSTRUCTION

Ductwork is the controlled route for the air or gases for the exhaust system. Large systems can involve ductwork of complex design, whereas small systems may be arranged to employ standard metal or plastic pipe or tubing. Choice of construction is complex. The need for good aerodynamic qualities should always be a paramount consideration to the designer. The most economical arrangement of ductwork does not consistently stay the same; it will be influenced by items such as: size, quantities, tolerances for fit, basic materials, coatings, method of jointing, sequence or space limitations for installation, field connection requirements. There is no substitute for test experience in evaluating life versus costs.

Design References

See Ref. 1, 2, and 8.

Design Considerations

1. Wherever space will allow use round ductwork on exhaust systems. The round shape provides many advantages over rectangular shapes: (1) the round shape is the most economical use of metal, by weight; (2) the round duct is stronger as a section, retaining its shape when under more abnormal pressure conditions than will rectangular shapes; (3) velocities can be kept more uniform in round ducts without requiring internal vanes or other aids; (4) internal drainage is less of a problem to control in round ducts; and (5) supports can remain more simple with round ductwork. The one principal disadvantage of round ductwork is it makes less efficient use of critical space than do rectangular shapes. However, the more round ductwork used instead of rectangular shapes, the less will be over-all weight of metal and the lesser wetted areas subject to needed coatings, insulations, or expensive construction.

2. For air-tight construction in metal ductwork an appropriate method of welding is preferred for all longitudinal and girth seaming between disconnect points. Flanged joints, gasketed and bolted, are best at disconnects. A minimum number of joints should be applied consistent with the needs of erection, coating, inspection, etc.

3. Coating requirements, as well as other surface preparations, must respect the size of pieces being applied in the system. Example: Interior surfaces on small duct sizes are difficult to prepare and coat. The spray coating of sizes less than 12" diameter is not reasonable. These should be hand brushed, with lengths limited to four (4) feet to say within arms reach from either end. Sizes 8" and less are not practical for even hand brushing. Dipping may be considered for small sizes (less than 8").

4. Where fire protection and radiation safety regulations permit, plastic ductwork may be applied at substantial savings in low pressure systems. As suction (or pressure) increases in the system of ductwork, thereby increasing the loading on the surfaces, full plastic materials become less attractive to needs. For systems having medium and high pressure conditions (approximately 4" wg or higher) dipped or coated metal ductwork is more appropriate. Plastic materials, such as polyvinyl chloride (PVC) and polyethylene (PE) cannot resist heat beyond 150°F without some adverse effects. A system having a serious potential of hazard should be given very close evaluation before applying ductwork sections that are all plastic.

5. Any ductwork system intended to handle radioactive materials deserves a pressure-leak testing, before initial service, to prove its capability for the intended use(s).

6. The recommended ductwork construction listed in the ASHRAE Guide and Data Book does not list a test pressure for each style of sizing. The ASHRAE recommendations are applicable, more directly, to uses having internal positive pressure conditions. Extreme care should be given to their use as suction systems. For suction applications, their capabilities are not the same. The type of joint and choice of reinforcement method greatly affect the suction strength of sections. Further care must be exercised in specifying the test pressure for such types of constructions.

   The following types of construction have been used successfully over extended periods (years):

Exposed Round Ductwork Systems Operating Up to 8" wg Suction
12" wg Test Pressure

Size	Material	Joints	Reinforcing
6" thru 12" dia	16 ga carbon steel, metal arc welded; interior coated (or dipped) exterior painted enamel.	Flanges of 1/4" plate up 8 or 1 1/2" x 1 1/2" x 3/16" angles on 10" and 12" dia; gasketed and bolted (5" o.c., max) 4' lengths	None, except for girth rings of angle at support points.
Above 12" thru 36" dia.	14 ga carbon steel, metal arc welded; interior-exterior painted enamel.	Flanges of 1 1/2" x 1 1/2" x 3/16" rolled angle, gasketed and bolted (5" o.c., max) 4' and 8' lengths, depending upon coating needs.	1 1/2" x 1 1/2" x 3/16" angle girth rings (welded) at midpoint between flanges of 8' lengths.

SYSTEM INSTRUMENTATION

Instrumentation for exhaust systems can be selected to: (1) monitor system conditions, (2) provide for the automation of certain system functions, or (3) the combination of these two features. Reliability is borne out of simplicity.

Design References

See Ref. 1.

Design Considerations

1. Simplicity of controls and instrumentation is always to be desired over arrangements involving greater numbers of items and more interdependability of control action. Never choose two when one will do.

2. To determine conditions of system performance, both flow rate(s) and pressure must be obtained.

3. For systems that must provide for standby fan startup, never rely on monitoring motor current failure alone to initiate automatic action. Basically, flow or pressure, whichever is deemed more critical, must be sensed with an abnormal status being detected to cause standby startup or changeover of fan units.

4. In choosing whether to allow dual exhaust fan operation or single fan (standby) operation, the analysis of dual fan effect on the system must be made. Excessive flows or pressures must be tolerable and not jeopardize the integrity of filters, ductwork, or other components.

5. Manual adjustments of system pressures and flows are to be preferred in applications where changes are minor and/or infrequent. Manual adjustment of devices such as valves and fan speeds provides a high degree of simplicity and reliability where fast response time is not a factor. For situations needing a fast response to an abnormal situation, such as an electrical power failure, automated correction is mandatory.

6. Controls must be selected to fail to the safer condition of operation.

PERFORMANCE TESTING

Testing the performance of a system is as basic as designing the system. It proves, or disproves, the system will accomplish the design objectives originally established as criteria. Only through testing can this convincing knowledge be gained.

Design References

See Ref. 1 and 6.

Design Considerations

1. Testing is essential to gain the required knowledge for good system operation. Actual system capabilities must be demonstrated by testing. Carefully record all test data acquired in a form clearly legible for anyone to decipher.

2. Standard methods of flow measurement must be used. Multi-point traverses should be prepared in a systematic manner to allow repetition.

3. Test points and traverse stations must be preplanned and have access provisions made to afford maximum use.

4. Refer to ASHRAE Guide and Data Book, 1963, Chapter 16, "Measurements and Instruments," for the accuracies of different types of measuring instruments.

REFERENCES

1. ASHRAE Guide and Data Book, 1963, Fundamentals and Equipment, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 345 East 47th Street, New York , New York.

2. Fan Engineering, Sixth Edition, Buffalo Forge Company, Buffalo, New York.

3. Gilbert, Humphrey, Palmer, James H., High Efficiency Particulate Air Filter Units, TID-7023, USAEC, Washington 25, D. C.

4. Govan, Francis A., Selection and Maintenance of Air Filters, Report No. 34, for the Federal Construction Council by Task Group T-28, Building Research Advisory Board, Washington, D. C.

5. American Standard Fundamentals Governing The Design and Operation of Local Exhaust Systems, ASA Z9.2-1960, American Standards Association, Inc., 10 East 40th Street, New York 16, New York.

6. Industrial Ventilation, A Manual of Recommended Practice, Seventh Edition, American Conference of Governmental Industrial Hygienists.

7. Trickler, C. J., Is the System Correctly Designed?, Air Conditioning, Heating and Ventilating, May, 1960.

8. Brown, Robert A., What You Should Know When Designing Plastic Ventilation Systems, Heating, Piping and Air Conditioning, September, 1962.

9. Building Materials List, Underwriters' Laboratories, Inc., 207 East Ohio Street, Chicago 11, Illinois.

10. Standard Test Code for Air Moving Devices, Publication 210, Air Moving and Conditioning Association, Inc., 2159 Guardian Building, Detroit 26, Michigan.

11. AEC Manual (Design Criteria), Chapter 6306, "Heating, Ventilating and Air Conditioning," USAEC.

12. Parrish, E. C., Schneider, R. W., Tests of High-Efficiency Filters and Filter Installations at ORNL, ORNL-3442.

13. The National Fire Codes, National Fire Protection Association, Vol. III, Building Construction and Equipment, and Vol. IV, Fixed Extinguishing Equipment.

Session Chairman: Gentlemen, the last prepared text in Session II is a joint effort by ORNL personnel. The paper, "Containment and Ventilation Systems in the Transuranium Processing Plant," by W. D. Burch, B. F. Butterfield, W. E. Unger, O. O. Yarbro, and J. P. Nichols. W. D. Burch will deliver the paper.

CONTAINMENT AND VENTILATION SYSTEMS IN THE TRANSURANIUM PROCESSING PLANT

B. F. Bottenfield
W. D. Burch
J. P. Nichols
O. O. Yarbro
W. E. Unger

ABSTRACT

The unique features of the ventilation and containment systems incorporated into the Transuranium Processing Plant, which is under construction at the Oak Ridge National Laboratory, are described. This facility is designed to recover from irradiated target rods by solvent extraction and ion exchange techniques gram quantities of many of the heavy actinide elements for research in many laboratories throughout the country. Containment of process solutions is insured by surrounding the equipment with multiple negative-pressure systems, including final containment by maintaining the entire building at a - 0.3 in. pressure. The effects of operational and accidental activity releases from the facility are discussed.

The Transuranium Processing Plant (TRU) is a new facility currently under construction at Oak Ridge National Laboratory designed to recover for research purposes gram quantities of many of the very heavy actinide elements including americium, curium, berkelium, and californium. Target rods, containing initially Pu-242, will be irradiated in the High Flux Isotope Reactor (HFIR), then dissolved and the products recovered in TRU, and the lighter isotopes refabricated into recycle rods for further irradiation. The containment problems for TRU are in many respects completely unique. Shielding requirements were dictated by neutrons from the spontaneous fissioning of Cf-252 and Cf-254, but very high levels of gamma emitting fission products are also routinely handled. Containment criteria are very stringent because of the extremely high level of alpha emitters. For instance, the facility will contain up to 300 gm of Cm-244. In comparison with alpha decay from plutonium, this is equivalent to 430 kg of Pu-239. The problem is extremely acute because of the very high specific activity; the sources are extremely concentrated. One gram of Cf-252 contains 645 alpha curies, emits 3×10^{12} neutrons/sec from spontaneous fission and represents 4×10^{10} body burdens of activity.

In addition to the normal methods of containment, three additional features have been incorporated into the building to insure positive containment. First, the major equipment has been installed within secondary enclosures within the hot cell bank. These enclosures, termed cubicles, are maintained 0.3 in. of H_2O pressure below the cell proper. Secondly, the master slave manipulators, provided to operate the equipment within the cubicles, will be double booted and a pressure monitoring system will be incorporated into the space between the boots to insure against leakage from this vulnerable source. Finally, as a more positive means of insuring against total loss of containment from the facility, the entire building will be maintained at - 0.3 in. H_2O with respect to atmospheric pressure.

BUILDING DESCRIPTION

The building is a two-story structure, approximately 120 feet square (Fig. 1) roughly divided into two equal parts, the first containing the cell bank, limited access area and cell operating areas, and the other containing eight laboratories, building service and office areas. The cell bank contains nine cells, seven for process use and two for analytical purposes. Each cell is divided internally by a two-foot shielding wall (Fig. 2). In the operating side is the cubicle containing the equipment racks. In the rear is the tank pit area where process storage tanks, evaporators, and waste tanks are located. Equipment is removed from and installed in the cubicles by another special containment device, the equipment transfer case, shown on top of the cubicle in Fig. 2. The door in the cubicle ceiling is sealed and locked to the transfer case door while both doors are raised into the transfer case. After the equipment has been lowered into the cubicle by means of a hoist within the case, the doors are lowered into their normal positions, unlocked, and the transfer case removed. For handling contaminated equipment, a one-foot thick concrete shield is provided; and the transfer case can be operated through the shield. Similar double-door, mechanically-sealed closures are provided on the conveyor access openings in each cubicle (see Fig. 1) to limit the spread of contamination from one cubicle to the others and to the transfer area at the end of the cell bank. To date, the mechanical operations of both these seal systems have been adequately tested, but actual demonstrations with contaminated equipment and cells have not been performed.

The second floor (Fig. 3) contains the remainder of the laboratories, a chemical make-up area for servicing the cell bank, and the recirculating cooling water equipment.

VENTILATION SYSTEMS

Four primary zones of containment, defined by the degree of activity contained, are included in the cell bank ventilation system (see Fig. 4). The process equipment is vented to a caustic scrubber system maintained at - 10 in. of H_2O while the cubicles are held at - 1.7 in. by a control valve. The cell pressure is controlled at - 1.4 in. of H_2O and the building surrounding the cell at - 0.3 in.

Cubicle Ventilation System: Both the vessel off gas and cubicle vent systems exhaust through the same scrubber, filter, and blower system. Air flow requirements here are approximately 20 CFM for the vessel off gas and 500 CFM for the cubicle purge. Cooling of each cubicle is achieved by separate

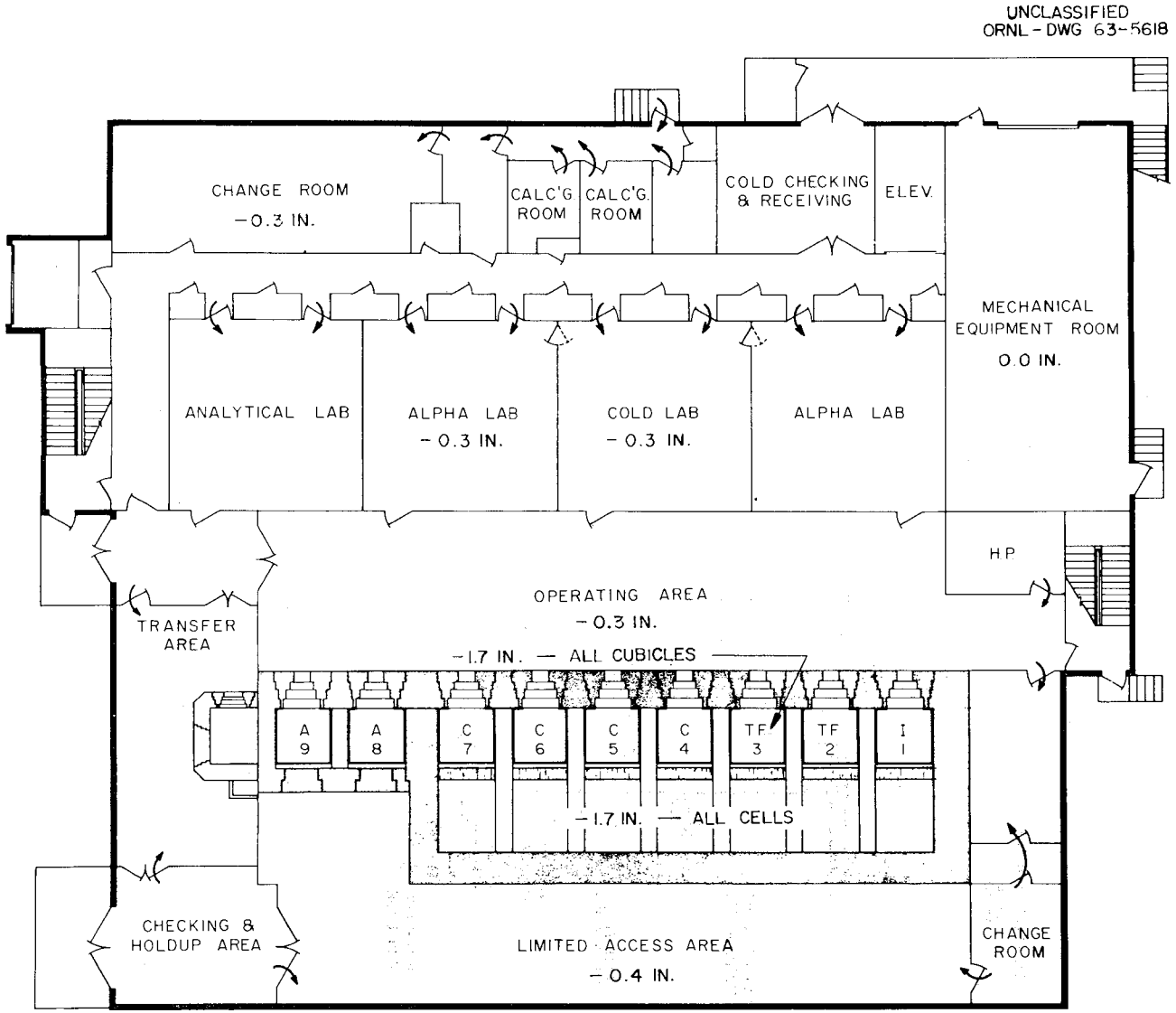
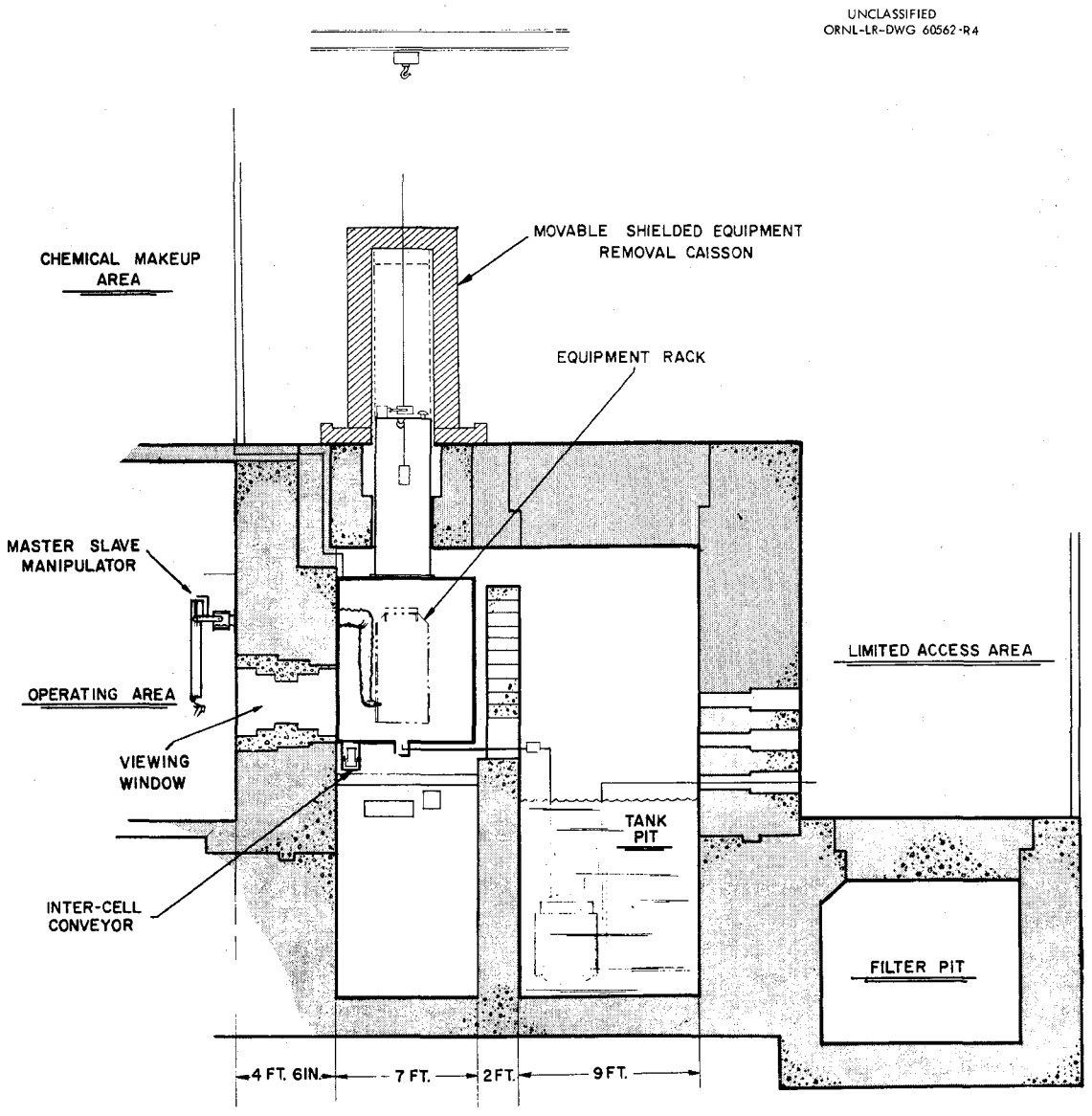


Figure 1 TRU FIRST FLOOR PLAN--VENTILATION FLOWS AND PRESSURES



Transuranium facility cell cross section.

Figure 2

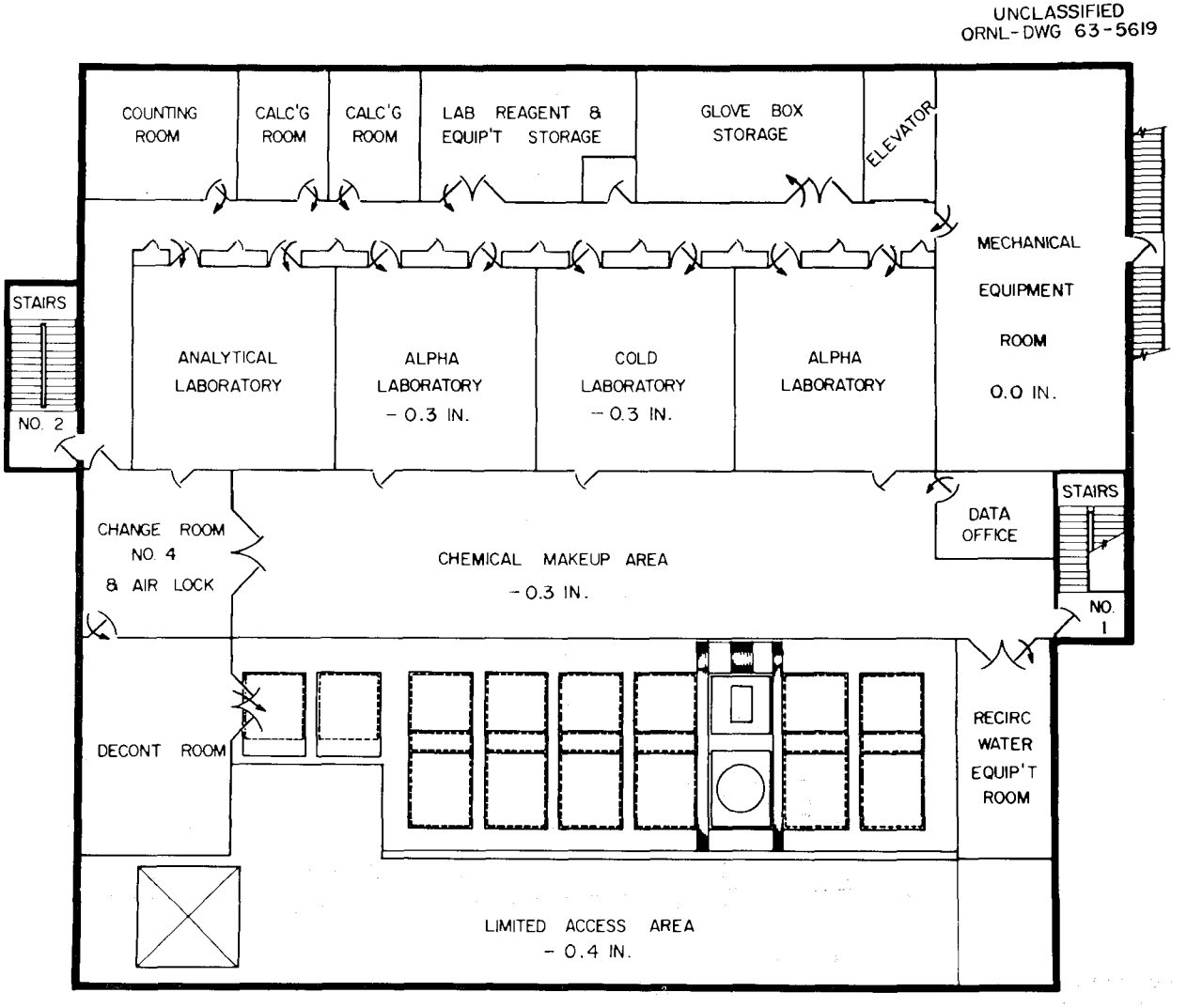


Figure 3 TRU SECOND FLOOR PLAN--VENTILATION FLOWS AND PRESSURES

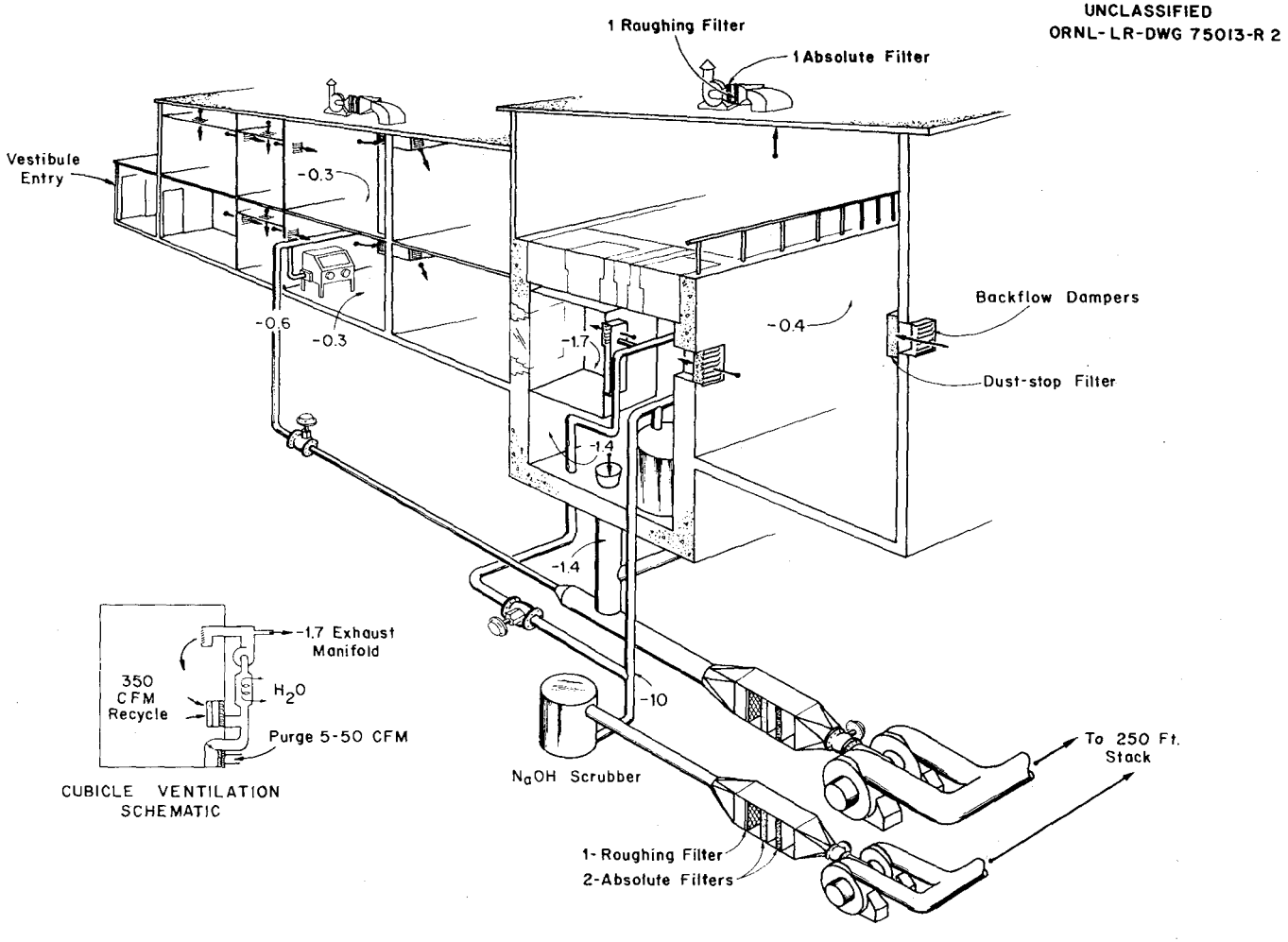


Figure 4 TRU PLANT VENTILATION SCHEMATIC

blower systems which circulate 350 CFM of air within the cubicle through absolute filters for cleaning, an external cooling coil and back into the cubicle. The major source of heat with the cubicles is from the lighting system. Purge air through the cubicles is manually set in the range of 5 to 50 CFM. Cubicle pressure is controlled through a pressure control valve in the exhaust manifold. Thus all cubicles are tied together, but contamination spread from one cubicle to another is eliminated by back flow preventers in addition to the positive air flow into the manifold. One roughing and two absolute filters are provided in the air stream down stream of the caustic scrubber.

Cell Ventilation System: Flows from 300-1000 CFM are maintained through each cell, depending on heat removal requirements, which are in turn governed chiefly by the number and size of evaporator vessels within the cell. Air is admitted through roughing filters and back flow preventers at the top rear face of the cell and exhausted into the cell ventilation duct which runs beneath the cubicles. The total stream of approximately 6000 CFM is exhausted through an absolute and two roughing filters, thence to the 250 foot stack. Pressure is controlled in the main header at - 1.4 in. by means of dampers in the blower suctions. During maintenance operations in which one cell is opened up, the system is so designed to provide an extra 6000 CFM flow into this cell while maintaining normal flows and pressures in the others. Fire protection is provided in the cells by dual detection devices which first alarm on signal from a rate-of-rise detector, then provide an automatic deluge upon fusion of a Quartzoid element. A similar system in the cubicles detects and alarms from a rate-of-rise detector, but water spray is actuated manually. Each cell is protected separately to minimize the quantity of water used.

Up to 100 alpha glove boxes in the laboratory wing are also exhausted through the cell ventilation system.

Filter Housings: Filters for both the cubicle vent system and the cell vent system are installed in parallel with shut off valves for isolation during replacement. In each system (Fig. 5) the roughing and absolute filters are installed together in a single housing. This reduces the cost of the original installation by minimizing the number of the special joints required between filters, but results in some additional operating costs for changing filters. The filter housing installation is designed for safe filter changing even with gross quantities of contamination on the filters. After isolating a filter unit, a slide guillotine valve is lowered into place to close off each end of the filter housing, and the housing, containing the dirty filters, is removed into a specially built disposal box. If gross contamination is

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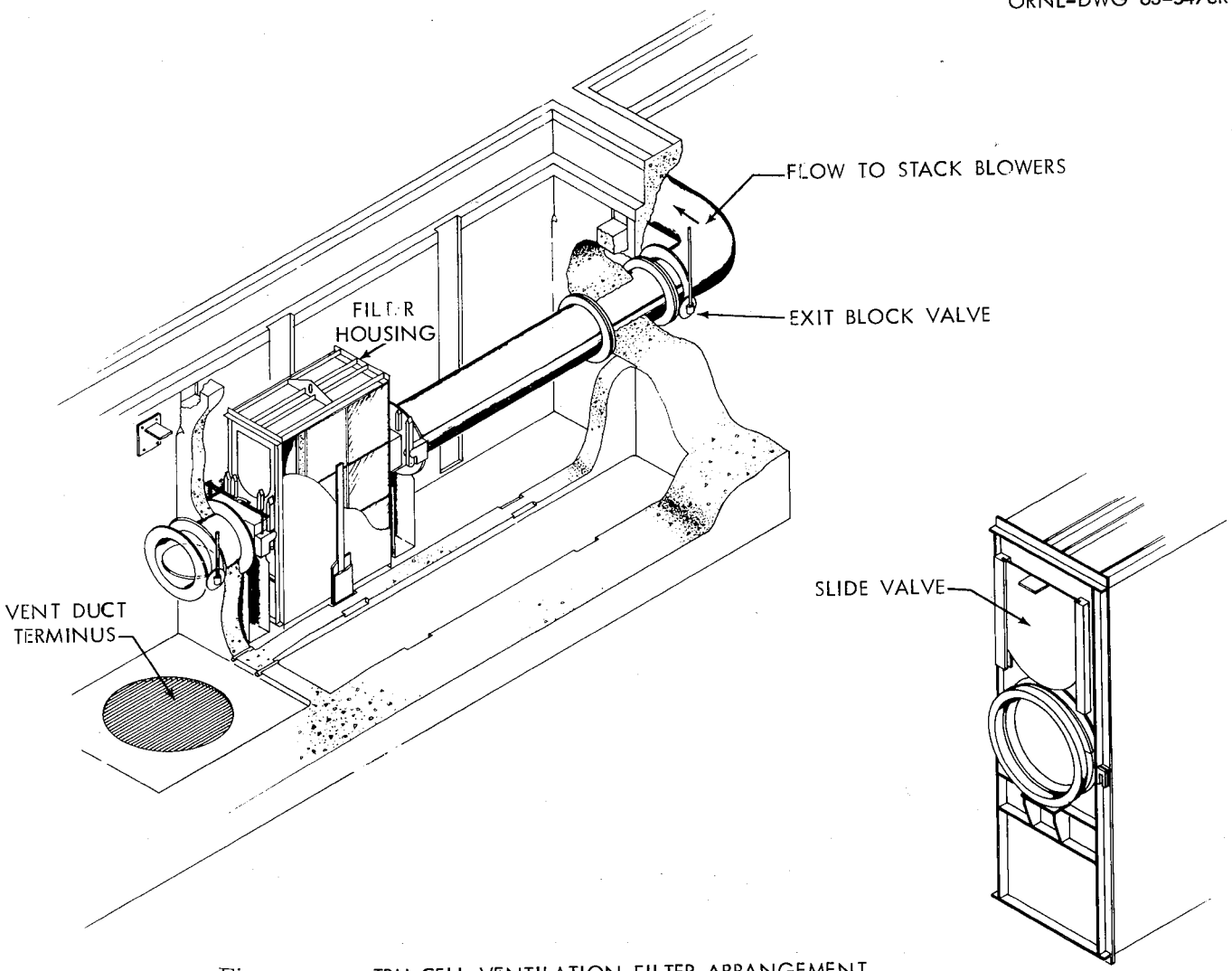


Figure 5 TRU CELL VENTILATION FILTER ARRANGEMENT

present, the disposal box is handled in a one-foot thick concrete shield. The filters are located below floor level in the limited access area, thus insuring against activity release from the building during filter changes. Filters are sealed by a spring-loaded flange operated by a lever extending up to the operating floor.

HAZARD ANALYSES - FILTER EFFICIENCY REQUIREMENTS

Routine Operational Activity Releases: During routine operation of the plant, small quantities of radioactive rare gases, halogens, and aerosols will be released through absolute filters and scrubbers in the vessel and glove box ventilation systems to the 250 foot stack (Table I).

Dissolution of HFIR targets will result in release of < 40 curies Xe^{133} and < 1 curie I^{131} (18 curies released, assume 1 curie through scrubber) over a several-minute period about every two weeks. The xenon release will cause maximum downwind ground concentrations averaged over the time of release of only 10% of the maximum permissible concentrations in air for occupational exposure. The average annual concentration and deposition resulting from the xenon release is negligible. Release of one curie of I^{131} will cause maximum downwind concentrations over the time of the release of 2.5 times MPC. This concentration averaged over a year will be negligible. Maximum deposition of I^{131} on the ground will be 4400 d/min-dm^2 and the maximum levels of deposition averaged over yearly weather conditions will be 50 d/min-dm^2, both levels tolerable in the area surrounding the Transuranium Processing Plant.

The continuous release of radioactive rare gases from spontaneous fission of californium in storage in the facility and the release of aerosols of alpha-emitting actinides and fission products from handling operations in the facility will result in acceptably low air concentrations and deposition rates.

Accidental Releases: The worst accidents that may credibly occur in TRU (Table II) would result from dispersal of the maximum quantity of radioactive material in a cell or glove box by a fire or explosion.

Our studies have shown that, in the event of credible (contained) accidents, the activity released from successive leaks through the primary and secondary containment walls is insignificant as compared to the credible release through the ventilation filters. In a credible accident, the blast effects of an explosion are confined to the region of primary containment (glove box, lab, or cell). Although a radioactive aerosol may leak through the primary containment wall and become mixed with the air in the secondary

Table I

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OPERATIONAL RELEASE OF RADIOACTIVE GAS AND AEROSOL FROM TRU

SOURCE OF RELEASE	TYPE ACTIVITY	DOWNWIND GROUND CONCENTRATION % MPCa-40		GROUND DEPOSITION d/min.-100 cm^2	
		MAX. AVG.	MAX. AVG. ANNUAL	MAX. AVG.	MAX. AVG. ANNUAL
HFIR TARGET DISSOLUTION 40 CURIES Xe^{133} AND <1 CURIE I^{131} RELEASED IN SEVERAL MINUTES EVERY TWO WEEKS	Xe-133 I-131	10 250	0.0001 0.01	——— 4400	——— 50
CONTINUOUS RELEASE RARE GAS F.P.'S 100 WATTS SF IN Cf	Xe & Kr	2	0.04	5000 (Cs 138)	8 (Cs-137 Sr-89)
CONTINUOUS ESCAPE OF AEROSOLS OF ACTINIDES (10 μc/day) & NONVOLATILE F.P.'S (1000 μc/day) FOR 10 YRS.	ACTINIDES F.P.'S	0.2 0.002	0.005 0.00001	——— 270	5 80

Table II

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EFFECTS OF MAXIMUM CREDIBLE ACCIDENTS IN TRU

TYPE OF ACCIDENT	EFFECTS OF ACCIDENT
RUPTURE OF GLOVE BOX CONTAINING 1 g. Cm^{244} BY EXPLOSION AND FIRE	(a) < 1 g Cm^{244} DISPERSED TO LABORATORY GLOVE BOX. OPERATOR MUST EVACUATE IMMEDIATELY TO PREVENT INGESTION OF A LETHAL DOSE (b) 2 mg Cm^{244} ESCAPES THROUGH FILTERED VENTILATION SYSTEM; MAXIMUM DOWN-WIND DOSE, 2 rems; 8.5 sq. mi. CON-TAMINATED ABOVE 30 dis/min-dm^2
RUPTURE OF CELL CUBICLE CONTAINING 1 g Cf POWDER BY EXPLOSION	(a) < 1 g Cf RELEASED TO CELL (b) ~5 x 10^{-8} g Cf RELEASED TO BUILDING CAUSING PERSONNEL EXPOSURES OF ~1 rem BEFORE EVACUATION (c) 0.2 mg Cf ESCAPES FROM STACK THROUGH FILTERED VENTILATION SYSTEM; MAXIMUM DOWNWIND DOSE 0.2 rems; 6.5 sq. mi. CONTAMINATED ABOVE 30 dis/min-dn^2

containment zone (building) during the period when the primary containment zone is pressurized, the leaked air is ordinarily not sufficient to raise the secondary containment pressure above atmospheric.

The so-called "AEC absolute" filters that are widely used in radiochemical plants are the weakest link in the containment of credible accidents. The susceptibility of the filters to both physical and chemical degradation necessitates that their integrity and efficiency be assured by routine in-situ testing or by preplacement testing plus careful installation and operation. The filters must be protected from excessive corrosion and excessive loadings of dust or water, and must be located such that they can withstand the blast wave from credible explosions without rupture. In typical facilities the tortuous path and expansions and contractions of the ventilation duct are sufficient to reduce the blast wave from credible explosions to a tolerable level at the filters.

In the evaluation of the credible accidents in TRU, it is assumed that no more than 20% of the radioactive aerosol that is dispersed in the primary containment zone passes to the filters and that the remainder is deposited on the walls and ventilation ducts. The fraction of aerosal penetrating the filters is estimated from the assumed particle size distribution in the aerosol and efficiency of the filters as a function of particle size.

Experience with AEC absolute filters operating at the rated flow indicates that they have greater than 99.95% efficiency for removing particles of size greater than 0.3 microns, that the efficiency decreases to a minimum of approximately 87% for particles of 0.05 to 0.1 μ size and that the efficiency is greater than 87% for particles of smaller size.[1] Cheever has shown that these filters are approximately 99.5% efficient in removing smoke from a plutonium metal fire, varying in size from 0.004 to 0.03 μ, and that the addition of one to six backup filters in series did not significantly improve the efficiency.[2]

In these studies it is assumed that filters have removal efficiencies of 99% for particles smaller than 0.05 μ, 87% for particles 0.05 to 0.1 μ, 95% for particles 0.1 to 0.3 μ, 99.95% for particles 0.3-5 μ, and 100% for particles larger that 5 μ. Smokes from fires of metal, solid carbonaceous materials, or organic liquids which would be predominantly 0.01 to 0.1 μ in size are assumed to be 99% removed in filters. This slightly enchanced

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[1] L. Silverman, Harvard Air Cleaning Laboratory, personal communication with J. P. Nichols, ORNL, February 1960.

[2] C. L. Cheever, "Recent Air Cleaning Developments at Argonne National Laboratory," p 308-326, TID-7627 (March 1962).

efficiency, as compared to 87%, partially compensates for the effects of agglomeration in the duct and improved efficiency because of filter loading in moderately large fires involving carbonaceous solids or organic liquids.

The maximum credible accident in the glove box laboratories of TRU would result from an explosion and fire in a glove box that contains 1 g of Cm-244, the maximum quantity anticipated to be used in glove boxes. Such an accident could result in dispersal of < 1 g Cm-244 into the laboratory requiring that glove box operators evacuate immediately to prevent ingestion of a lethal dose. Allowing for 80% deposition of the smoke in the glove box and laboratory and assuming that the filters are only 99% efficient in removing the smoke approximately 2 mg of Cm-244 would be released from the roof of the building through the filtered ventilation systems. This release could cause maximum downwind ingestion doses (accumulated over a lifetime) of approximately 2 rem and contamination of approximately 8.5 square miles downwind to levels greater than 30 $d/min\text{-}dm^2$ of alpha.

While absolute prevention of such glove box ruptures is impractical, the probability of such accidents is to be maintained at an acceptably low value by inclusion of multiple safe-guards. The effects of fires in glove boxes are to be minimized by heat-activated water fog nozzles in the boxes as well as through the use of ventilation systems designed to maintain the differential pressure resulting from credible glove box fires below ~ 6 in. w.g., which is required to break gasket seals. Those boxes to be operated at temperatures above the flash point of the process solvents will be supplied with an inert gas atmosphere to prevent explosions.

The maximum credible accident in the cell area would be an explosion (of Al-air, H_2-air, or organic-air) in a cell cubicle containing 1 g of californium as fine powder. The explosion could have sufficient violence to shatter the vessel or cubicle and scatter its contents within the cell but would not rupture the cell wall or ventilation filters. The californium released through broken "alpha" seals in the cell wall into the building might cause lifetime doses to operating personnel of approximately 1 rem. Assuming a conservative particle size distribution (98.8% = 0.3 μ, 1.1% between 0.1 and 0.3 μ, and 0.1% less than 0.1 μ) and assuming 80% removal by deposition before the filters 0.2 mg of Cf could be released through the cell ventilation system to the 250-foot stack. This could cause maximum downwind doses (accumulated over a lifetime) of approximately 0.2 rem and contamination of approximately 6.5 square miles downwind to levels greater than 30 $d/min\text{-}dm^2$ of alpha.

The possibility of such dispersive accidents will be minimized through inclusion of multiple safeguards.

It is not credible that an explosive mixture could occur in a significant portion of an entire cell since the ventilation rate is sufficient to dilute the maximum credible formation rates of organic vapor or hydrogen below its explosive limit.

DISCUSSION AND COMMENT

The filter efficiency was based on experimental data, much of which was presented at the last Conference. For example, the efficiency in absolute filters for smoke was of the order of 99%. The smoke has a particle size of .01 to .05 μ when it is formed assuming the particle size distribution.

The only rationale for two-in-series filter is that we consider the second filter as a safety factor.

The presumption for shielding was based on a full gram of californium, which is estimated to contain a quantity of californium-254, and thus was shielded down with four feet of high-density concrete to a quarter mr per hour.

A water spray fire-protection system is provided within the cubicle.

Session Chairman: My appreciation and thanks to all four speakers for the excellent papers presented during Session II.

SESSION III - CLEANING METHODS FOR RADIOACTIVE PARTICULATES

Afternoon - 22 October 1963

W. E. Browning, Jr., Chairman

Session Chairman: Will the meeting come to order? Mr. D. D. Cowen, of the Oak Ridge National Laboratory, which plays host to meetings such as this, has an announcement.

MR. COWEN: Good afternoon, gentlemen. I had a feeling this morning you had three or four welcomes, but I, too, would like to welcome you on behalf of the AEC-Oak Ridge National Laboratory, and the prime operating contractor, Union Carbide.

I am sure you have heard by now that we have a little trouble, trying to struggle along with it, and this meeting is further complicated by the fact that we are doing an international conference on approximations in Gatlinburg at the same time.

We are happy to have you, again, as our guests at Oak Ridge, under rather adverse circumstances. If we can do anything here--within reason, of course--to make your visit more informative, more profitable, more pleasant, please see us and we will try to see what we can arrange. Thank you very much, gentlemen.

Session Chairman: We are pleased in Session III to have a UKAEA contribution, "Experience in Trapping Iodine-131 and Other Fission Products Released from Irradiated AGR-Type Fuel Elements," by D. A. Collins, R. Taylor, and W. D. Yuille. The paper will be delivered by Mr. Collins.

EXPERIENCE IN TRAPPING IODINE - 131 AND OTHER FISSION PRODUCTS RELEASED FROM IRRADIATED AGR - TYPE FUEL ELEMENTS

by

D. A. COLLINS
R. TAYLOR
W. D. YUILLE

SUMMARY

Iodine-131 and other fission products have been released from irradiated stainless steel-clad uranium dioxide under conditions relevant to potential accidents in the Advanced Gas-Cooled Reactor.

Measurements have been made of the penetration of Iodine-131, Tellurium-132, Caesium-137 and Strontium-90, released in the above manner, through a trapping system consisting of an absolute filter, followed by a 4" deep bed of charcoal and a final absolute filter, in series. No significant penetrations have been observed except in the case of iodine-131 in the form of alkyl iodides. Some small fraction of the iodine released from the irradiated fuel is in this form and investigations have shown some conditions in which this form can be produced from iodine initially present in other forms.

Experiments with macroscopic amounts of methyl iodide, representing the above form of iodine, have shown that it is only delayed on activated charcoal at temperatures up to 100°C, but part of it can be permanently retained at 200°C. Oxidising catalysts show some promise of effectively retaining methyl iodide, but the presence of carbon monnoxide interferes.

INTRODUCTION

An efficient fission product trapping, or clean-up plant is an essential part of the containment system of the AGR and of various other types of reactor. If we can establish confidence in the ability of containment systems to prevent the spread of fission products in the remote event of a reactor accident, relaxation in reactor siting requirements could follow. A programme of experimental work to prove the ability of the trapping plant to remove dangerous fission products in the case of the AGR is now in hand at the UKAEA Reactor Group Laboratories at Windscale.

The fission product which causes greatest concern is iodine-131 so that it is chiefly the behaviour of iodine which determines the design of trapping plants. Other fission products that have to be considered include Tellurium-132, Caesium-137 and Strontium-90. The rare gas isotopes would be extensively released in a reactor accident, but, as they can be fairly rapidly dispersed from a high stack, they do not present a major hazard with current sizes of reactor, and current designs of trapping plant for gas-cooled reactors are not intended to retain them.

It was known from earlier work, notably at AERE[1] and at ORNL[2], that the trapping plant should include an absolute filter and a bed of activated charcoal. In addition, a heat sink would be necessary to ensure that the operating temperature limits of the charcoal were not exceeded. Other traps, for example, aqueous alkaline scrubbers or copper mesh, are effective against I_2 vapour, but workers at AERE have shown that when elemental iodine vapour is released into the atmosphere at low concentrations, part adsorbs on solid aerosols and part forms chemical compounds with trace impurities. Against iodine emissions of this nature, the combination of absolute filter and charcoal bed provides the best available barrier. More recently, it has been shown at AERE[3] that two types of iodine compounds are formed in such releases: inorganic compounds which are reactive and easily removed by caustic soda and organic compounds which include methyl, ethyl and higher alkyl iodides and which are not easily removed from the gas.

The chemical and physical forms in which fission product iodine would be released from heated irradiated uranium dioxide in carbon dioxide atmospheres were not known at the outset of this work and were expected to depend upon the burn-up of the fuel and the conditions in which it was heated.

Two representative types of reactor accidents are taken as the basis of the experimental study:-

(a) pressure circuit rupture, leading to escape of fission product activity into the containment volume and a need for clean-up by recirculation through the trapping plant.

(b) channel blockage, which leads to overheated fuel and release of fission products into an intact pressure circuit which may be cleaned up by direct blowdown through the trapping plant.

In both these cases, a trapping plant which restricts the penetration of iodine to less than 1 part in 10^4 of that presented to it is considered to provide satisfactory protection of the environment.

EXPERIMENTAL

The experimental approach is to release fission products from irradiated fuel elements, to measure the amounts and forms in which they are released and, in the same experiment, to measure their penetration through scaled-down trapping systems. This work is augmented by studies of techniques by which the forms of iodine released from irradiated fuel may be simulated with separated iodine isotopes. These techniques are then used to study iodine behaviour and to test trapping systems on a larger scale.

The experiments fall into three main categories:

(a) Laboratory-scale experiments in which activity is released into gas at atmospheric pressure in glass apparatus and presented, with little time delay, to a gas treatment system. Irradiated miniature fuel elements can be handled up to a total activity of about 50 curies in a lead-shielded cell (Fig. 1). Similar experiments are carried out in unshielded apparatus in which iodine is released from trace-irradiated miniature fuel elements or from identical unirradiated fuel elements to which separated iodine-131 has been artificially added. This work has been in progress for about 18 months.

(b) Larger scale experiments in which iodine can be allowed to age, under conditions appropriate to its release in a reactor accident, and is then presented to commercial-sized filters and charcoal beds. This work includes experiments in a large steel filter test rig (Fig. 2), which has only recently been brought into operation, and allows reactor accidents to be simulated with separated iodine-131 or 132, or with iodine released from trace irradiated fuel.

(c) A single highly active experiment in a small steel rig (Fig. 3) in which fission products are released from irradiated AGR fuel elements at ~2000 MWD/te burn-up, on the scale of about 4000 curies total activity. After the release of fission products into gas at high pressure, the performance of a correctly-scaled trapping system is measured under conditions simulating (i) direct blowdown of the pressure circuit through the trapping system (ii) rupture of the pressure circuit and release of its contents into the containment volume, with subsequent recirculation of the containment volume contents through the treatment system. This experiment has been carried out but final evaluation of its results is not yet complete.

A fourth aspect of the programme is the testing of the installed trapping plant of the Windscale AGR with artificially generated releases of iodine-132. Some tests were carried out earlier this year, but further work is planned.

Trapping System Components

Unless otherwise noted, the trapping system used in the experiments consisted of a coarse pre-filter (Vokes glass fibre material), an absolute filter (Vokes VAF 76 glass fibre paper), a 4" deep x 1" dia. bed of activated charcoal maintained at 100°C (SCII coconut charcoal - 8 + 12 B.S.S. mesh size), and final coarse and absolute filters.

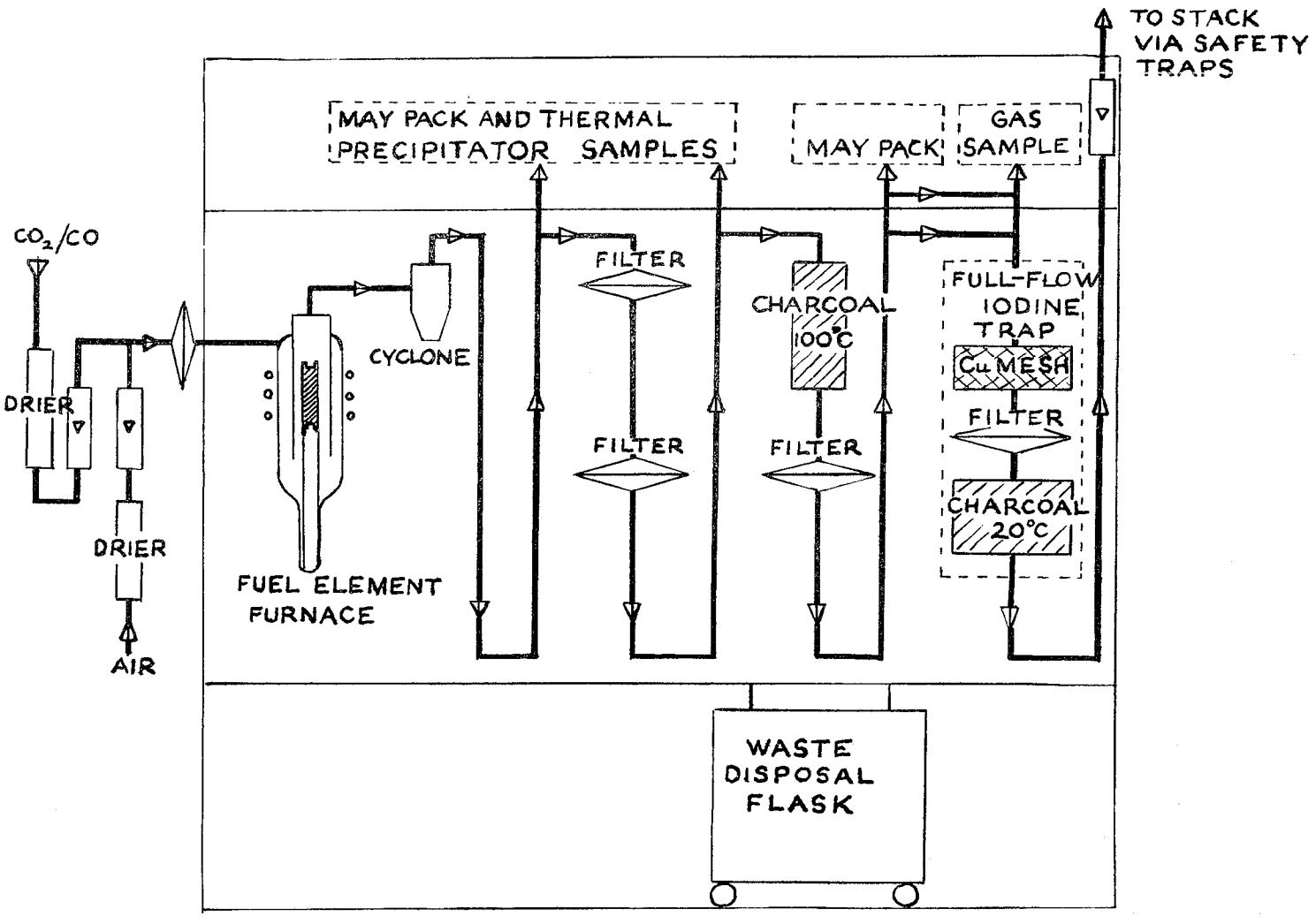

TO STACK
VIA SAFETY
TRAPS
MAY PACK AND THERMAL
PRECIPITATOR SAMPLES
MAY PACK
GAS
SAMPLE
CO_2/CO
DRIER
DRIER
AIR
CYCLONE
FUEL ELEMENT
FURNACE
FILTER
FILTER
CHARCOAL
100°C
FILTER
FULL-FLOW
IODINE
TRAP
Cu MESH
FILTER
CHARCOAL
20°C
WASTE
DISPOSAL
FLASK

Figure 1

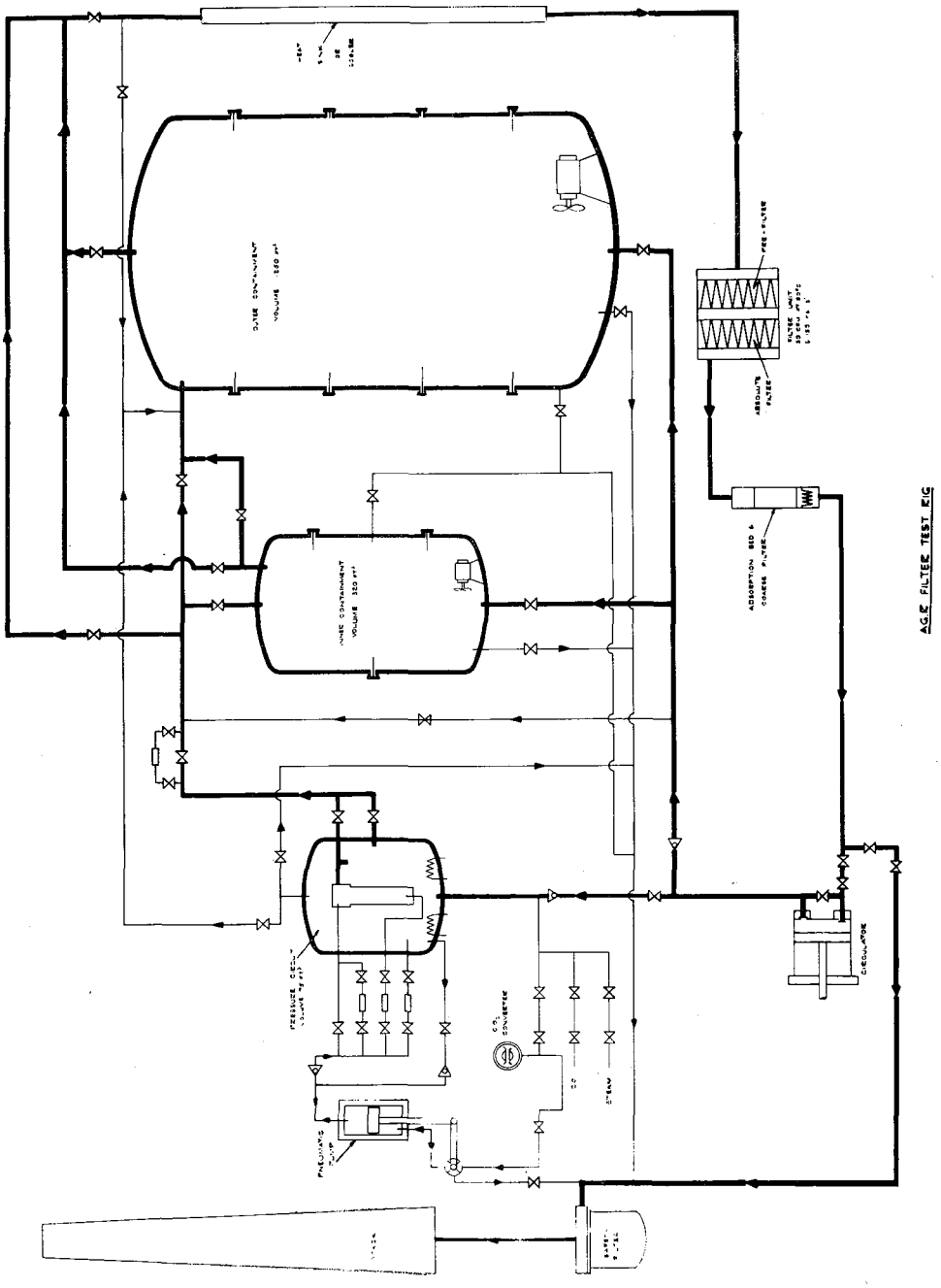


Figure 2

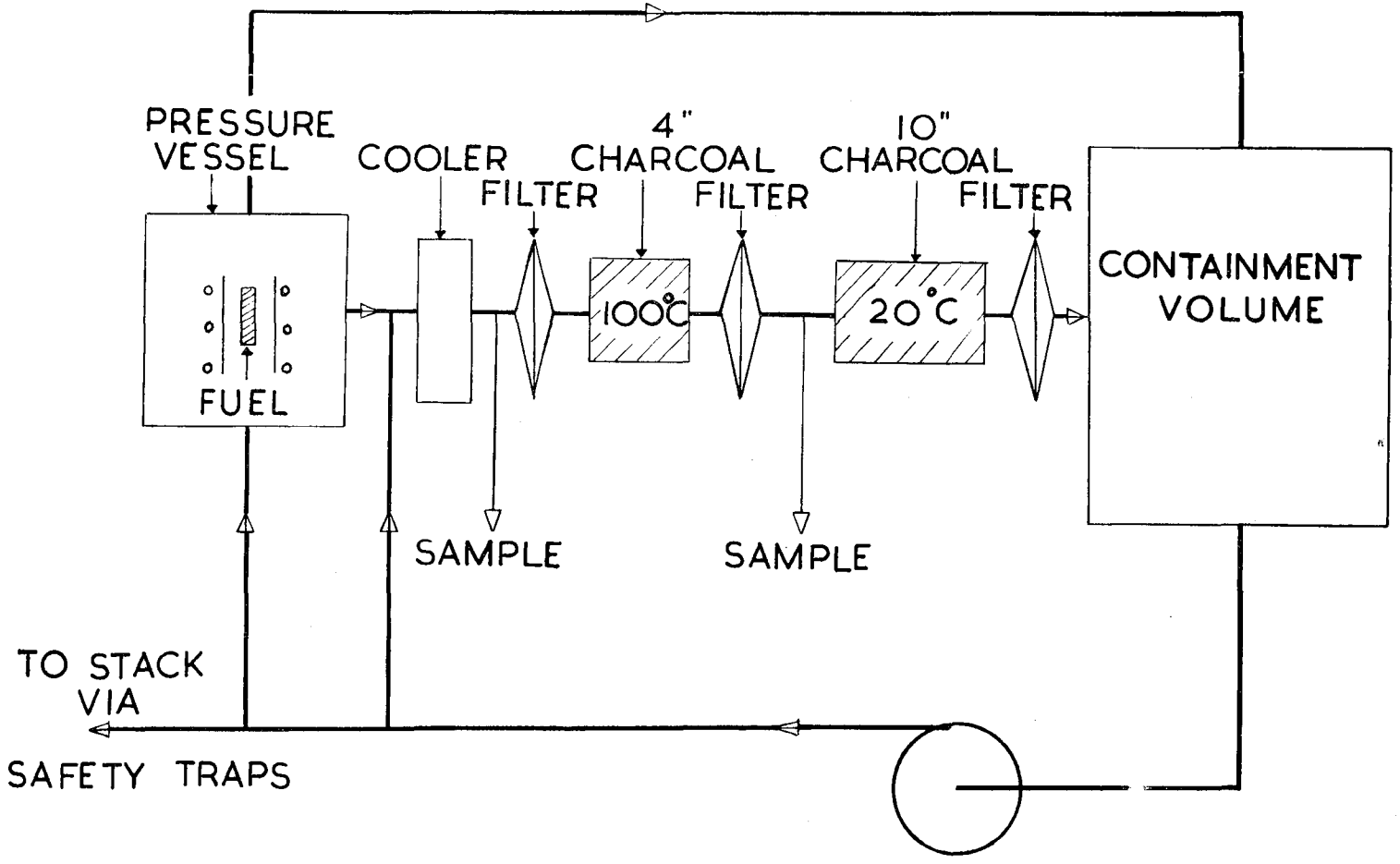


Figure 3

HIGHLY ACTIVE TEST

Iodine Samplers

The fission product activity in the gas is measured at points before and after components of the trapping system by sampling packs designed principally to distinguish between different forms of iodine. These are called "May Packs" after F. G. May of A.E.R.E. who originated them.

The version we use (Fig. 4) consists of the following components which the gas passes in succession as it traverses the pack.

(a) Four layers of fine copper gauze, especially cleaned before use and effective against elemental iodine vapour.

(b) Type PH millipore filter, which is highly effective against all sizes of particles and consequently gives a good measurement of particulate iodine.

(c) Two carbon-impregnated glass fibre papers (Whatman Type ACG/B). Activated carbon is the best known adsorber for ill-defined compounds of iodine that can penetrate elemental iodine adsorbers (such as copper) and particulate filters. By using these papers, the equivalent of only a very shallow bed is presented so that only the more reactive compounds are retained.

(d) Two successive 2" deep beds of SCII charcoal (-18 + 52 B.S.S. mesh size). These beds are effective against the less reactive iodine compounds.

The components of the pack are separated by PVC gaskets and the whole assembly is welded inside a PVC envelope to prevent leakage. Holes to permit gas passage are cut in the envelope just before use. The pack is designed to take a gas flow of 600 cc/min. The separate components are analysed by gamma spectrometry after use in the experiment.

Particle size analysis

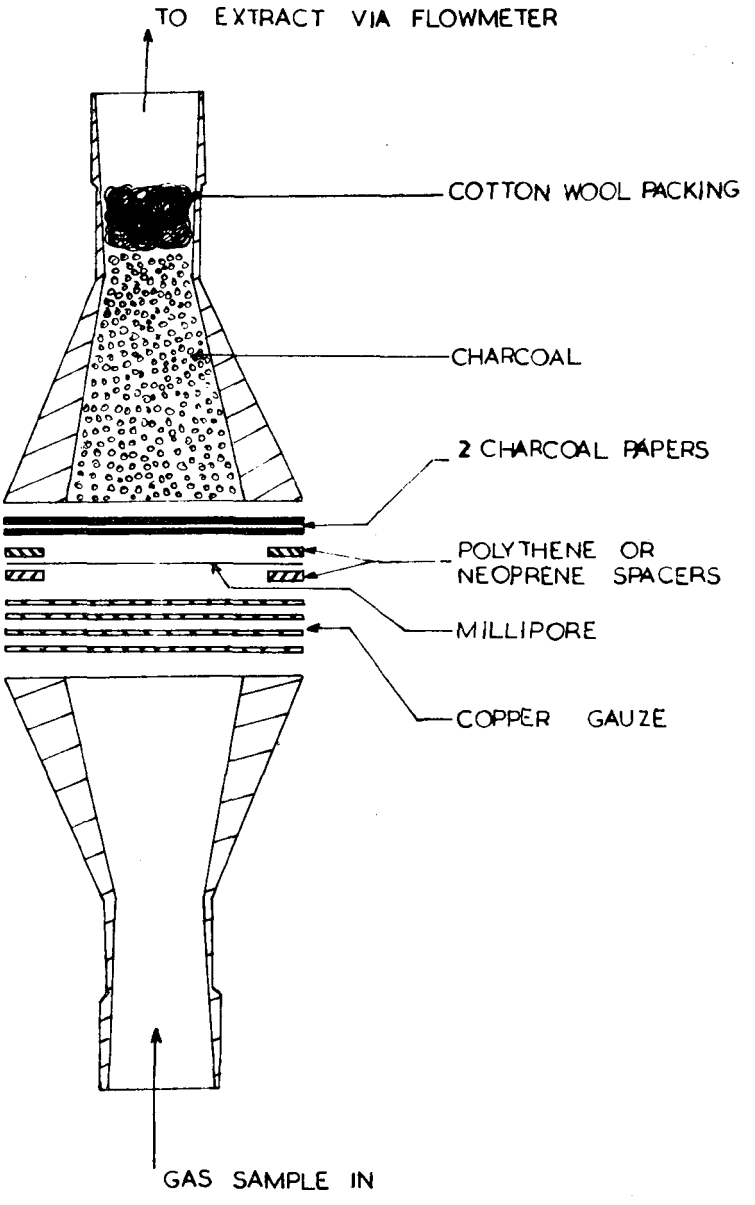
The particle emission from the heated fuel element is sampled by thermal precipitators before and after the coarse filter and first absolute filter. The particles are deposited on a silicon monoxide film which gives a very clean background when examined in the electron microscope (only 10-100 particles per hundred fields of view at x 50,000). Samples taken before the filter on type PH millipore filters and on thermal precipitators give particle size distributions that agree very well with one another. However, millipore filters cannot be used after the absolute filter because their background contamination is too high for sensitive detection of particles which are present at very low concentrations in the gas.

Fuel Elements

The AGR fuel elements consist of uranium dioxide pellets canned in stainless steel and miniature elements are made up from three full size UO_2 pellets sealed inside a short length cut from an actual AGR stainless steel can. Fission products are released by induction heating the elements to above the melting point of the can, either in carbon dioxide containing some carbon monoxide, which is the normal coolant in the reactor, or in mixtures of these gases with air which, in some fault conditions, may be present in the gas surrounding the fuel elements.

MAY PACK

Figure 4



RESULTS AND DISCUSSION

General Summary

Growing knowledge of the complex behaviour of iodine when released into the atmosphere as elemental iodine vapour, has led one to expect at least equally complex behaviour when the release is from irradiated fuel elements into a reactor circuit and containment. It is therefore encouraging to find in many experiments that the combination of absolute filter and charcoal bed provides adequate performance.

Only one class of iodine compounds has been found with which the above trapping system may not be able to deal effectively. These are the alkyl iodides, of which methyl iodide is the predominant and most penetrating member.

The alkyl iodides appear to form only a very small proportion of the primary products in the emission of iodine from irradiated uranium dioxide fuel at about 1500°C to 1700°C in CO_2, but it is possible that the amounts produced may be sufficient to penetrate activated charcoal when the total amount of iodine released is such that the loading on the charcoal exceeds a few µg iodine per gram of charcoal.

In experiments with small quantities of irradiated fuel, iodine released at 1500°C to 1700°C and carried immediately to a trapping system, penetrates the system to an extent not exceeding a few parts in 10^4 at low levels of iodine release (about 10^{-2} µg/m^3 in the gas stream) and dropping to about one part in 10^5 at concentration levels of relevance to serious reactor accidents (about 500 µg/m^3). The penetration of iodine through the system is not significantly increased by continued passage of gas for at least 24 hours after the iodine has been presented to the system and is independent of variations in gas composition ranging from pure CO_2 to CO_2 containing 50% CO and CO_2 containing 50% air. These experiments cover a range of iodine loadings on the charcoal from 5×10^{-4} µg/g to 2 µg/g.

In a larger scale experiment the total iodine loading on the charcoal was about 40 µg/g and the penetration amounted to a few percent of the iodine on the charcoal; that coming off being identified as a mixture of alkyl iodides. This behaviour may have resulted from the larger quantity of alkyl iodides presented to the charcoal simply because of the larger amount of irradiated fuel used in the experiment. On the other hand, the conditions of the experiment were such that a large proportion of the iodine released from the fuel deposited on vessel walls and other surfaces at temperatures up to about 400°C and it has been shown in other experiments that iodine desorbed from surfaces in these conditions contains an enhanced proportion of alkyl iodides.

The extent to which alkyl iodides can be formed by this latter route will be related to the ease with which the primary forms, released from the fuel, deposit on the surfaces (especially steel surfaces) where the secondary production of alkyl iodide appears to occur. Iodine released from irradiated fuel elements into a fairly rapid flow of carbon dioxide (about 600 cm/sec. past the specimen), does not deposit readily on pipework and other surfaces and hence is unlikely to result in the secondary production of significant quantities of alkyl iodides. On the other hand, slow gas flow past the heated fuel, which may encourage the iodine-containing particle emission from the fuel element to grow to sizes at which it deposits out readily, or the presence of air, which enccurages the release of readily-deposited elemental iodine vapour, may favour the secondary production of alkyl iodides after the primary forms have deposited on surfaces.

The need for a specific trapping process for methyl iodide and other, similar, organic iodides will depend upon the limit that can be placed on the production of alkyl iodides in specific reactor accidents. The development of such a process is currently receiving attention but no really satisfactory solution can be specified at present.

Of the other fission products, none, except the rare gases, has been found to penetrate the trapping system. Caesium-137 and Tellurium-132 are released from irradiated uranium dioxide fuel elements virtually entirely as solid aerosols, of which less than one part in 10^4 penetrates the absolute filter. Strontium-90 is also released in a particulate form but so little is released from the fuel that it is below the limit of detection after the absolute filter.

The above general statement of the present position derives from experimental results that are considered in more detail below.

Fission product release from overheated fuel elements

The forms and amounts in which the dangerous fission products are released from the fuel have been studied under controlled conditions in the laboratory. For practical reasons, the miniature fuel element (containing 25 g. UO_2) is heated at atmospheric pressure in a gas flow equivalent to about half the normal mass flow per unit weight of fuel in an AGR channel. (i.e. in a flow of 17.5 l/minute which passes over the specimen surface at 600 cm/sec.). The gas composition, fuel element temperature and irradiation dose have been varied.

If the initial fission product content of the fuel is calculated from the neutron dose, the percentage release of the dangerous fission products in 30 minutes at a temperature of about 1500 to 1700°C is as given in Table I.

The release factors do not appear to vary systematically with fuel burn-up in the range <1MWD/te to ~2000 MWD/te, although there may be an effect of cooling period, since, of two specimens irradiated to about 2000 MWD/te, one, cooled 5 days, released about 70% of its iodine while the other, cooled 30 days, released only about 10%.

At lower temperatures the release of iodine is much slower. Work with trace-irradiated miniature fuel elements shows that release begins to be measurable at between 1200 and 1400°C and continues at the rate of a few percent per hour up to about 1550 to 1600°C where there is a sharp increase in rate and substantial release occurs in a few minutes. This behaviour seems to be independent of whether air is present in the CO_2 or not.

TABLE I

FISSION PRODUCT RELEASE FROM IRRADIATED UO_2 HEATED AT ABOUT 1500°C TO 1700°C FOR 30 MINUTES AT ATMOSPHERIC PRESSURE

Atmosphere	Iodine 131	Tellurium 132	Caesium 137	Strontium 90
95% CO_2/5%CO	~30	~30	~50	~0.01%
50% air/50% CO_2	~ 30	~ 30	~10*	not available

*only 10 mins. above 1500°C.

The forms in which iodine is carried in the gas stream leaving the furnace have been classified by the May Pack. In the absence of air, the majority of the released iodine is attached to solid aerosols and the remainder is present as undefined vapour compounds of iodine. The presence of air causes a larger fraction of the iodine to appear as elemental vapour and, although the proportion attached to solid aerosols is much reduced, a significant proportion is still as vapour compounds of iodine (Table II). When the iodine is released from the fuel in CO_2/CO mixtures about 90% of it is retained by the first absolute filter and the remainder is over 99% in the form of vapour compounds of iodine. Methyl iodide has recently been identified in the gas at this point, to the extent of a few percent of the total iodine present (a few tenths of a percent of the iodine released from the fuel). The identity of the remaining compounds is not yet known: they are not retained in a sodium carbonate scrubber but they are apparently strongly held by charcoal. In air/CO_2, 80% of the iodine which penetrates the absolute filter is elemental iodine vapour and the remaining 20% has not yet been examined although, again, it is apparently strongly held on charcoal.

The particulate fraction is associated with the solid particles emitted from the heated fuel element components and graphite. These particles consist of agglomerates of primary particles which lie in the size range about 0.005 to about 0.1 micron; the agglomerates themselves range in size from 0.01 to over 1 micron diameter. The mean frequency size of the primary particles tends to decrease with increasing irradiation dose to the fuel elements and, to a lesser extent, with increasing temperature. Experiments with unirradiated fuel element components have shown that the mean frequency size of the primary particles increases almost linearly with pressure in the range 0-500 p.s.i.g.

In the oxidising atmospheres which were used for these experiments and which are generally relevant to potential accidents in an AGR, the released Tellurium, Caesium and Strontium were associated virtually entirely with the particles and did not penetrate the absolute filters in significantly measurable amounts.

At temperatures below the melting point of the stainless steel can, particulate emission from the fuel element is very much reduced and any iodine which is released tends to be in the form of elemental iodine vapour and vapour iodine compounds. As the temperature rises, the particulate fraction increases at the expense of the other two forms, although in the presence of air, even at a concentration of only 1% in CO_2, elemental iodine predominates to higher temperatures (Table III).

Trapping plant performance

The effectiveness of the trapping plant against iodine released from irradiated miniature fuel elements as described in the above paragraphs and carried immediately in the gas stream to the plant, is shown in Table IV.

TABLE II

FORMS OF IODINE RELEASED AT 1500°C TO 1700°C FROM IRRADIATED STAINLESS-STEEL-CLAD UO_2 IN CO_2/CO AND AIR/CO_2

(2" x 0.4" dia. fuel element, containing 25g UO_2, heated in a gas flow of 17.5 l/min. passing over the specimen surface at ~600 cm/sec.)

Gas	Gas-borne iodine concentration $\mu g/m^3$		Distribution of iodine on May Pack components			
			Copper	Millipore	Charcoal paper	Charcoal granules
air/CO_2	before filter	~0.001	83.5	8	8.5	-
	after "		not measured			
CO_2/CO	before "	~0.05	7	66	13	14
	after "	~0.01	0.5	0.5	50	49
CO_2/CO	before "	~0.5	8	65	7	20
	after "	~0.05	<0.1	<0.1	50	50
air/CO_2	before "	~0.5	60	30	9.5	0.5
	after "	~0.2	80	2	16.5	1.5
CO_2/CO	before "	2-4	12	66	17	5
	after "	~0.5	0.25	0.75	67	32
CO_2/CO	before "	7-9	11	75	12	2
	after "	~1	0.5	0.5	42	57
CO_2/CO	before "	196	9.5	76.5	13.2	0.8
	after "	~20	1.0	0.5	71	27.5
CO_2/CO	before "	980	12	81.8	6	0.2
	after "	~100	~0.5	~0.5	50	49

Table III

SUMMARY OF RESULTS SHOWING EFFECT OF TEMPERATURE ON IODINE FORMS RELEASED FROM TRACE-IRRADIATED UO_2-FUEL IN DEFECTED STAINLESS STEEL CANS

Temp. °C	Distribution of iodine forms on May Pack components								
	in CO_2			in 1% air/CO_2			in 50% air/CO_2		
	Copper	Millipore	Charcoal	Copper	Millipore	Charcoal	Copper	Millipore	Charcoal
1000-1100	67	6	27	-	-	-	92	3.5	4.5
1200-1300	46	36	18	65	15	20	95	2	3
1400-1500	13	69	18	60	33	7	87	7	6
1600-1800	13	80	7	33	62	5	71	23	6

The overall penetration of iodine through the system is measured by three methods, from which the highest result obtained is given in Table IV. The May Pack analysis on an aliquot of the gas stream is backed up by analysis of a deep charcoal bed which takes the full flow of gas through the system and an independent check is provided by direct gamma-spectrometry of a sample of the residual gas obtained after chemically absorbing carbon monoxide and carbon dioxide. The last method allows a limit to be placed on the amount of iodine which could be present in a form not held on charcoal and hence not detected by the other two methods. In almost every case the May Pack analysis gave the highest results and duplicate May Packs agreed to well within a factor of 2.

The measured penetrations decrease with increasing amounts of iodine released from the fuel; from a few parts in 10^4 at about 10^{-3} µg to less than one part in 10^5 at about 1 mg. This is also illustrated in Fig. 5 in which the linearity of the slope suggests that, under the conditions of these experiments, a more or less constant, small amount of iodine is being produced in a form which will penetrate the trapping system. If the recent measurement of the proportion of methyl iodide in the release is held to b representative of the whole series of experiments, the amount of methyl iodide presented to the charcoal increases in these experiments from about 10^{-6} µg to about 2.5 µg. Penetration of 10 to 20% of the assumed methyl iodide component could account for the observed penetrations in the sub-microgram emmisions, but it is then difficult to explain why much larger amounts of methyl iodide are more efficiently retained in the later experiments. However, it may be that the amount of iodine present in other forms can influence the behaviour of the methyl iodide.

The fraction penetrating the system at the lower concentrations was reduced by a factor of between 5 and 10 by increasing the depth of charcoal from 4" to 12".

The highest additional penetration observed in this series of experiments when various clean gas mixtures of CO_2, CO and air were passed through the charcoal bed (at 100°C) for up to 30 hours after the presentation of iodine, was less than 1 part in 10^4 of that presented to the system.

At very low iodine concentrations in the gas (less than 10^{-3} µg/m^3) inconsistent behaviour occurs and some very high penetrations (up to 10%) have been observed. These are not reproducible, however, and are believed to result from reaction of iodine with trace impurities over which the experimenter has no direct control. It is possible that a high proportion of the total iodine is converted to methyl iodide on the occasions when very high penetrations occur.

None of the other hazardous fission products could be detected in significant amounts downstream of the first absolute filter, in these experiments. The measured penetrations of Tellurium-132 do not exceed a few parts in 10^5 of that presented to the system and the vast majority of the released Tellurium is trapped on the absolute filter.

Few measurements have so far been made of Caesium-137 and Strontium-90 penetrations. These showed a Caesium-137 penetration of only a few parts in 10^6 with virtually complete retention on the first absolute filter, whether in CO_2/CO or in air/CO_2. The Strontium-90 release from fuel was so small ($\sim$0.01%) that measurements of its concentration in the gas stream do not have a very high level of reliability. After the absolute filter the concentrations were below the limit of detection, which sets an upper limit to the penetration of about 1% of that presented to the system (1 part in 10^4 of that in the fuel initially).

PRACTICAL DATA ON TRAPPING OF IODINE RELEASED FROM IRRADIATED AGR FUEL

TRAPPING SYSTEM : ABSOLUTE FILTER ⟶ 4" CHARCOAL BED ⟶ ABSOLUTE FILTER

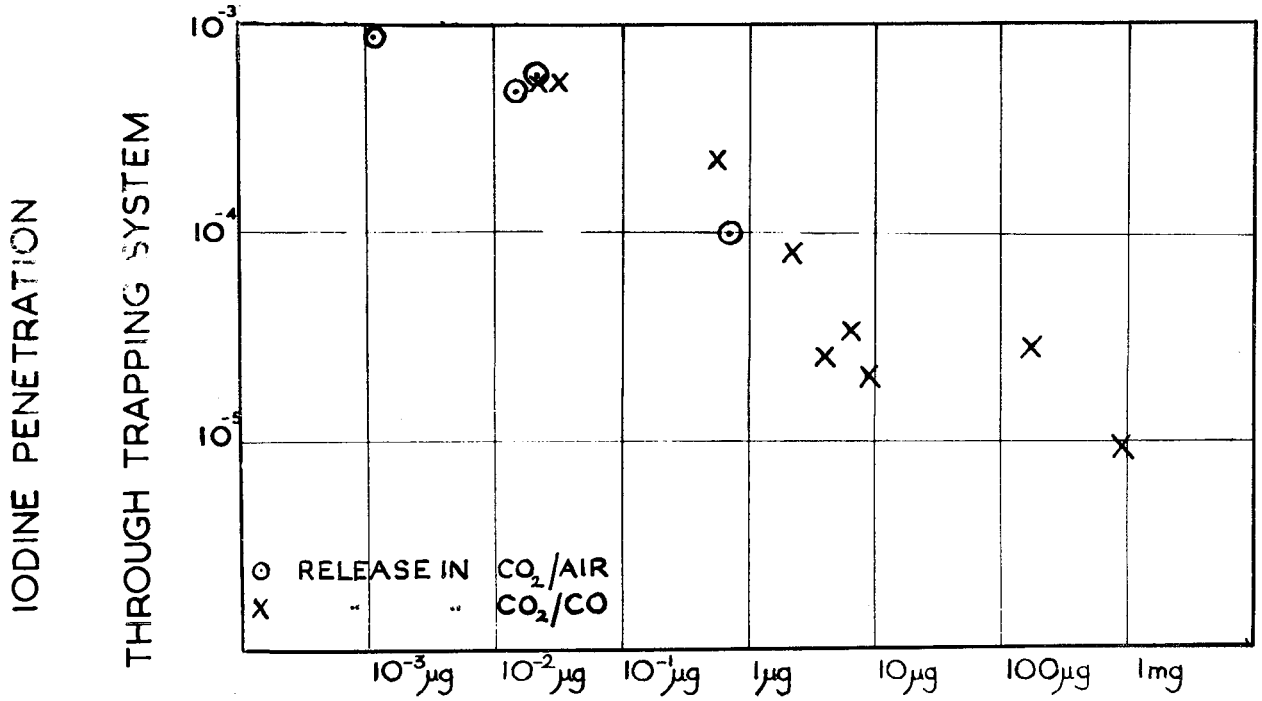


Figure 5

MASS OF IODINE PER CUBIC METRE OF GAS

TABLE IV

PENETRATIONS OF IODINE-131, RELEASED FROM IRRADIATED, STAINLESS STEEL CLAD UO_2 AT 1500 TO 1700°C, THROUGH ABSOLUTE FILTER + 4 in. CHARCOAL BED at 100°C + ABSOLUTE FILTER

Average total iodine concentration in gas presented to trapping system $\mu g/m^3$	0.001	0.015	0.02	0.02	0.03	0.05	0.05	0.5	0.6	2.0	4.5	7.1	8.9	196	980
Iodine 131 penetration through trapping system parts in 10^4	9	4	4.5	4.3	4.0	0.7*	0.5*	2	1	0.8	0.2	0.25	0.16	0.42	0.085
Gas composition 50% air/50% CO_2 or 95% CO_2/5% CO	CO_2	air/ CO_2	air/ CO_2	CO_2/ CO	CO_2/ CO	CO_2/ CO	CO_2/ CO	CO_2/ CO	air/ CO_2	CO_2/ CO	CO_2/ CO	CO_2/ CO	CO_2/ CO	CO_2/ CO	CO_2/ CO

*increased depth of charcoal

In the larger-scale highly active test, a much greater quantity of iodine was presented to a trapping system of the same size as that used in the laboratory-scale experiments, giving an iodine loading of about 40 μg/g charcoal.

The iodine was released from irradiated fuel elements by heating them to about 2000°C inside a graphite crucible, supported within a steel pressure vessel which contained a CO_2/CO mixture at 400 p.s.i.g. The walls of the pressure vessel and the bulk of the gas inside it were maintained at about 400°C. Fission products released from the fuel elements were passed to the trapping system either a) directly, to simulate pressure circuit blow-down, or b) via. a containment volume, holding some air, to simulate pressure circuit rupture followed by recirculation. The results showed first, that an unexpectedly high proportion (over 90%) of the released iodine was retained within the pressure vessel or on connecting pipework and secondly, that, of the amount which reached the charcoal bed, a significant fraction penetrated it within a few hours of recirculation.

The penetration in the brief blow-down phase amounted to about 1 part in 10^5 of the iodine initially present in the fuel and about 50 times this amount penetrated the system in the first hour of recirculation during which gas continued to pass over the heated fuel. Fuel heating was then stopped and no more gas was passed through the pressure vessel but gas continued to be recirculated between the containment volume and the trapping system for another 20 hours. During this time iodine continued to arrive at the charcoal bed, presumably by desorption from the walls of the circuit, until it finally reached 5% of the amount originally present in the fuel. In the first 14 hours of this recirculation the penetration amounted to 0.35% of the iodine originally present in the fuel and the last six hours contributed a further 0.07%. A sample of the iodine leaving the bed was identified by gas chromatography as a mixture of organic iodides, containing a predominance of methyl iodide together with ethyl iodide and higher alkyl iodides.

It is believed that conditions within the pressure vessel encouraged the growth of considerably larger particles than are formed in the laboratory experiments and that these then settled out on surfaces in the pressure vessel carrying much of the iodine with them, which would account for the retention of much of the iodine in the pressure vessel. However, two explanations are possible for the high penetration of the trapping system by the iodine that was not retained in the pressure vessel. The first is that, if the release is assumed to contain the same proportion of methyl iodide as that observed in a recent laboratory experiment, the amount of methyl iodide presented to the charcoal bed would have been about 50 μg, and this may have been sufficient to cause breakthrough. The second possibility is that reactions taking place between the iodine deposited on surfaces and organic impurities present in the gas or on the surfaces, may have resulted in the conversion of a much larger fraction of the iodine to organic iodides, part of which, subsequently penetrated the charcoal bed.

Both explanations suggest that in certain conditions of reactor accidents, sufficient methyl iodide or similar organic iodides may be formed to result in penetration of the installed charcoal beds. It may therefore prove necessary to develop alternative trapping plant, capable of retaining alkyl iodides.

Deposition behaviour of iodine released from irradiated fuel elements

After the release of iodine from the fuel elements its retention by deposition within the reactor core and containment could provide a mechanism by which the amount available to leak to atmosphere is reduced.

TABLE V

DISTRIBUTION OF IODINE FORMS RELEASED ARTIFICIALLY FROM UNIRRADIATED FUEL ELEMENTS AT 1500-1700°C, AND THE PENETRATION OF THE RELEASED IODINE THROUGH THE STANDARD TRAPPING SYSTEM

Gas Composition		CO_2					50% air/CO_2	
Iodine concentration in gas $\mu g/m^3$		0.03	0.05	0.1	15	2.6×10^4	0.05	0.1
Distribution of iodine on May Pack components	Copper	12	9	7	12	69	90	91
	Millipore	75	83	75	70	27	5	4
	Charcoal paper	6.5	4	6	16.5	3.9	4	4.5
	Charcoal granules	6.5	4	12	2.5	0.1	1	0.5
Penetration of iodine through trapping system, parts in 10^4		1	0.3	3	0.9	0.5	0.5	0.1

On the other hand, as we have seen in the highly active test , its deposition on surfaces could result in the production of a high proportion of the penetrating alkyl iodides.

Measurements have been made of the rate of deposition of iodine released from irradiated miniature fuel elements heated at 1500 to 1700°C in a fairly rapid flow of 95% CO_2/5% CO, both in a long cold mild steel pipe with many bends, and on to cold flat specimens of mild steel, stainless steel, graphite and concrete. The measured velocity of deposition on to the cold flat surfaces at a gas velocity of ~100 cm/min. was in the order of 10^{-3} cm/sec., while on graphite maintained at 400°C (a tubular specimen with the gas passing through it) the deposition velocity was a factor of 10 higher. Only about 3% of the total gas-borne iodine deposited on 33 feet of cold mild steel pipe at a gas velocity in the pipe of ~70 cm/sec., which again corresponds to an overall deposition velocity in the order of 10^{-3} cm/sec.

These measurements are consistent with the absence from the release of elemental iodine vapour, which would have been expected to have a deposition velocity in these conditions at least two orders of magnitude higher, and with the predominance of iodine in the forms of (a) particle agglomerates with a mean frequency size of about 0.05 microns and (b) relatively unreactive vapour compounds. They are not, however, consistent with the high retention of iodine in the pressure vessel in the highly active test. It is considered that the higher pressure in this experiment, the higher concentration of vapourized fuel element material and the virtually static gas surrounding the heated fuel elements must inevitably have resulted in the production of much larger particles than have been observed in the laboratory-scale experiments. Such particles are likely to have settled out in the pressure vessel, carrying much of the released iodine with them to the walls.

The deposition behaviour to be expected in a reactor accident cannot yet be predicted. In the case of a blocked channel accident it seems likely that behaviour similar to that observed in the highly active test would occur, with much of the iodine being retained within the channel; but of that which escaped, an appreciable proportion might be in the form of penetrating alkyl iodides. In the case of a pressure circuit rupture, much would depend on the gas flow that could be maintained through the core and the temperature reached by the fuel elements.

Experience with iodine generated artificially

Work with irradiated fuel elements is slow and difficult and can only be done on a large scale at great expense. It is therefore very desirable to be able to simulate the behaviour of iodine released from fuel by artificial methods of generation. A technique used at Windscale is to deposit carrier-free iodine-131 (or with a known amount of stable iodine) inside a short length of stainless steel fuel can, to add unirradiated UO_2 pellets and then to re-seal the can. The can is then heated in the same way as an irradiated specimen and iodine is released when the can melts.

When the specimen is heated in a rapid flow of CO_2 in glass apparatus, the distribution of iodine forms and the penetration of iodine through the trapping system are both closely similar to those obtained from irradiated fuel in similar conditions, although there is not a pronounced difference in penetration over a wide range of concentrations. In the presence of air the distribution is qualitatively similar to that obtained from irradiated fuel, but the proportion of elemental iodine vapour is rather higher and that of particulate iodine rather lower (Table V).

The identity of the iodine compounds which penetrate to the charcoal components of the May Pack is not known at present, but they have recently been shown in one experiment to contain some alkyl iodides.

In view of the association of a relatively high penetration of the trapping system in the highly active test with the presence of a relatively high concentration of alkyl iodides, it is of interest to discover under what conditions the production of alkyl iodides from other forms of iodine can be enhanced.

Eggleton and Atkins at AEPE [3] were the first to identify alkyl iodides in various iodine emissions used for testing trapping systems and showed that it is formed in small amounts when milligram quantities of iodine crystals are dispersed in very large volumes of air; when carrier-free NaI^{131} is oxidised in air; and when fission product iodine-131 is released from irradiated uranium wire at about 800°C in air.

We have found a variety of conditions in which up to 10^{-3} µg to 10^{-2} µg iodine can be produced in the form of alkyl iodides. These include

a) iodine deposited from CS_2 solution on ultra-clean glass-ware and heated in argon or helium at temperatures in the range 100°C to 400°C.

b) iodine deposited from aqueous sodium iodide solution on ultra-clean glassware and heated in argon or helium at temperatures from 200°C to 400°C.

c) iodine deposited from CS_2 solution or from aqueous sodium iodide solution on stainless steel surfaces and heated in inert gas, air or carbon dioxide/carbon monoxide atmospheres at temperatures from 400°C to ~1300°C.

d) iodine attached to particles released from unirradiated fuel element components at about 1800°C, captured on a stainless steel sinter and subsequently desorbed from this surface in air or argon at about 500°C.

In each of these cases, when the amount of iodine added was in the order of 10^{-3} to 10^{-2} µg, or less, 50% or more of the iodine was found in the form of alkyl iodides (chiefly methyl iodide) but when amounts of stable iodine equal to 10 µg or more were added the proportion present as alkyl iodides was so small that it could no longer be detected.

The readiness with which methyl iodide is formed at very low iodine concentrations makes it tempting to ascribe the unreproducible high penetrations, which have been observed at these levels, to its presence. However, as pointed out earlier in this paper, it is difficult to reconcile this idea with the detection of much greater amounts of methyl iodide in the gas presented to the charcoal bed in a recent experiment in which no measurable penetration was detected, unless the retention of small amounts of methyl iodide on charcoal is dependent upon the presence of a sufficient quantity of other, more easily retained, forms of iodine. So far no method has been found of producing percentage quantities of alkyl iodides artificially in an emission anywhere near as concentrated as that which emerged from the pressure vessel in the highly active test (several hundred µg/m³ in the gas).

Whatever the source, however, it seems likely that sufficient alkyl iodides were produced in the highly active test to cause penetration of the 4" deep charcoal bed. Since their production to a similar degree in reactor accidents cannot be excluded, it is prudent to develop an improved method of trapping them.

Methyl iodide trapping

Methyl iodide is produced in much larger quantities than any other alkyl iodide and is likely to be the most intractable. Experiments are therefore being carried out with iodine-131-labelled methyl iodide to find a suitable trapping method for reactor application.

It has been illustrated that, under the same gas flow conditions as used in the fission product trapping experiments, milligram quantities of methyl iodide penetrate a 4 " deep by 1" diameter bed of SCII charcoal in a matter of minutes when the bed is at 100°C and in about one and a half hours when the bed is at 20°C. Further experiments are in hand to discover whether retention occurs at some lower level of methyl iodide loading.

The search for alternative methods of methyl iodide trapping is at present based on a) methods involving oxidation b) methods involving hydrolysis c) methods involving specific reactions in organic media. Only methods in category a) have so far received significant attention.

It has been found that the commercial preparation HOPCALITE (basically MnO_2+CuO) at 100°C appears to retain about 90% of the methyl iodide presented to it in 100% CO_2. Most of the iodine which penetrates the HOPCALITE is in the form of molecular iodine and is retained on SCII charcoal at room temperature. About 99.9% of the methyl iodide was retained by the two beds in series.

In the presence of carbon monoxide, however, the HOPCALITE'S efficiency is reduced and only about 50% of the methyl iodide is retained during a few hour's passage of 5% CO/CO_2. The methyl iodide which is not adsorbed on HOPCALITE is unchanged chemically and is only retained for an hour or so on the charcoal bed. The presence of carbon monoxide is almost inevitable in any accident to an AGR so that these observations are not encouraging.

The use of a silver-coated copper knitmesh bed at 300°C in CO_2 had no effect on the behaviour of methyl iodide.

50% retention of about 100 mg. methyl iodide has been found on passage through SCII charcoal held at about 200°C. This suggests that oxidation can occur at some sites on charcoal and lends hope that a charcoal of higher ignition temperature may be even more effective above 200°C. It also raises the possibility that rather higher penetrations of small amounts of methyl iodide might be observed through a charcoal bed maintained at room temperature than through one allowed to operate at 100°C, as in the experiments described in this paper.

CONCLUSIONS

The present form of fission product trapping plant, consisting of a combination of absolute filters and a bed of activated charcoal, provides adequate protection against the escape of dangerous fission products from the Advanced Gas-Cooled Reactor, with the possible exception of iodine-131 in the form of alkyl iodides.

Pending further elucidation of the mechanism and extent of formation of alkyl iodides and of conditions which may enhance their production, it is prudent to develop a specific method of trapping them.

REFERENCES

1. A. C. CHAMBERLAIN, Physical chemistry of iodine and removal of iodine from gas streams - AERE R4286 (1963).

2. Semi-annual progress reports on Nuclear Safety Programme, for period ending June, 30th 1962 (ORNL-3319) and for period ending December 31st 1962 (ORNL-3401).

3. A. E. J. EGGLETON, and ATKINS, D. H. (A.E.R.E.) Identification of radio-iodine compounds formed on releasing carrier-free I-131 in air. Paper given at 1963 Annual Meeting of American Nuclear Society at Salt Lake City . (also AERE-M1211).

DISCUSSION AND COMMENT

We have thought about decomposing the methyl iodide with high temperature and one of the first experiments tried was to pass the methyl iodide through a heated bed of alumina, about 400° C. to give an extended surface for the reaction to occur. Although some decomposition occurred, it only gave a factor of about five. We are looking at oxidative catalysts which are showing much more promise, and one of these, if I can just enlarge on this point now, is hopcalite, with which you are probably familiar and it does seem to be particularly effective in decomposing methyl iodide. From our point of view one snag is that the presence of carbon monoxide, which is almost inevitable in any graphite moderated reactor, seems to interfere. We have some evidence this can be overcome provided the carbon monoxide is first reduced to a very low percentage, and then enough air is added to the gas to the equivalent of the carbon monoxide, so that the hopcalite is not used up, and is therefore free to continue to decompose methyl iodide. But these results are still preliminary, and we do not regard this as the most attractive system.

At the Salt Lake City American Nuclear Society Conference earlier this year, a Harwell Colleague, Dr. Eggleton, described the manner in which he discovered that the iodine was in the form of methyl iodide. We extended the use of the method to analyze the gas obtained from the release of fission products from irradiated uranium dioxide, and we found the same peaks. In fact, we sent a sample of our gas to him and he confirmed our result by his method; we were happy that these cross-checks confirmed that the material is in fact methyl iodide. But, it is only a small constituent of the total iodine release. There are more major constituents of the release which are not elemental and which are not particulate, and which we have not yet identified. It is very important that we should have information on these, particularly if we wish to design on a rational basis trapping systems which do not depend upon activated charcoal. The only reason I have not enlarged upon this form of iodine is that activated charcoal does seem to be very effective in stopping it. But activated charcoal beds may not be the most appropriate form of reactor trap in every reactor system, and we would like to know all the iodine compounds with which we have to deal.

Session Chairman: Thank you, Mr. Collins.

Our next paper was prepared by Robert B. Boise, of the National Lead Company of Ohio, and is titled, "Exhausting Corrosive Fumes with Quick Draft Eductors."

EXHAUSTING CORROSIVE FUMES WITH QUICKDRAFT EDUCTORS

Robert B. Boies

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Cincinnati, Ohio

1. ABSTRACT

The uses of Quickdraft eductors in handling and diffusing various types of corrosive fumes are described. A number of specific applications are discussed and illustrated.

2. INTRODUCTION

In the processing of uranium compounds to metal and the fabrication of uranium metal to fuel cores, many noxious and corrosive fumes are evolved. The Laboratory, Pilot Plant, and production areas, all generate these fumes, which include nitric, perchloric, hydrochloric, and hydrofluoric acid vapors; nitrous and nitric oxide; sulfur dioxide; and ammonium chloride fumes. The fumes are passed through electrostatic precipitators, dust collectors, scrubbers, and other devices to render them harmless before release to the atmosphere.

Air eductors have many advantages over conventional exhaust fans in handling such corrosive fumes. These advantages will be described.

3. DESCRIPTION OF EQUIPMENT

The eductors used at the National Lead Company of Ohio for corrosive service are manufactured by the Quickdraft Corporation of Canton, Ohio. This eductor is a unique, patented type, operating on a modification of the venturi principle. Air is introduced by a blower into the eductor through a slotted annulus. This can be seen in the cutaway drawing, Figure 1. This slotted annulus is the principle characteristic by which this unit differs from a regular venturi using a jet or nozzle for its motive force. The principal parts of the eductor are:

1. The eductor body, which is designed for the air flow needed.

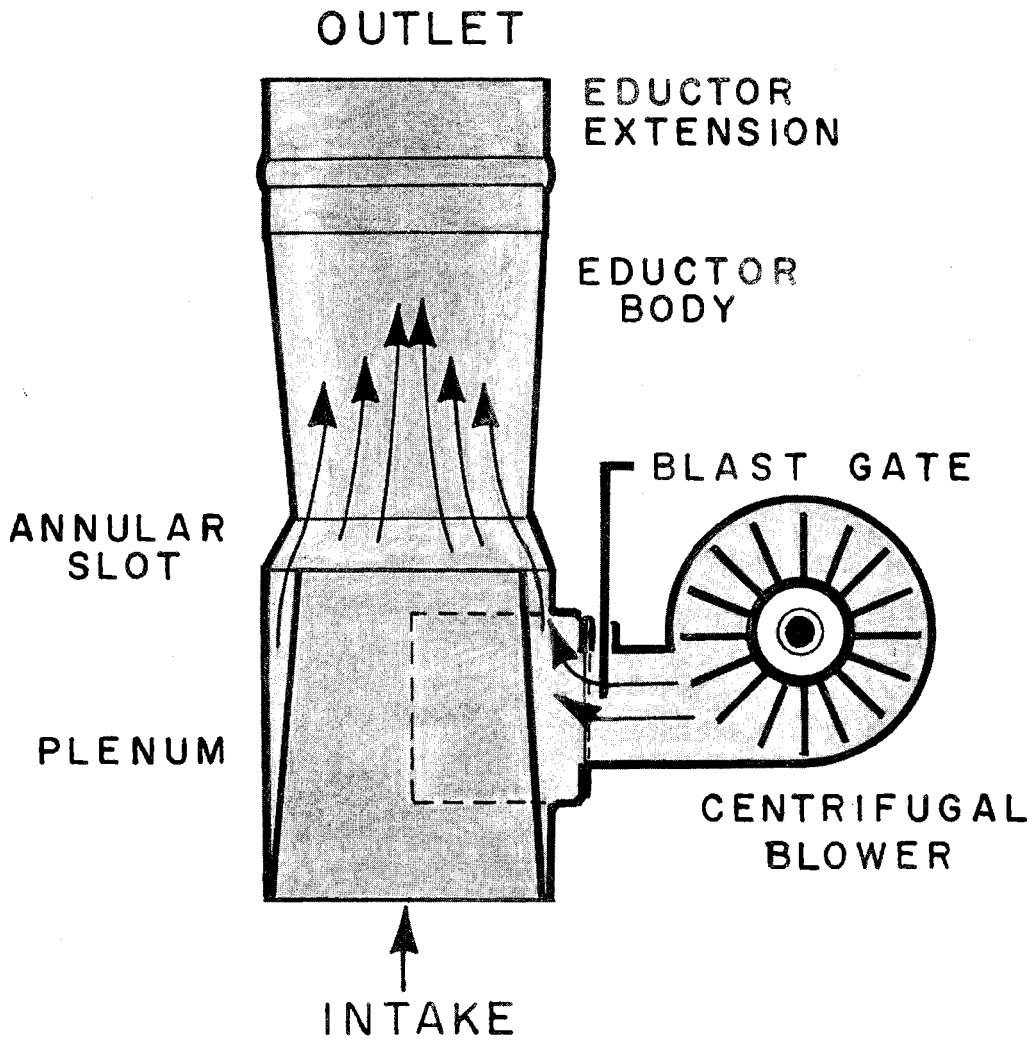
2. The eductor extension, which increases the efficiency of the eductor.

3. The plenum, which acts as a distributor for the blower air to the annular slot.

4. The annular slot, through which air is discharged around the periphery of the eductor.

5. The blast gate, which controls the air flow from the blower.

Quickdraft eductors are available in a variety of sizes, with volumes ranging from 100 cubic feet per minute to



QUICKDRAFT EDUCTOR

CUTAWAY VIEW

Fig. 1

90,000 cubic feet per minute and static pressures from 0.02 inches of water to 140 inches of water. Figure 2 is a graph showing the performance of a standard 6-inch-diameter Quick-draft eductor at various blower horsepower. As can be seen, a wide selection of volumes and static pressures are available. By installing a blast gate at the blower outlet any desired combination of pressure and volume on a given horsepower curve may be attained. Models are available in black iron, vitreous enameled steel, stainless steel, hastelloy, fiberglass- or dynel-reinforced polyester or epoxy resins, and unplasticized polyvinyl chloride, or other plastic coatings designed for use in hot and corrosive atmospheres.

4. PRINCIPLE OF OPERATION

1. The annular method of discharging the blower air into the eductor causes a velocity pattern different from that in a normal venturi (see Figure 3). In the Quick-draft eductor, air velocity is greater at the outer periphery than at the center of the unit, just the opposite of the velocity pattern in a regular venturi. Two significant gains are realized from this phenomenon: (1) corrosive fumes are kept essentially in the center of the exhaust system, away from possible condensation and corrosion on the walls; and (2) in material handling operations, the amount of abrasion is greatly reduced. This action can be demonstrated simply by holding a string at the intake of one of these units and watching it progress from intake to outlet. This is shown in Figure 4, a clear plastic model of an eductor unit.

Performance Curves for Std. 6" Dia.

QUICK DRAFT EDUCTOR

at Various Blower H.P.

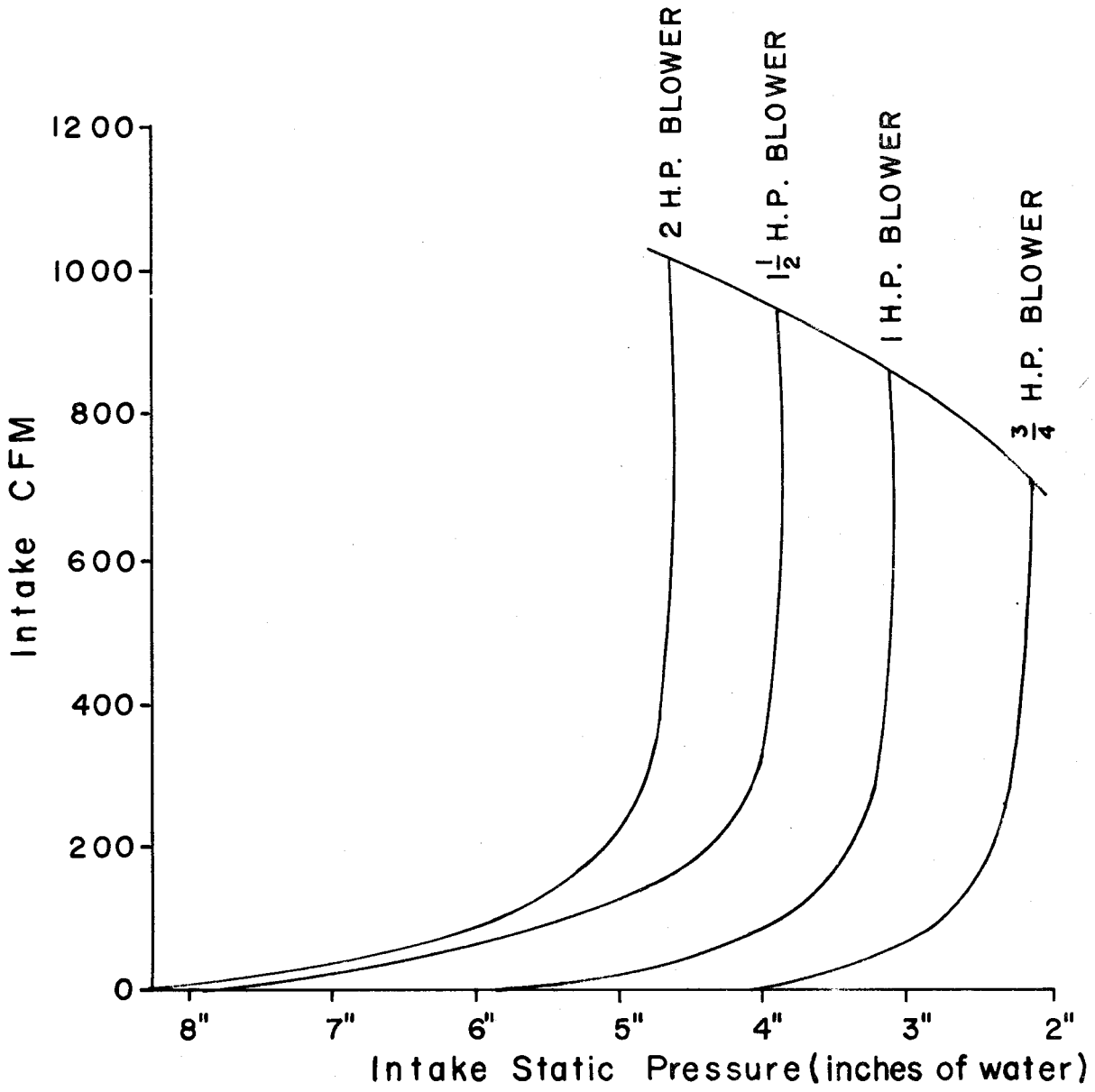
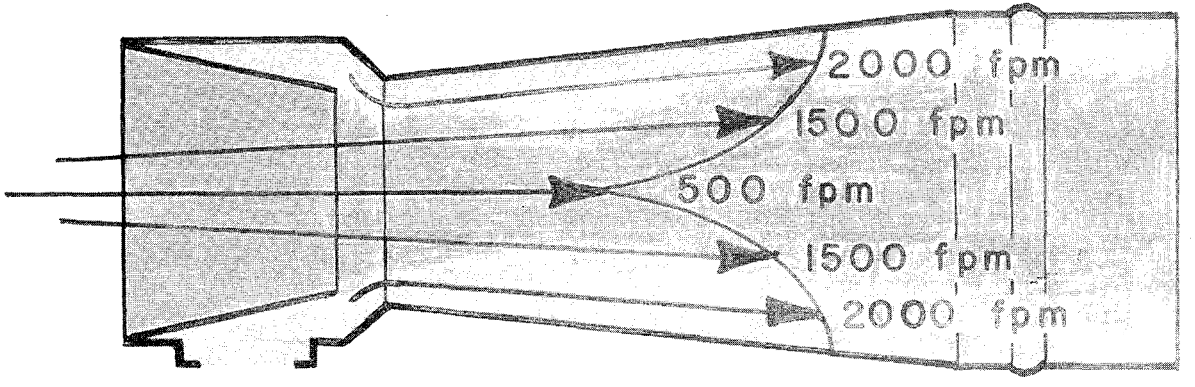


Fig.(2)



VELOCITY PATTERN INSIDE QUICKDRAFT UNIT

Fig. 3

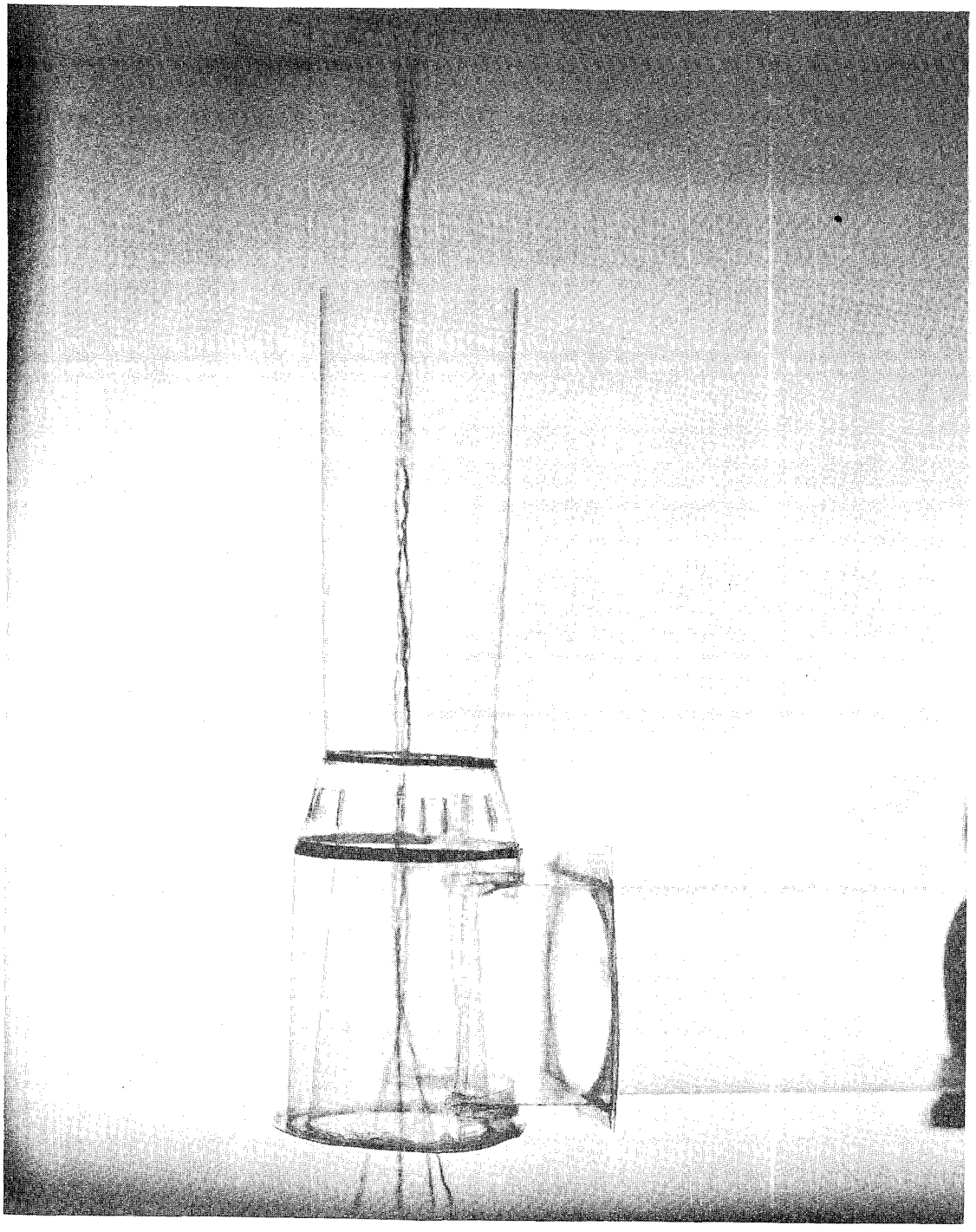


FIGURE 4 Plastic Operating Model of Quickdraft Unit; Yarn Shows Path of Intake Air

We have not yet had an opportunity to use the Quickdraft eductors in material handling applications at this site. However, I have seen these units in use at several paper mills, an aluminum sheet manufacturer, and a mylar thread manufacturer. In all of these installations, the principle of the material being transported in the center of the air stream is employed to great advantage.

5. GENERAL USAGE

One of the greatest problems in a chemical plant is disposal of fumes. Dilution into the atmosphere is usually the most economical method. The Quickdraft unit is particularly adapted to such fume dispersion. Heavy white ammonium chloride and nitrous oxide fumes emanating from a chemical operation in our plant have been almost completely dispersed by use of a Quickdraft unit as an exhauster. Thus plume effect from an exhaust duct is either eliminated or greatly reduced. The unit has an added advantage in that it atomizes large liquid particles in the gas stream, thereby speeding their vaporization into the atmosphere.

The ratio of air intake at the eductor to air intake at the blower is quite high at lower static pressures. At eductor intake pressures of 0.02 inches to 2.5 inches of water, the ratio is approximately 4 to 1; at 10 inches to 15 inches of water, the efficiency of the unit drops to around a 1 to 3 ratio. This drop in efficiency, which means an increase in the relative amount of blower air in the unit's exhaust, is put to good advantage in the dilution and dispersion of exhaust fumes, especially ammonium chloride and hydrogen. Cooling of hot exhaust gases is yet another advantage.

6. APPLICATIONS AT THE NATIONAL LEAD COMPANY OF OHIO

Described and illustrated on the following pages are a few of the installations of these eductors at our plant. In one interesting application a Quickdraft unit is used to exhaust a hydrogen-rich atmosphere. In this particular installation, an emergency source of power for the eductor is required for safety. This emergency supply is provided by 150 psi steam connected into the eductor plenum (see Figures 5 and 6).

These eductors are also used at this site to exhaust laboratory fumes. Perchloric acid fumes, which are particularly difficult to handle, are exhausted by Quickdraft eductors (see Figure 7).

In Figure 8, is shown an application of a Quickdraft unit in a forced-air furnace exhaust through a scrubber. A problem was encountered in this application, in that ammonium chloride was being carried over from the furnace through the caustic scrubber. This material flash-dried in the eductor until the throat was completely plugged. By introducing a warm water spray into the driven air stream (see Figure 9) this buildup was eliminated.

The solution of the above problem also provided us with a possible means of mixing and atomizing a liquid or solid into a gas stream for production blending purposes.

In Figures 10 and 11 are shown Quickdraft units which are dissipating the hot exhausts from three corrosive scrubbers, two of which exhaust streams include HF fumes.

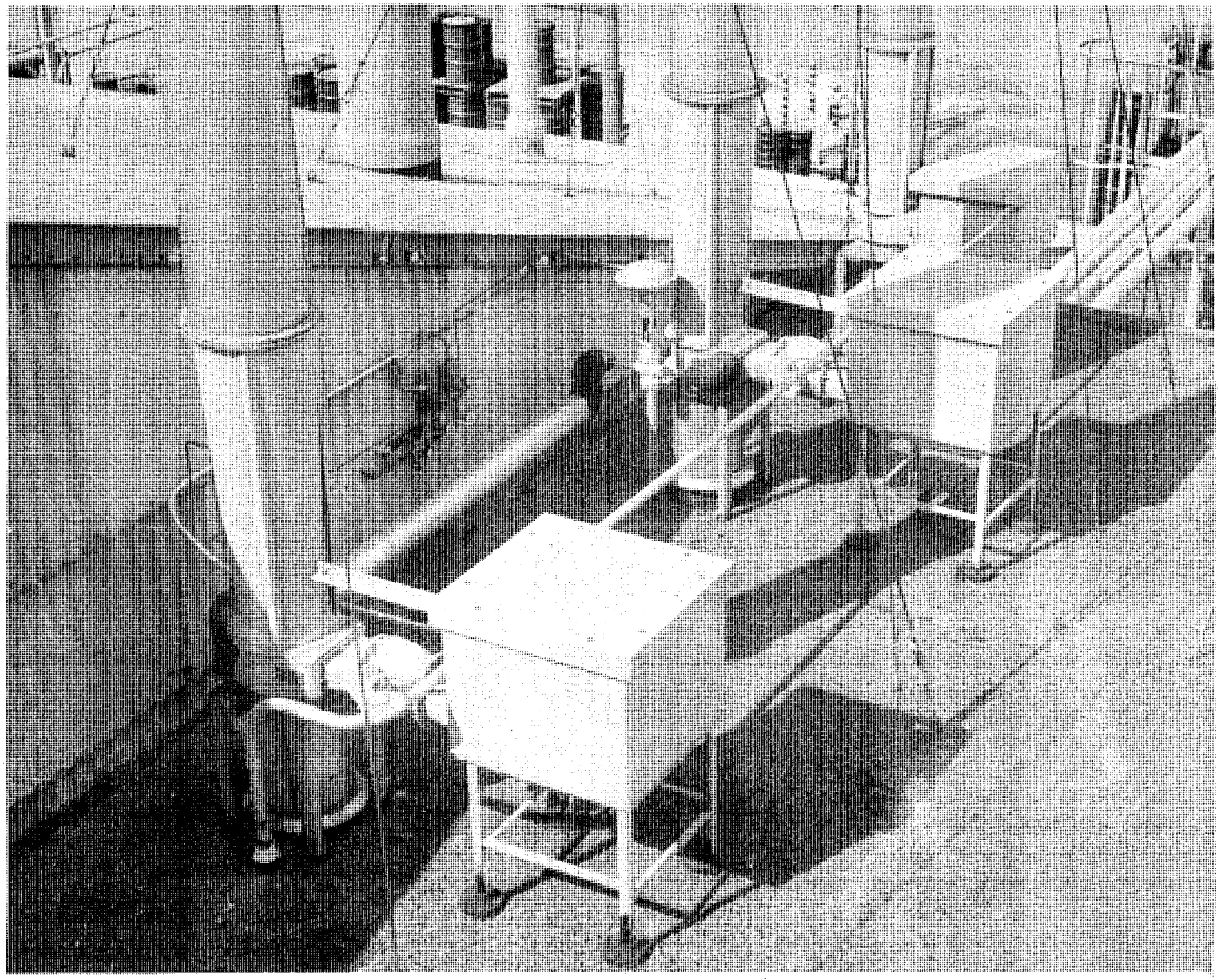


FIGURE 5 Roof-Mounted Eductors Exhausting Hydrogen-Rich Fumes

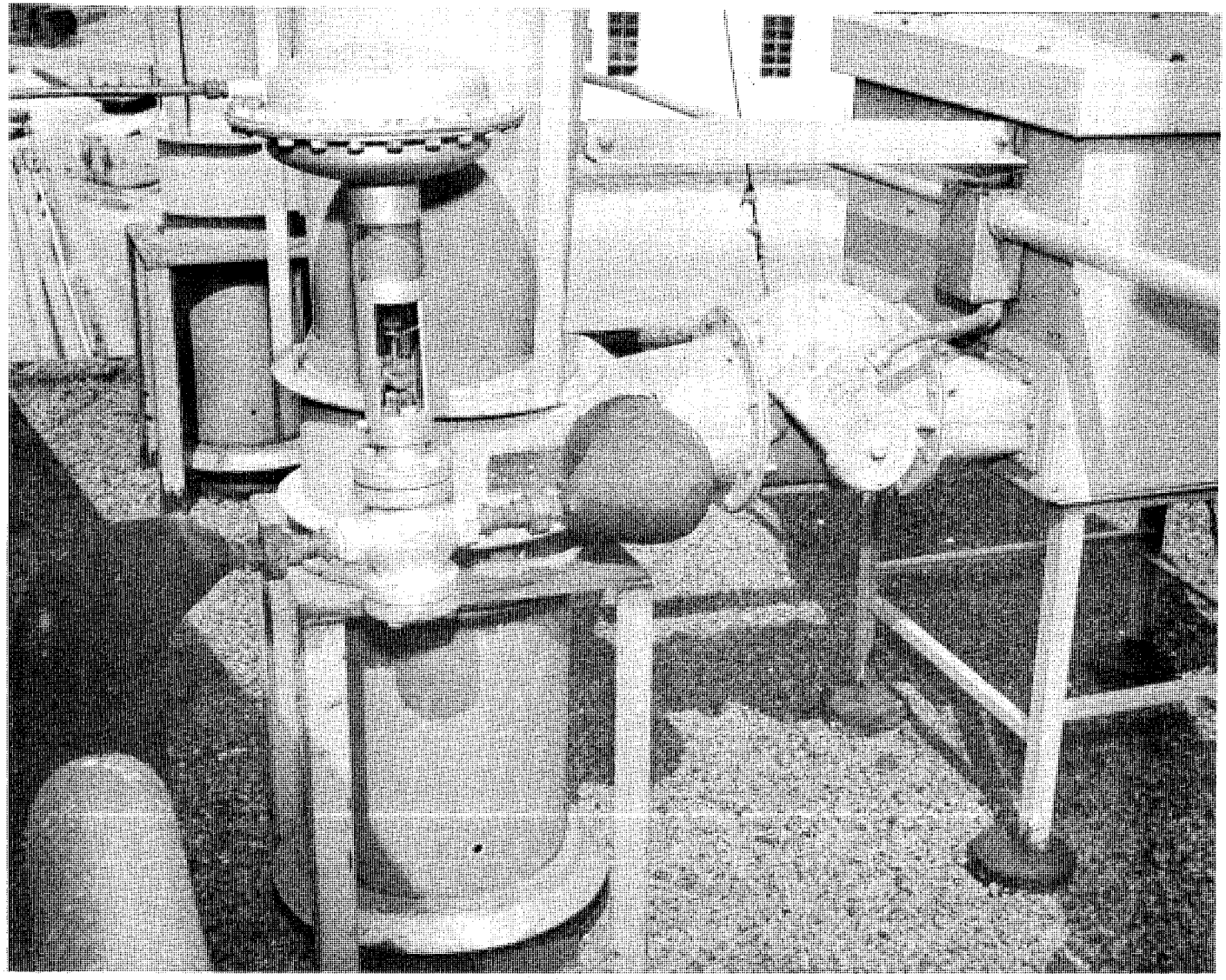


FIGURE 6 Close Up of Emergency Steam Supply for Hydrogen Exhaust Eductor

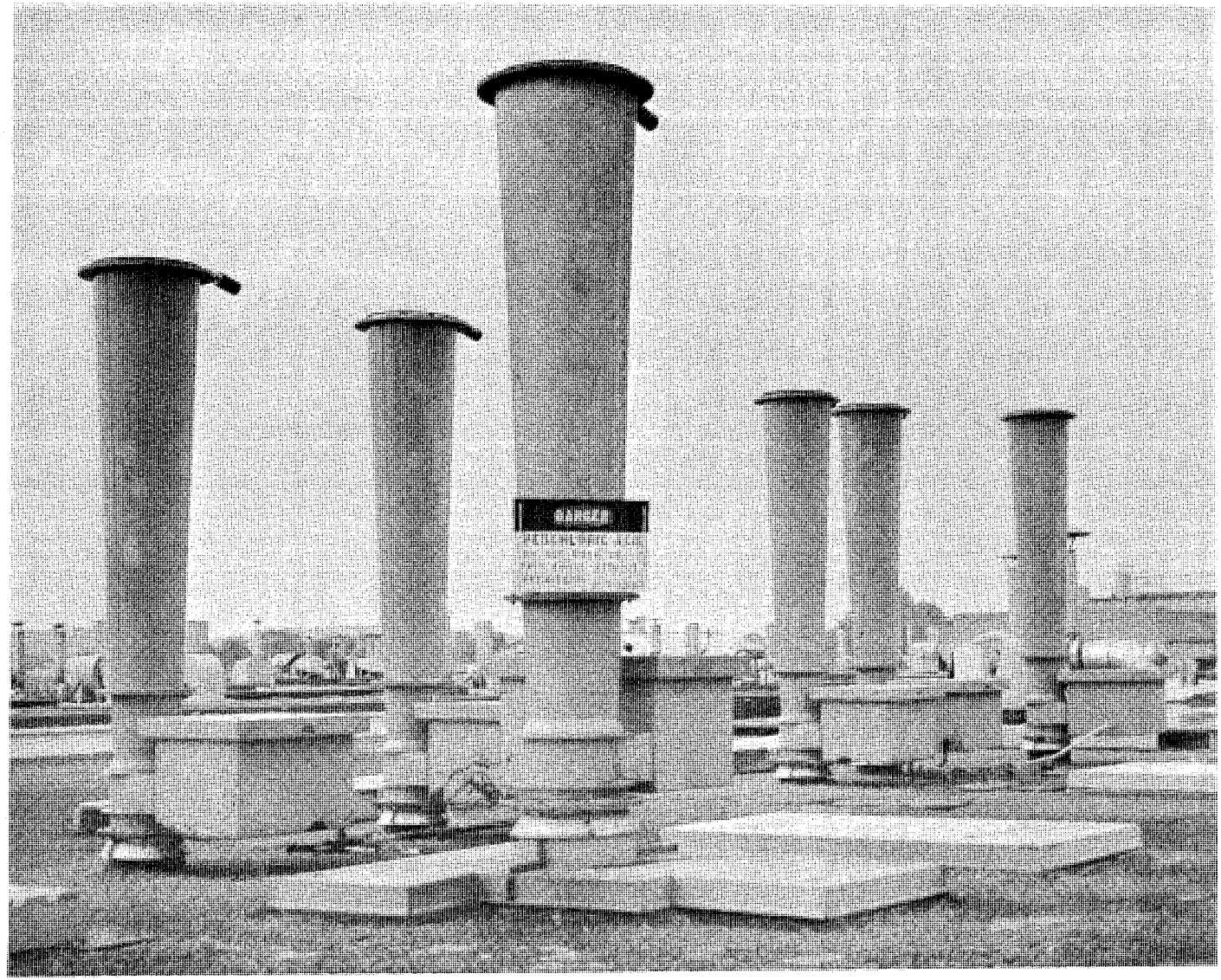


FIGURE 7 Quickdraft Eductors on Roof of Laboratory

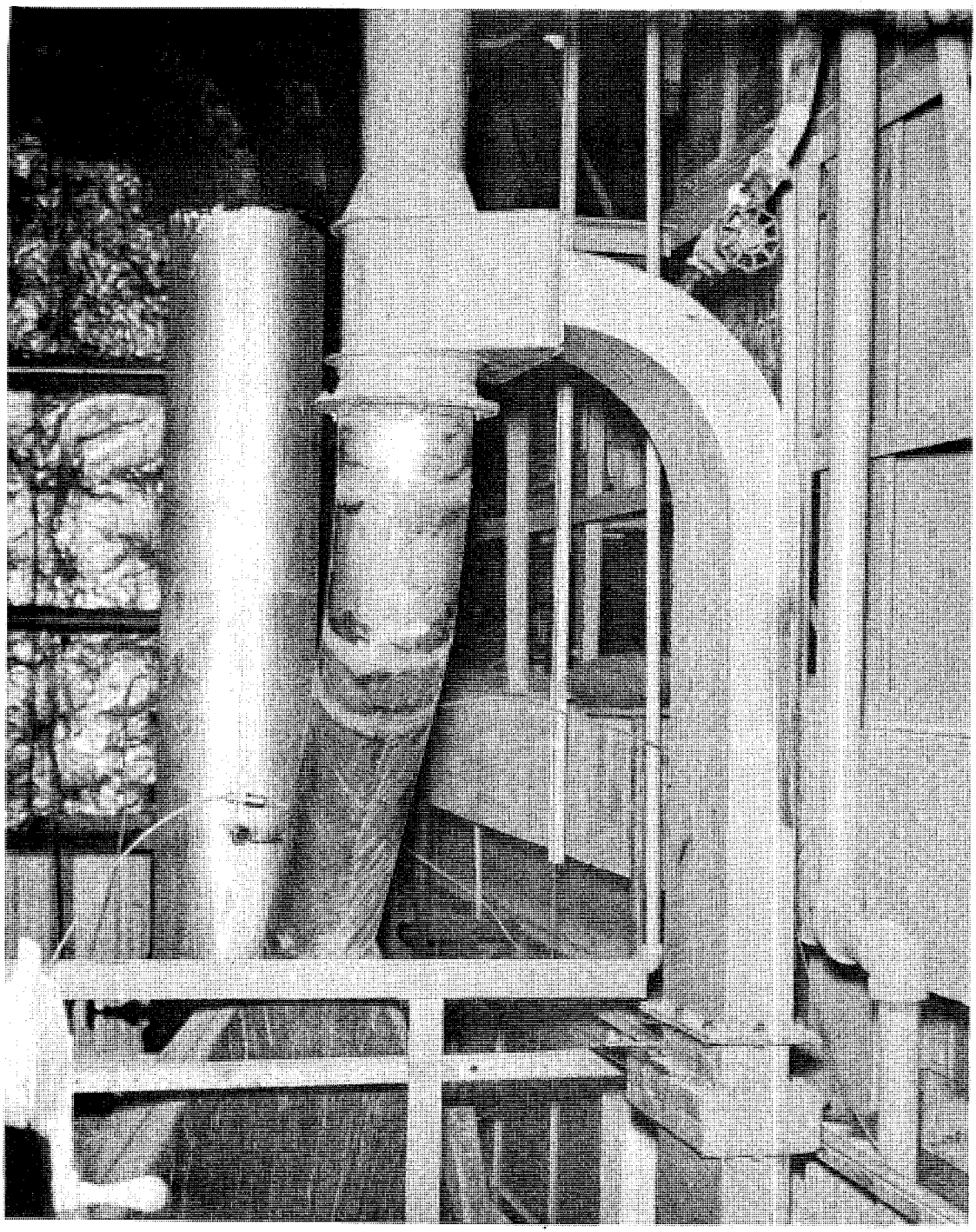


FIGURE 8 Furnace Scrubber Exhaust Eductor Showing Remote Blower Mounting

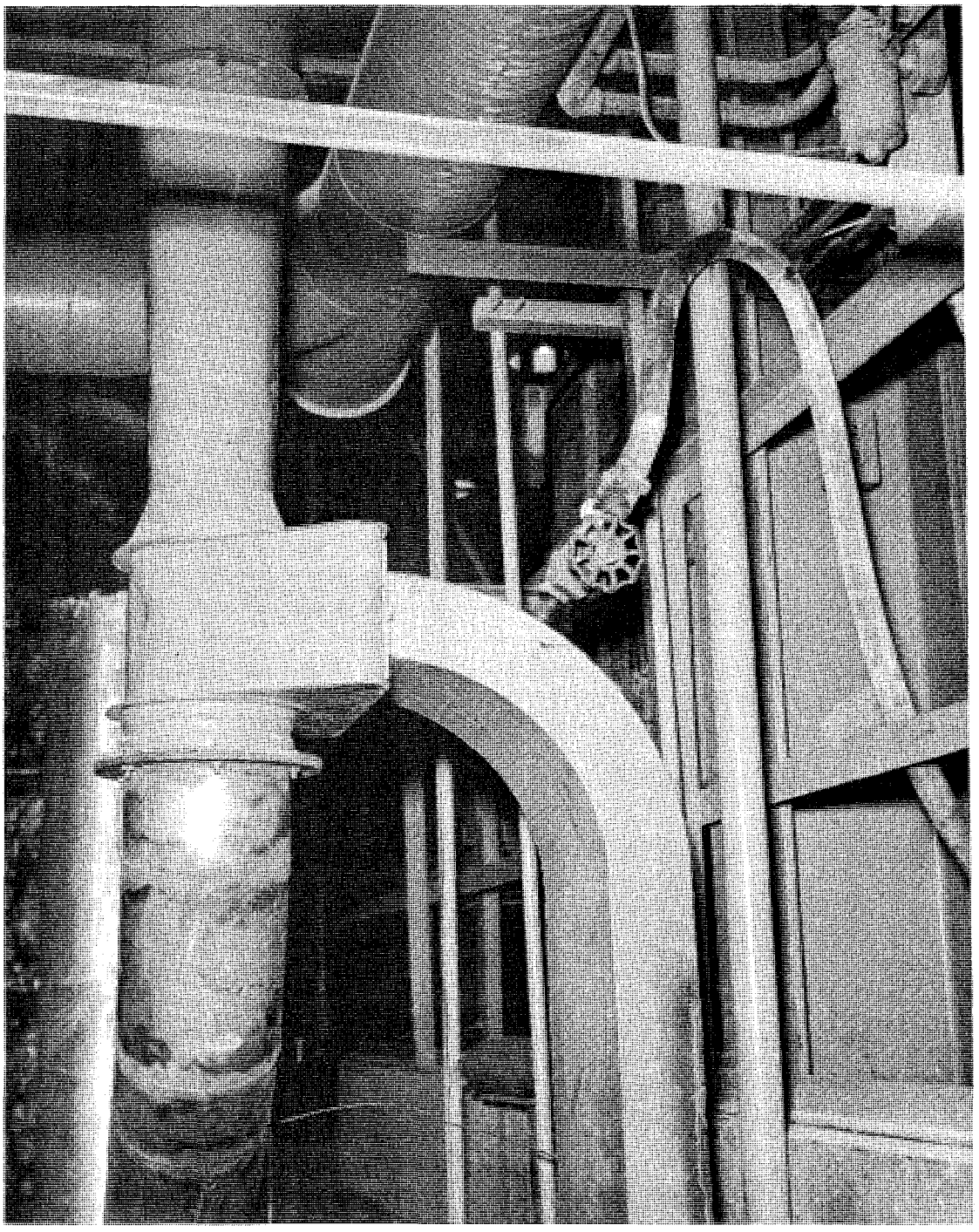


FIGURE 9 Close Up of Eductor Showing Warm Water Valve at Blower Discharge

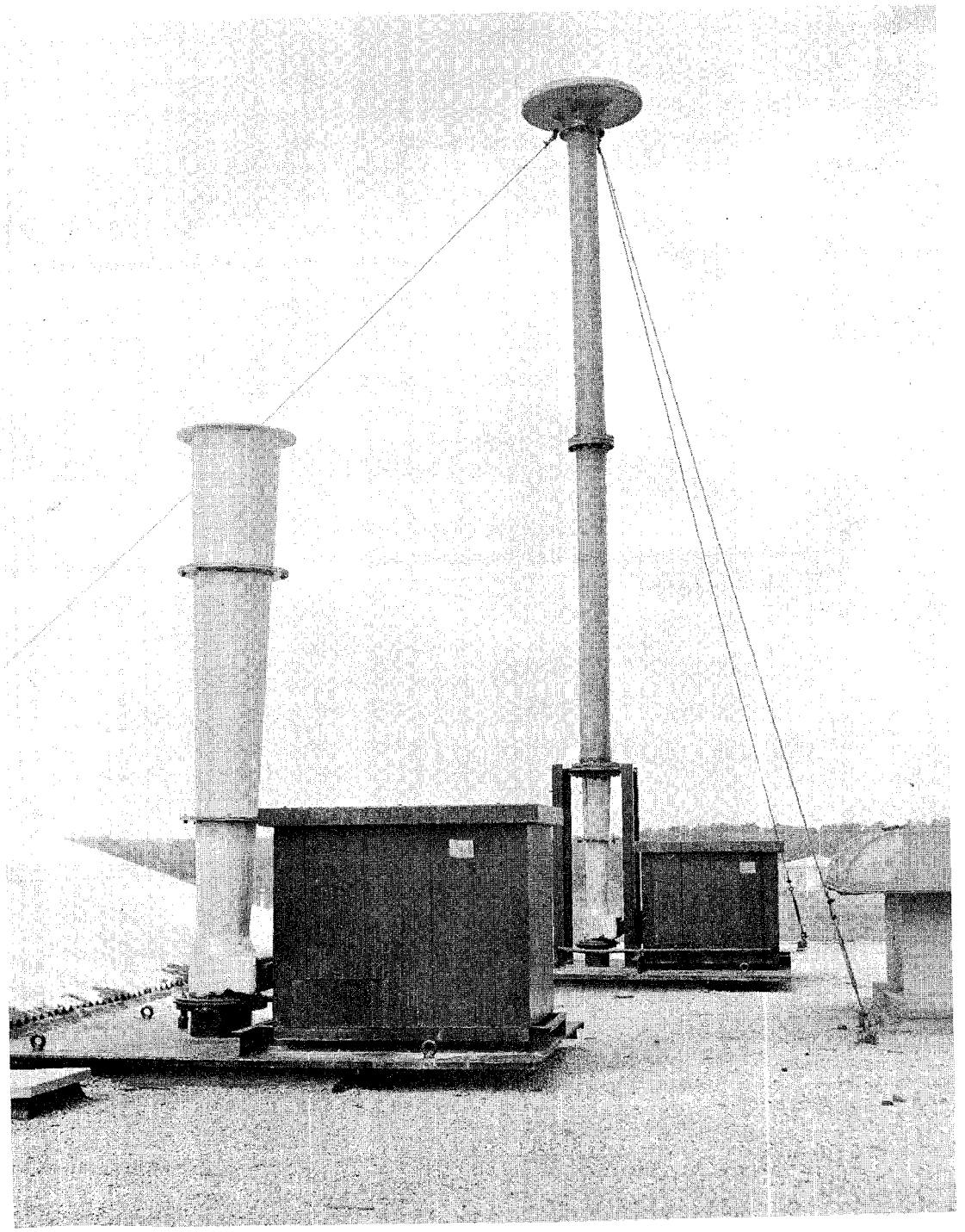


FIGURE 10 Corrosive Scrubber Exhausts Using Dynel-Reinforced Polyester Resin Quickdraft Eductors and Ductwork

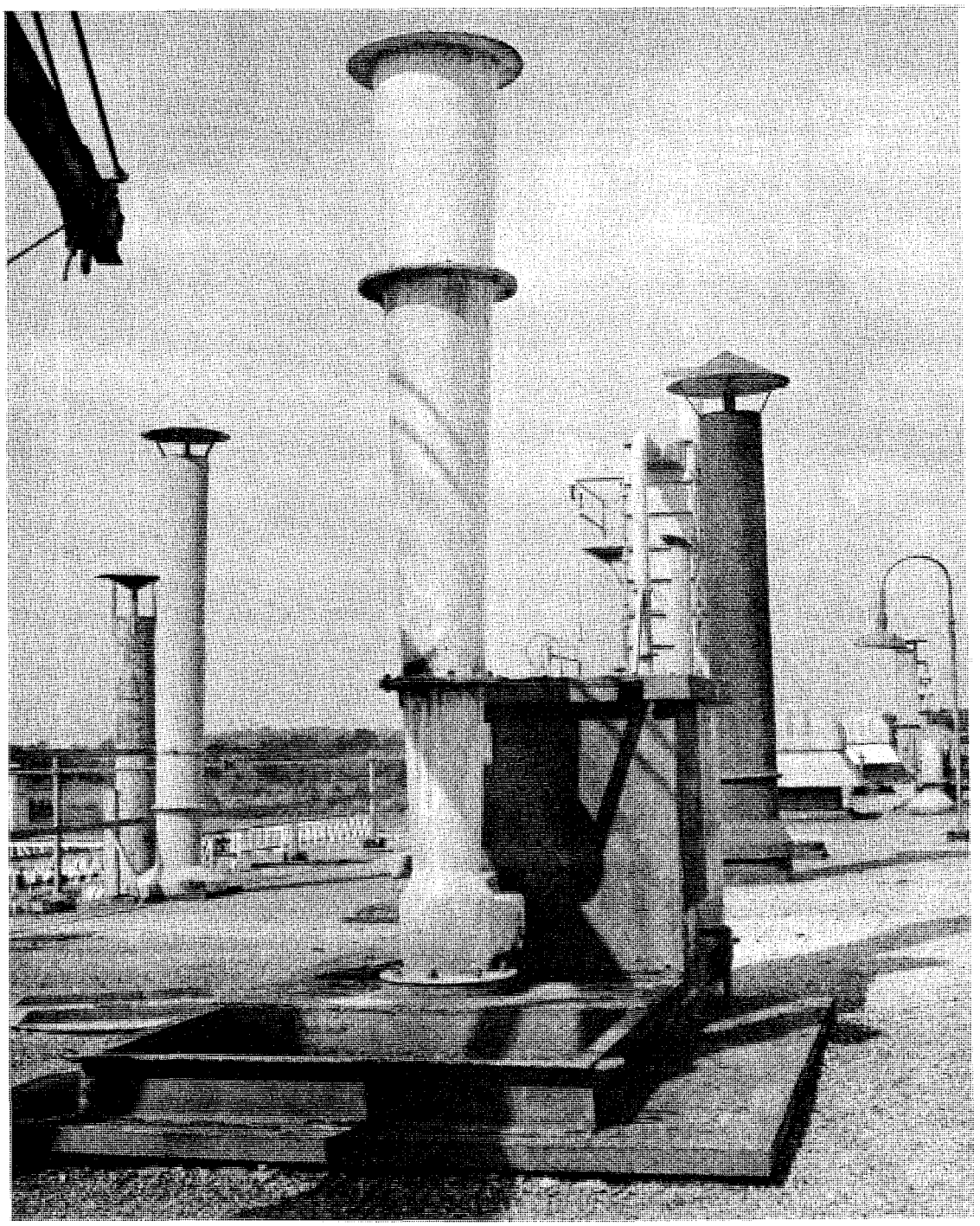


FIGURE 11 Corrosive Scrubber Exhaust Using Fiberglass-Reinforced Polyester Resin Quickdraft Eductor and Ductwork

Prior to the installation of the Quickdraft units, these scrubbers were exhausted by centrifugal blowers with plastic wheels. These wheels required replacement approximately every three weeks. The Quickdraft units have eliminated the cost of replacing these units as well as expensive downtime. To resist the very corrosive HF, the units are constructed of Duverre 22 polyester resin reinforced with dynel cloth.

Figure 12 shows a small Quickdraft eductor venting a zirconium decladding tank. This unit has outlasted three blowers in this installation.

The final application of these units to be discussed is shown in Figure 13. In this application the eductor is being used to exhaust corrosive fumes from Eimco filters. The units are fabricated fiberglass-reinforced polyester resin. The sharp elbow in the duct immediately below the Quickdraft unit is not recommended practice, but it does permit the use of the eductor in close quarters.

7. CONCLUSIONS

I have attempted to point out in this paper the numerous advantages of this unit as a ventilation source with special emphasis on its usage in handling corrosive and noxious fumes where all moving parts of the air mover must be kept out of the corrosive stream. The Quickdraft eductor is not a replacement for exhaust fans and blowers but, rather, is a valuable new tool to be used by air pollution and environmental control

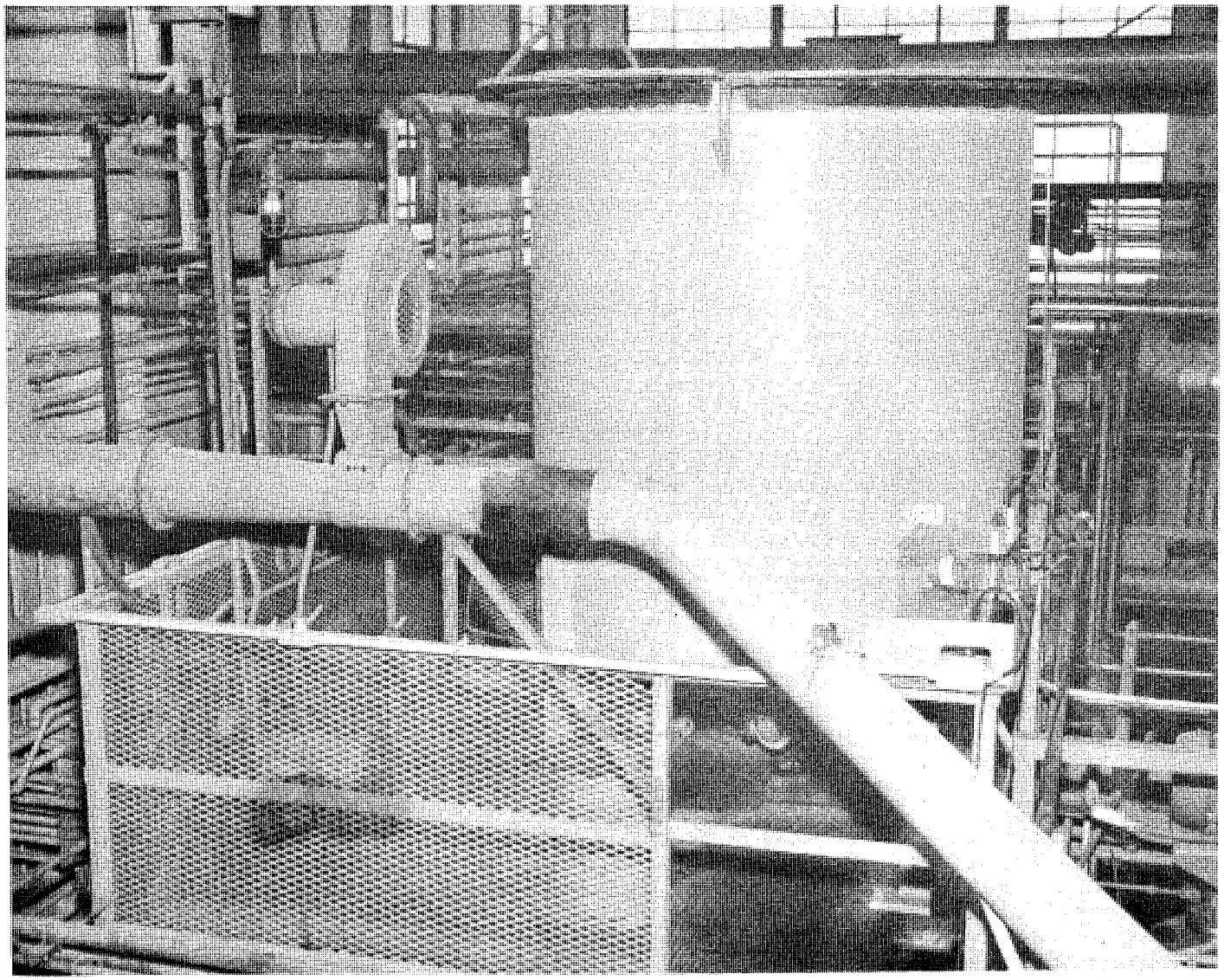


FIGURE 12 Zirconium Decladding Tank Exhaust; Horizontally Mounted Quickdraft Unit

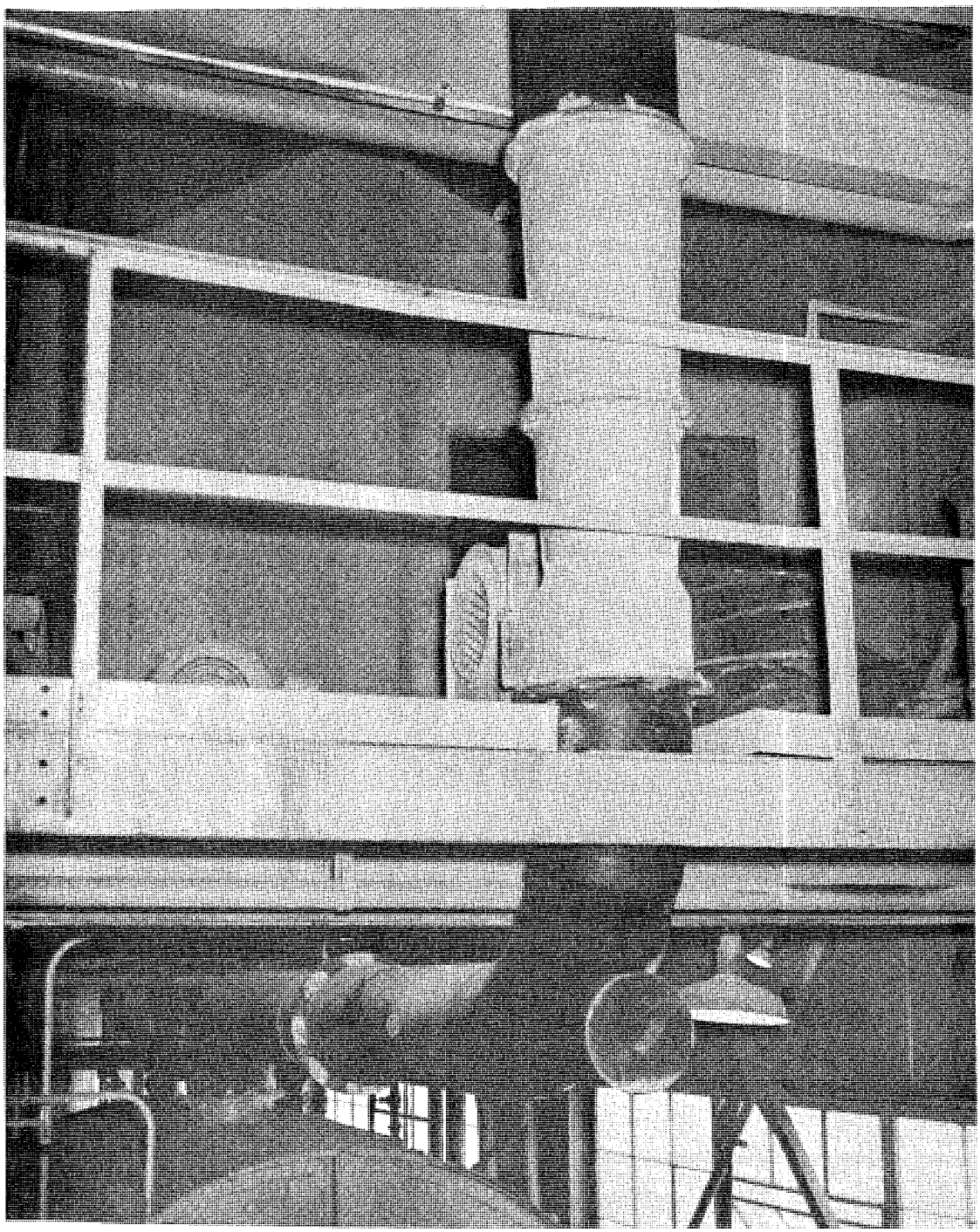


FIGURE 13 Eimco Filter Exhaust Fiberglass-Reinforced Polyester Resin Quickdraft Eductor and Duct

engineers in certain problems which were heretofore difficult to solve.

DISCUSSION AND COMMENT

The units run somewhat higher than 60% efficiency due to the manner in which the air is inducted. However, the efficiency drops off terrifically as higher statics are approached.

The proper way to evaluate may be to determine the mechanical efficiency of the power put into the system in the primary blower, and the power out in terms of the amount of air flow and the static. No figures were given on true mechanical efficiency but it was revealed that this would vary accordingly to the particular unit installed. It was estimated that the efficiency would be somewhere about or slightly below a regular blower.

The life of #304 stainless steel with perchloric acid was extended about three times. Nitric acid showed practically no attack. PVC, unplasticized, will be used from now on.

The units at lower static pressures using a quarter to one-half inch static are being purchased economically at approximately or slightly less than the price of a regular blower. The favorable purchase price was explained by the employment of a direct drive, high rpm unit.

Session Chairman: The next paper is "Final Results of Economic Survey of Air Cleaning Equipment Used at AEC Contractor Sites." Dr. M. W. First, Associate Professor of Industrial Hygiene at the Harvard Air Cleaning Laboratory, will present the paper.

FINAL REPORT OF ECONOMIC SURVEY OR AIR AND GAS CLEANING OPERATIONS WITHIN THE AEC

M. W. First

and

L. Silverman

Harvard University School of Public Health

INTRODUCTION

The Harvard Air Cleaning Laboratory has been conducting an economic survey of AEC air cleaning costs over a period of several years. Reports on the progress of this survey have been presented at past AEC Air Cleaning Conferences and they are available in the volumes of published proceedings (1,2,3). The economic survey has been completed and all of the data and results will become available soon as a numbered Harvard Air Cleaning Laboratory AEC Report is prepared.

The cost of owning and operating air cleaning equipment is a matter of interest and concern to all users and especially to organizations such as the AEC that handle exceedingly toxic materials that must be carefully and closely controlled regardless of cost because of the serious threat to life that would otherwise exist. Even in situations where health considerations take precedence over costs, it makes good sense to provide the needed protection at the least possible expense. It has been suggested by experienced engineers (4) that the development of power reactors in the U. S. is being seriously retarded by the cost of excessive safety provisions and that certain minimal risks should be accepted in the interest of low cost nuclear power production. Air cleaning is only one factor in the overall safety program, and perhaps a minor one with many types of reactors, but this type of thinking points up the necessity for a rigorous examination of costs as they relate to air cleaning effectiveness, regardless of how one responds to the idea of relaxing existing safety standards.

The exact purchase price of specific air cleaning devices is readily determined by consulting the manufacturer but the costs of erection plus the purchase of associated equipment such as ducts, stack, blower, water pumps, etc. often represent a far greater cost than the purchase price of the air cleaner. A rule

of thumb that has been suggested is that the installation cost will not exceed two and one half times the purchase price of the air cleaner; but of course this is quite variable and often it is desirable to analyze the individual cost components.

Even less information is available on operational costs than on purchase and installation costs. One reason for this may be the great variations in operating conditions which exist from industry to industry and from plant to plant within the same industry. Undoubtedly, nonuniformity in accounting practices is responsible for some apparent differences in what would seem to be closely similar operations.

In spite of efforts to collect accurate and up-to-date cost information, it must be emphasized that the data represent broad averages and that significant deviations may be anticipated when out-of-the-ordinary requirements must be satisfied or when installation and servicing present special difficulties by reason of difficult terrain or unusual toxicity. When conditions do not deviate markedly from the norm, we believe the figures given here will provide a basis for performing planning functions and preparing budgetary estimates for a wide range of air and gas cleaning applications.

At the last conference (3) survey results on the cost of installing and operating AEC absolute filters and dry fibrous prefilters were reviewed. At this time, some of the data pertaining to (a) cleanable industrial fabric filters, (b) electrostatic precipitators, (c) dry mechanical dust collectors, and (d) scrubbers will be summarized. In the interests of brevity, the general methods of analysis that were discussed in the previous published progress reports to which I have already referred, will not be repeated.

CLEANABLE INDUSTRIAL FABRIC DUST FILTERS

Industrial fabric filters differ principally in the cleaning methods used to remove the accumulated dust cake and restore the permeability of the fabric. In the older of the two basic methods, the dust-laden filter is isolated from the air stream and cleaned by shaking, vibrating and/or reversing air flow through the fabric. In the other method, small fractions of the dirty fabric are cleaned continuously (while filtration proceeds) with the aid of a traveling jet of high velocity reverse flow air. Details of these cleaning methods have been published elsewhere(5).

In Table I are shown acquisition and operating costs for 90 cleanable fabric filters in service at AEC installations; 82 reverse jet cleaned filters and 8 shaken-bag units. The filter units are also grouped with respect to the size of the installation, i.e., cubic feet per minute of air flow capacity. From the Table, it may be seen that on the average the cloth-to-air ratio (cfm per sq. ft. of fabric) increases with increasing size of installation for both types of collectors. The reasons why this should be so are not known with certainty. The fact that acquisition and operating costs tend to decrease rather sharply with increasing size of installation suggests that small units are not only more expensive per unit of capacity (this was found to be the case for

Table I

Costs for Industrial Fabric Filters

Capacity cfm	Number Install'ns	Total Ann. Cost per 1,000 cfm Aver.	Min.-Max.	Cloth-Air Ratio-Av. cfm/sq.ft.	Cost-Analysis - % Total Cost Purchase & Install'n	Power	Maint. & Repairs
A. Reverse-jet Cleaned Filters							
<1,000	5	1,947	333-3,131	5.8	31.7	7.9	60.4
1,000 - 5,000	34	1,168	222-4,481	8.2	18.8	10.6	70.6
5,000 -10,000	22	989	267-3,456	11.6	9.5	21.0	69.5
10,000 -20,000	17	1,213	192-5,221	14.9	7.2	21.9	70.9
>20,000	4	196	142- 259	21.9	29.6	29.6	40.8
B. Shaken Bag Filters							
1,000 - 5,000	6	520	302- 748	3.5	29.0	18.9	52.1
5,000 -10,000	2	1,723	224-3,221	4.2	7.8	5.3	86.9

AEC filters and prefilters, also) but in addition, that small installations tend to be associated with out-of-the-ordinary and difficult applications (such as vacuum cleaning, incinerator effluent cleaning, etc.) that produce abnormally high dust loadings or dust deposits with high air flow resistance. From this it may be concluded that small size, high dust loadings, difficult operating conditions, low air-to-cloth ratios, and high costs tend to occur together. Most of the fabric filter installations that have been reported are located in plants processing uranium ores. For many units, filter bags are removed each 3-6 months and incinerated to recover the metal accumulated in the fabric. This practice has a profound influence on total operating costs and largely accounts for the abnormally high costs of the reverse jet collectors in the 10,000 - 20,000 cfm size class. The most costly of the 90 cleanable fabric filters recorded in Table I occur in this group.

The number of shaken bag units reported (eight) is far fewer than for the reverse jet type and averages are not as meaningful. For the 1,000 - 5,000 cfm size group, the total costs of shaken bag units are about half those of reverse-jet filters whereas for the 5,000 - 10,000 cfm size group the cost relationship is reversed. It seems probable that these differences reflect special use conditions rather than an inherent cost differential between the types. A recent study (6) indicates that annual unit costs are closely similar when all types of fabric filters are employed on more usual industrial applications. It is evident from Table I that reverse jet cleaned fabric filters have average air-to-cloth ratios that are $2\frac{1}{2}$ times those of shaken bag units.

For both types of fabric filters, maintenance and repairs account for over 50% of the annual unit costs, except for units in excess of 20,000 cfm capacity. Again, this reflects special AEC applications of a difficult nature.

LOW-VOLTAGE TWO-STAGE ELECTROSTATIC PRECIPITATORS

Two-stage electrostatic precipitators are used both for supply and exhaust air cleaning applications at AEC sites. Supply air cleaning is, by far, the more common use for this type of unit. In Table II, costs are analyzed by the nature of the application and it is evident that unit costs are much higher for treating exhaust air. Whereas the two-stage precipitator usually performs well with low loadings of fine dust customarily encountered in outside and recirculated indoor air, it is not constructed to handle high dust loadings, moist or corrosive atmospheres, abnormal temperatures, or any of the other unfavorable conditions commonly encountered with effluent process air and gas streams. That a two-stage precipitator is a misapplication for an exhaust air stream is revealed by high total costs as well as by the high percentage of these costs (> 90%) that goes into maintenance and repairs.

The supply air precipitators show a normal decrease in unit operating costs with increasing size and maintenance; and repairs account for 25% or less of the total cost.

Table II

Costs for Two-Stage Electrostatic Precipitators

Capacity cfm	Supply Air Units: Number Install'ns	Total Ann.Cost $/1000cfm/yr Ave.	Min.	Max.	Cost Analysis-% Total Cost: Purchase & Install'n	Power	Main. & Repair	Exhaust Air Units: Number Install'ns	Total Ann.Cost Ave.	Min.	Max.	Cost Analysis % Total Cost: Purchase & Install'n	Power	Main. & Repair
1,000-5,000	1	130			61.6	13.8	24.6	1	164			71.3	10.5	18.2
5,000-10,000	5	76	32	144	53.3	20.0	26.7	0	-	-	-	-	-	-
10,000-20,000	1	24	--	--	45.8	33.3	20.9	3	680	201	920	6.8	1.8	91.4
>20,000	1	27	--	--	55.5	33.3	11.2	2	7,094	45	14141	0.6	0.2	99.2

DRY MECHANICAL DUST COLLECTORS

Costs were reported for ten dry mechanical dust collectors ranging in type from a simple gravity settling chamber to a small diameter multi-cyclone installation. Unit size ranged from 800-8,000 cfm. Cost data for each installation are shown in Table III as there are not enough representatives of each type and size to make average cost figures meaningful.

In general, overall annual unit cost is high when "maintenance and repairs" represents a large percentage of total cost. When total cost is low, power costs represent a sizeable fraction of the total annual cost. With the exception of the gravity settling chamber, this class of dust collectors has an air flow resistance in the range of 3-6 in. w.g. and when there are no unusual maintenance costs (because of erosion, corrosion, or special difficulties associated with the disposal of the collected dust), power tends to be a major fraction of the total cost.

It is, perhaps, somewhat surprising to learn that operating costs for simple mechanical dry dust collectors may, under unusually severe operating conditions, exceed $500.00 per 1,000 cfm of capacity per year. For normal operating conditions, annual costs of under $200.00 per 1,000 cfm of capacity per year are customary in conventional industrial plants and some of the AEC installations shown in Table III are within this cost figure.

WET DUST COLLECTORS

Cost data for four type "N" Rotoclones are shown in Table IV. Three have closely similar total annual unit costs; for the fourth, costs are approximately 300% greater. "Maintenance and repairs" represents 82% of the total for this latter unit and it may be assumed that unusually severe operating conditions make it necessary to give this collector constant servicings. "Maintenance and repairs" for the two Rotoclones handling exhaust air from a machine shop and foundry (a usual industrial application for these units) is only 5% of the total whereas power is 2/3 of the total cost, indicating a more normal "maintenance and repairs" situation for these dust collectors.

Total annual unit costs for type "N" Rotoclones are only slightly greater than those for the dry mechanical dust collectors, in spite of the fact that the collection efficiency of the type "N" for small particles is far better.

Table V shows annual purchase and installation costs for 32 Schutte-Koerting Scrubbers installed in a uranium refinery. Operating costs, other than for water requirements, are not available.

These eductor units are commonly used as a combination pump and scrubber when the corrosive properties of the gases and vapors make the use of mechanical blowers and exhausters impractical. As the mechanical efficiency of the unit when used as a blower is 10% or less, the quantities of water that must be pumped are large.

Table III

Costs for Dry Mechanical Dust Collectors

Type Unit	Capacity	Total Ann. Cost	Cost Analysis- % of total cost			Service Conditions
			Purchase & Install'n	Power	Maint. & Repairs	
	cfm	$/1000cfm/yr				
Settling chamber	4,000	103	3.7	17.5	78.8	Exhaust from graphite machining
Aerodyne	5,900	92	41.4	25.4	33.2	Incinerator flue gas.
Rotoclone "D"	4,000	593	12.2	28.3	59.5	Exhaust from graphite machining
Cyclone	3,570	203	16.3	34.6	49.1	Exhaust from carpenter shop
(2) Cyclone(Ducon)	2,200	409	33.1	22.9	44.0	Incinerator flue gas
(2) Cyclone (A,B,C)	2,200	170	22.9	55.3	21.8	Exhaust from U-machining
Cyclone (K & B)	8,090	135	17.8	69.6	12.6	Exhaust from U-machining
Multicyclone (Dustex)	800	511	46.5	18.3	35.2	Exhaust from sintering furnace

Table IV

Cost of Wet Dust Collectors
Installed at AEC Sites

Type Unit	Capacity	Total Ann. Cost	Cost Analysis- % of Total Cost			Service Conditions
	cfm	$/1000cfm/yr.	Purchase & Install.	Power & Water	Maint. & Repairs	
Rotoclone "N"	3,390	505	32.3	62.5	5.2	Exhaust from machine shop and foundry
"	5,500	422	20.5	74.8	4.7	" " "
"	5,900	1,399	2.1	16.2	81.7	Exhaust from U-refinery (U_3O_8)
"	13,000	547	4.9	41.5	53.6	" " "

Table V

Purchase and Installation Costs - Schutte-Koerting Scrubbers
(Uranium Refining)

Capacity cfm	Liquid rate gal/1000 cf air	Initial equipment cost $/1000 cfm/yr.*	Initial installation cost $/1000 cfm/yr.*	Total equipment annual cost $/1000 cfm/yr.*
128	70	483	388	871
300	60	167	134	301
400	60	130	103	233
750	60	66	53	119
1700	100	45	36	81
2100	150	39	67	106

* 30-year write off period.

The cost of pumping water in dollars per year per 100 gpm, is 16.1 x H, where H is the pumping head in feet. (Power is assumed to cost $.015/KWH and annual use to be 8000 hours). For a 30 foot pumping head (a commonly-used figure for low pressure applications), the annual cost per 1,000 cfm of air capacity will be $290.00 to $750.00 depending on the water requirements of each unit, as shown in Table V. This sum, plus the cost of maintenance and repairs, must be added to the annual equipment cost figures shown in the Table.

SUMMARY

Cost analyses of the many different types of dust collectors used at AEC sites show that installations that are critical from a health and safety standpoint as well as those involving the handling of heavy dust loadings and highly corrosive gases and vapors, result in unusually high annual unit costs. These conditions are not greatly different from those encountered in more conventional industrial experience except that unfavorable operating conditions and critical health problems are much more frequent within the AEC.

All types of units show lower unit costs as the size of the installation increases, up to about 10,000 - 20,000 cfm. For larger units, costs tend to be the same. For units of the same air flow capacity, treatment of exhaust air streams is usually 2-3 times as costly as treatment of ventilation air streams. For supply air units of 10,000 cfm capacity, dry fiber throw-away prefilters cost under $50/1000 cfm/yr.; two-stage electrostatic precipitators, $76/1000 cfm/yr.; and AEC absolute filters, $175/1000 cfm/yr.

For exhaust air cleaners of the same capacity (10,000 cfm), most dry and wet medium efficiency mechanical dust collectors will cost in the vicinity of $500/1000 cfm/yr., and cleanable fabric dust collectors about double this figure.

REFERENCES

1. 5th AEC Air Cleaning Conference Proceedings, TID-7551, Office of Technical Services, Washington, D. C., April 1958.

2. 6th AEC Air Cleaning Conference Proceedings, TID-7593, Office of Technical Services, Washington, D. C., October 1960.

3. 7th AEC Air Cleaning Conference Proceedings, TID-7627, Office of Technical Services, Washington, D. C., March 1962.

4. Siddell, E., "Statistical Analysis of Reactor Safety Standards," Nucleonics, 17(2): 64 (1959).

5. Billings, C., First, M.W., Dennis, R., and Silverman, L. "Laboratory Performance of Fabric Dust and Fume Collectors," NYO-1590R, Harvard University (1951).

6. Dennis, R., and Silverman, L., "Fabric Filter Cleaning by Intermittent Reverse Air Pulse," ASHRAE J., p. 43 (Nov., 1962)

CHARACTERIZATION OF GAS-BORNE FISSION PRODUCTS

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R. D. Ackley
M. D. Silverman

ABSTRACT

Two methods for determining the form of radioactivity in gases have been investigated. In the first method, diffusion coefficients for fine particles and for radioactive vapors such as iodine and its compounds are determined by measuring the distribution of radioactivity on the walls of a channel previously exposed to gas carrying radioactive materials and flowing under laminar conditions. This method has been utilized in investigating the nature and behavior of volatile iodine compounds. These have been observed to occur, in certain situations, in conjunction with the elemental form. Information on such compounds may be needed to design properly removal devices for radioiodine and to interpret deposition behavior. Composite diffusion tubes having, in the direction of flow, inner surfaces of silver, rubber, and, activated carbon have shown the presence of two non-elemental species of iodine in addition to the elemental. The compound or compounds which are retained by a rubber surface have an indicated diffusion coefficient in air of around 0.05 cm^2/sec, and that retained by activated carbon, about 0.10 cm^2/sec. These results together with data obtained by other means have provided clues as to the identity of the iodine compounds and further work is planned in order to identify them more explicitly.

The second method for measurement of the characteristics of radioactive aerosols makes use of fibrous filters. This method measures aerosols in terms of their response to the processes of inertial impaction, interception, and diffusion by determining their distribution versus depth in fibrous filters under carefully controlled conditions. The velocity dependence of the slope of distribution curves on a semilog plot identifies the mechanism of filtration, and the magnitude of the slopes indicates the intensity of the filtering action and thus the character of the particles. Experiments where diffusion is the controlling mechanism have been quantitatively treated and particle sizes in the 50 to 500 A^o range determined by this technique compare favorably with those obtained from concentrations and flow data and electron photomicrographs.

INTRODUCTION

The behavior of gas-borne materials depends markedly on their form; consequently, the prediction of their dispersal or transport or the selection and design of systems for their removal from gases requires information as to the distribution of radioactivity between the different forms which occur. Two methods for determining the form of radioactivity in gases have been investigated.

DIFFUSIONAL DEPOSITION OF IODINE COMPOUNDS

The first method for characterizing aerosols has been described previously (1). In this method, diffusion coefficients for fine particles and for vapors, such as iodine, are determined by measuring the distribution of radioactivity on the walls of a channel previously exposed to gas carrying radioactive materials and flowing under laminar conditions. As the diffusion coefficients are related to molecular properties or particle sizes, pertinent information as to the form of the fission products may thereby be obtained.

More recently, the diffusional deposition technique has been utilized in an effort to determine the identity of various iodine compounds which have been observed to occur in the diffusion tube experiments along with the elemental form. British workers in this field have previously reported that their data indicated some formation of iodine compounds when elemental iodine is released into atmospheric air (2, 3). Their results, however, correspond to considerably lower concentrations of iodine in air and so are probably not directly comparable. Some of the iodine compounds variously encountered may have very different deposition behavior in a gas coolant system and also are very likely removed with much lower efficiency than elemental iodine in adsorbers and scrubbers, and, consequently, knowledge of their behavior is needed to design properly radioiodine removal devices.

The probable presence of iodine compounds became apparent in this work when distributions in diffusion tubes did not conform to either those previously obtained or to those anticipated. In the earlier experiments corresponding to these observations, particles had been generated and labeled with I-131, but later on, in order to concentrate attention on the compounds, deliberate particle generation was omitted and the source air, which was the carrier gas in these studies, was rather elaborately filtered. Detailed examination of the diffusion tubes, which were silver-plated copper tubes, and of associated rubber tubing and activated carbon traps, then indicated the presence of two distinct species of iodine other than elemental. One of the species appeared to be quantitatively retained by the inner surface of rubber tubing and the other by activated carbon, but neither by silver metal. Both the origin and the importance of these two species are speculative but considering the important role of iodine in nuclear safety, further elucidation was deemed highly desirable. An experiment was then performed which included rubber tubing diffusion tubes; from the I-131 distribution in these a diffusion coefficient for one of the species in air was calculated to be about 0.05 cm^2/sec indicating a molecular weight (or weights) of about 300 amu. Of the total I-131 activity involved in the experiment, around 6% was estimated to be in the form of compounds. Also, the source iodine, which had I-127 as carrier, remaining after this experiment was analyzed by mass spectrometry and was observed to contain two compounds having masses well in excess of that of elemental iodine, the masses being 284 and 338. Two compounds having these weights are SiH_2I_2 and $C_6H_{12}I_2$, respectively, although this is not to suggest the identities but only to provide examples of the possibilities.

In another approach to this problem, the initial objective was to be able to prepare pure radioiodine and subsequently, to allow such material to contact other gases and various surfaces, and then to determine if volatile radioactive compounds were produced. The method of iodine preparation investigated was similar to that described by British workers (2, 3) and involved the evolution of iodine from melted potassium dichromate containing NaI-131 and KI-127. The purity was determined by means of the behavior of the iodine in diffusion tubes. With helium as a carrier gas, a purity of 99.6% was achieved; but with air, the

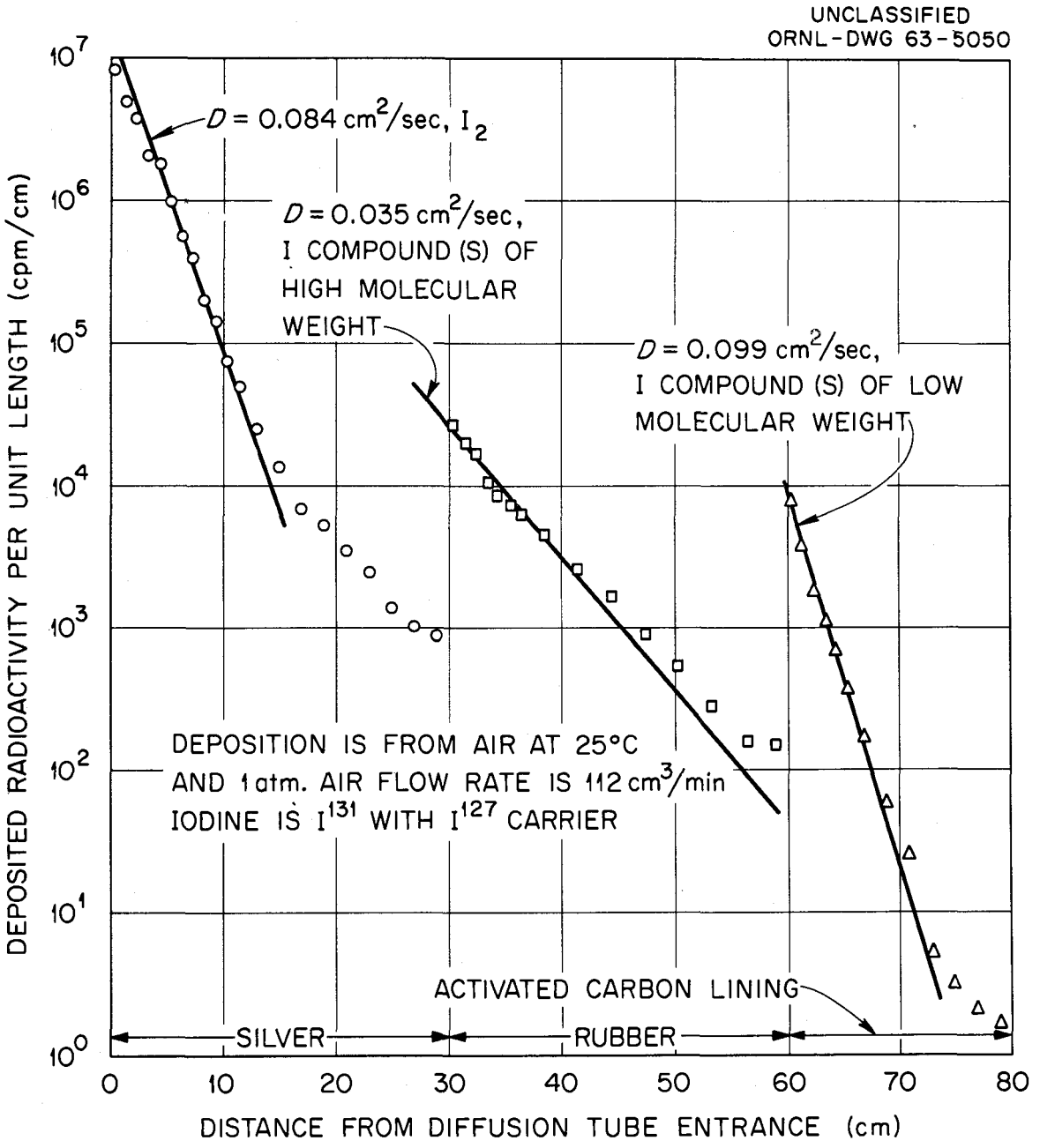
purity was only 98.8% and the principal impurity had a diffusion coefficient in air of 0.05 cm^2/sec, as had been obtained earlier. Since these observations indicated the air source was at least partially responsible for the appearance of compounds, attention was directed toward it. The air used in the test yielding 98.8% was plant air passed through an activated carbon trap. Since the activated carbon itself might have desorbed gases which subsequently reacted with iodine, as only traces would be required, it was replaced in the next experiment with a trap filled with Linde Molecular Sieves Type 5A. Also, the diffusion tube train had, in addition to silver-plated and rubber tubing, a following section of tube lined with activated carbon dust. Virtually all of the I-131 radioactivity which evolved from the dichromate melt and which entered the diffusion tube train was retained in the train and, of this iodine, 99.3% was indicated to be elemental. Most of the remaining 0.7% deposited on the rubber tubing and exhibited a diffusion coefficient in air of about 0.035 cm^2/sec, not greatly different from the previous results for rubber tubing. About 0.1% penetrated the silver-plated and the rubber tubing and deposited in the tube lined with activated carbon to yield a diffusion coefficient of 0.10 cm^2/sec which corresponds to HI or a slightly larger molecule than HI. These deposition results are shown in Fig. 1. A small portion of the evolved radioactivity did not reach the diffusion tube but deposited, probably due to a gas-phase reaction, as a yellow solid at a point where the air stream carrying the radioactivity was diluted by the main air stream. Preliminary indications are that the deposit was an iodine-oxygen compound.

As may be seen from the preceding, a variety of information has been obtained pertaining to the compounds of iodine which may occur in conjunction with the elemental form, and further studies toward this objective are planned.

CHARACTERIZATION OF AEROSOLS BY FIBROUS FILTERS

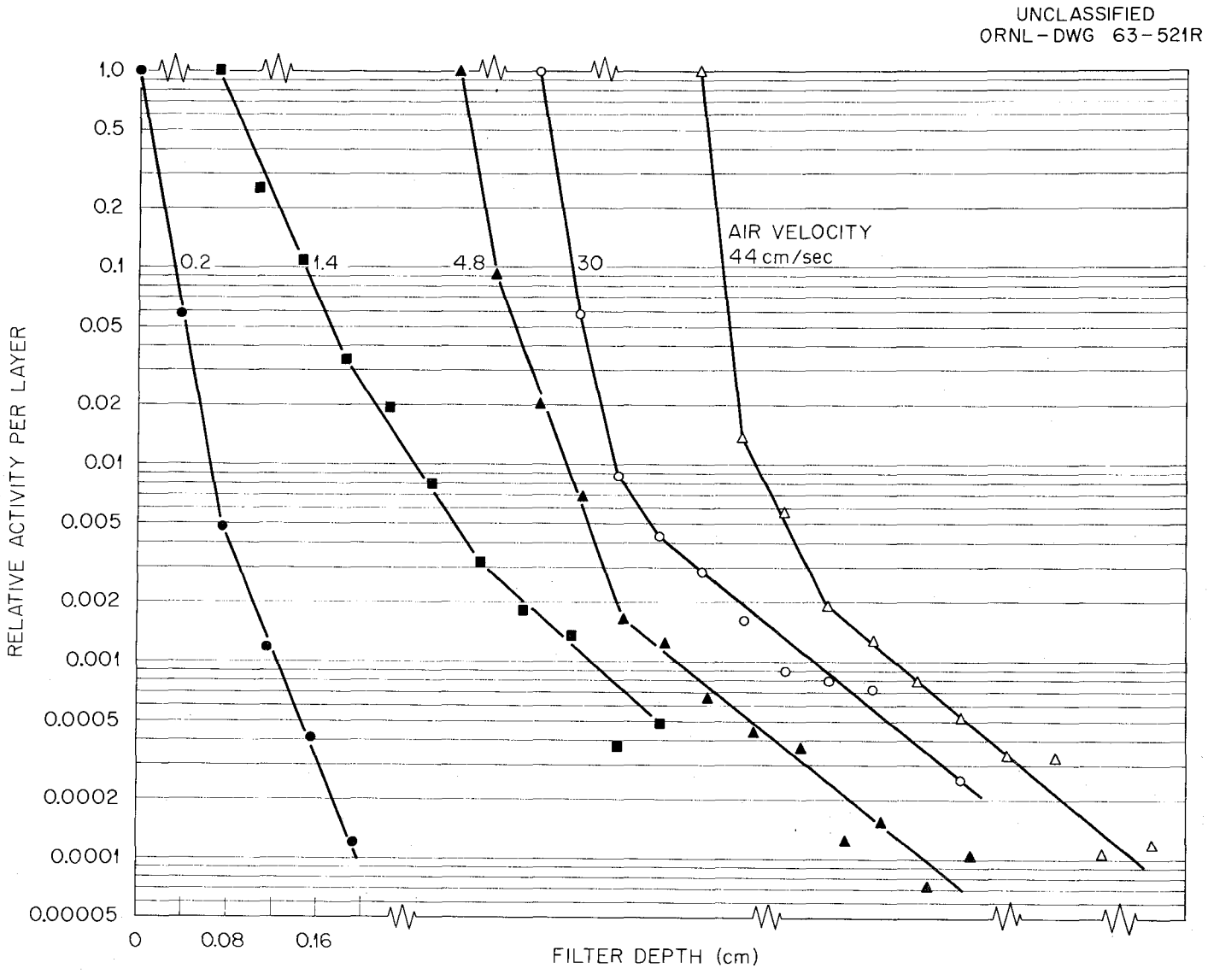
The second method for measurement of the characteristics of radioactive aerosols makes use of fibrous filters. The transport of an aerosol through an array of fibers brings into play the processes of inertial impaction, interception, and diffusion. Since all these processes have important effects on the behavior of radioactive materials in gases, it would be useful to be able to characterize radioactive aerosols by measuring their behavior in fibrous beds. This method measures aerosols in terms of their response to these processes by determining their distribution versus depth under carefully controlled conditions. A filter was developed having uniform fiber diameter to permit theoretical analysis and having a layered structure to facilitate separation of the fiber bed into discrete layers for radioassay after exposure to the aerosol. A radioactive aerosol of 0.004-0.03μ particles, containing Zn-65 was developed for initial tests of this method of characterizing aerosols.

Experiments have been conducted over a wide range of linear flow rates, from 0.2 to 44 cm/sec. The data are analyzed by means of graphs (Fig. 2) in which the log of the activity collected per layer is plotted against depth in the filter expressed as number of layers of material. Each layer contains approximately 10^4 cm of fiber per cm^2 of filter area, evaluated from disk weights and the density of the fiber. In the low flow region where Brownian diffusion is the dominant process for particle transport to the fiber, the efficiency of filtration decreases with increasing velocity. In the high flow region, where inertial impaction is the principal process for particle transport, the efficiency increases with increasing velocity. In the intermediate flow region, the interception range where geometrical considerations involving particle size and fiber size are very important, the filtration efficiency is largely independent of velocity. Thus, the velocity dependence of the slope of these distribution curves identifies the mechanism of filtration, and the magnitude of the slopes indicates the intensity of the filtering action.



Diffusional Deposition of Elemental Iodine and Iodine Compounds.

Figure 1



Distribution of Zn Activity vs Depth in Filter.

Figure 2

The filtering action of a fiber mat is the cumulative effect of particle removal by individual fibers. The collection efficiency of an individual fiber, η_d, is defined as the ratio of the cross-sectional area of the aerosol stream from which particles are removed to the projected area of the fiber in the direction of flow and may be obtained from the slope of the distribution curve on the semi-log plot. This slope may be substituted directly for $(\ln N/N_o)/L$ in the expression derived by Langmuir (4) and confirmed by Davies (5) and by Chen (6) for the single fiber efficiency:

$$\eta_d = - \ln \frac{N}{N_o} \frac{\pi(1 - \alpha)d_f}{4\alpha L} , \qquad (1)$$

where N_o and N are the upstream and downstream particle concentrations, respectively, α is the volume fraction occupied by the fibers, L is the thickness of mat, and d_f is the fiber diameter, all in consistent units. Fiber efficiencies, evaluated for those experiments conducted at linear velocities of 0.2 to 2.5 cm/sec showed that η_d is proportional to $1/\text{velocity}^x$. This decrease of efficiency with increasing velocity indicates that, in this flow region, diffusion is the primary mechanism of filtration.

Stairmand (7), using the same approach as Langmuir, based on diffusion of particles to the fiber surface in a fluid within a time equal to $\pi d_f/2v$, derived the following expression for the diffusion collection efficiency:

$$\eta_d = \left(\frac{8D}{vd_f}\right)^{1/2} , \qquad (2)$$

where v is the fluid velocity and D is the diffusion coefficient calculated from the Einstein expression (8):

$$D = \frac{CkT}{3\pi\mu d_p} . \qquad (3)$$

Here d_p is the diameter of the particle, C is the Cunningham coefficient, μ is the viscosity of the fluid, and the other symbols have their conventional meanings. The quantitative agreement between Eq. (2) and the experimental velocity dependence is confirmation that diffusion is the primary filtration mechanism under the specific conditions treated.

Particle diameters calculated from the experimental data using Eq. (2) are shown in Table I for experiments at several different velocities. The double sets of figures represent the two groups of particle sizes demonstrated by the separate portions of the curves in the semi-log radioactivity distribution plots discussed above. The use of Eq. (2) emphasizes the smaller size end of the particle spectrum and the results agree well with the lower size end of a particle distribution plot obtained from electron photomicroscopy. In the third column of the table under the heading "radiochemical data" another set of diameters, weighted toward the larger particle sizes, was calculated as follows: Radioassay results from the filter mats, along with specific activity data from the irradiated zinc foil electrodes, were combined to give the total weight of zinc removed by the filters. The number of particles produced was calculated from the volume of air transported and a particle concentration for the aerosol (read from a condensation nuclei counter, Gardner Associates). The concentrations observed are consistent with those which would be expected from the geometry of the experiment, and coagulation theory expounded by Whytlaw-Gray (9). From the weight of aerosol filtered (assuming a density of 1) and the number of particles per experiment, an average diameter was calculated for the particles in each experiment. It should be noted that at 2.5 cm/sec, the particle diameters

Table I. Comparison of Particle Sizes Determined by Different Methods

Gas Velocity (cm/sec)	Calculated Particle Diameter (A^{o})	
	From Diffusion Equation (2)	From Radiochemical Data
0.2	104	180
	168	
0.35	100	160
	180	
0.5	52	135
	98	
0.85	36	105
	70	
1.4	35	80
	105	
2.5*	13	65
	28	

*An aerosol prepared at 2.5 cm/sec, examined by electron microscopy, had a median diameter of 120 A^{o} and a geometric standard deviation of 2.0.

calculated theoretically are low compared with the radiochemical value, because the interceptional process is beginning to contribute to the filtration. The agreement between the three different methods for determining particle size is good.

Similar analyses of the distribution curves are being made for the inertial and interceptional regimes.

REFERENCES

1. W. E. Browning, Jr. and R. D. Ackley, "Characterization of Millimicron Radioactive Aerosols and Their Removal from Gases", Third Conference on Nuclear Reactor Chemistry, USAEC Report TID-7641, pp. 130-147.

2. A. C. Chamberlain, A. E. J. Eggleton, W. J. Megaw, and J. B. Morris, Faraday Society, London, Discussions, 30, 162-69 (1960).

3. W. J. Megaw and F. G. May, Reactor Science and Technology, 16, 427-436 (1962).

4. I. Langmuir, OSRD Report No. 865 (1942)(Washington: Office of Technical Services).

5. C. N. Davies, Proc. Inst. Mech. Engrs. (London) B1, 185 (1952).

6. C. Y. Chen, Chem. Rev. 55, 595 (1955).

7. C. J. Stairmand, Trans. Inst'n. Chem. Engrs. (London) 28, 130 (1950).

8. A. Einstein, Ann. Physik. 17, 549 (1905); 19, 37 (1906).

9. R. Whytlaw-Gray, J. Chem. Soc. 273 (1935).

Session Chairman: The last paper to be presented during Session III is by L. A. Haack of ORNL and is entitled "Analysis of a Possible Influence of Particle Size on Iodine Removal Efficiency of a Charcoal Filter."

ANALYSIS OF A POSSIBLE INFLUENCE OF PARTICLE SIZE ON THE IODINE REMOVAL EFFICIENCY OF A CHARCOAL FILTER

L. A. Haack

INTRODUCTION

The purpose of this paper is to show that to describe properly the efficiency of a filter in removing contaminants, especially iodine-131, from an air stream not only must the amount of impurities be specified (such as the number of curies or grams of iodine-131 per unit volume or parts per million) but also that the size distribution of particles in the air stream must be specified. Only in this way can the efficiency of a single charcoal filter, or of a system composed of a series of filters of various types, be properly described. The size distribution of particles is important since these particles might have iodine-131 associated with them.(a)

It is recognized that statements of this general type have been made previously by others. For example, Linderoth, Hilliard, and Healy stated:

> "...an investigation of particle emission should be made. This would include the determination of the types of fission products associated with the particles, the activity exhibited, and the size distribution of the aerosol."(1)

Dennis, et al.,(2) and Browning and Ackley(3) have made similar statements.

The importance of these statements is emphasized by the main feature of this paper; namely, a calculation in which it is shown that the efficiency of an assumed model of the filtering process compared quite closely with the efficiency which had been measured for an actual filter system. Based on the success of this agreement, the efficiencies of filters of two other situations were calculated:

1. Assuming that the air contained 10% of the total amount of iodine-131 associated with particles less than 0.3-micron diameter. (Absolute filters do not remove particles less than 0.3 micron with high efficiency.)

2. Injecting elemental iodine into the air upstream from a filter.

It is further suggested that it is quite easy for an exhaust stream to contain a significant percentage of particles smaller than 0.3 micron; namely, that such particles are produced by man and normally exist in the atmosphere. This fact,

(a) By "associated" it is meant that the iodine-131 is adsorbed or absorbed by a particle, or that the iodine-131 has formed a compound with one or more other elements, or a combination of the preceding. For the purpose of this paper it is not important to distinguish which is the case; rather, it is only important that a certain percentage of the total iodine-131 activity behaves in the filtering process as though it were particulate in the size range from about 0.001 to 0.3 microns.

as pointed out by Dennis, et al,[4] could greatly complicate and confuse the laboratory work of very accurately measuring the efficiency of filters since the amount of such particles varies widely from locality to locality and even varies with time at a given locality.

This paper is largely heuristic in nature, and therefore certain assumptions are made without attempting to justify them.

CALCULATIONS AND COMPARISONS

One of the main concerns in the operation of a nuclear reactor is that in case of an accident the materials which are released by the accident not cause a hazard to personnel or great damage to property. Specifically, the main concern in many reactors is the biological effect of the radioiodines, especially iodine-131.

A common method of limiting the potential biological hazard is to exhaust the air and its contaminants from the reactor building, pass it through a set of filters, and discharge it to the atmosphere from a high stack.

The key link in such a scheme is the filter system through which the air passes and which, ideally, removes the hazardous materials. This process must be very efficient for most reactors since as little as about 0.01% of the iodine-131 inventory contained within the fuel elements of some reactors, if released directly to the atmosphere, would exceed the present maximum permissible concentration.

Since the air exhausted is likely to contain particles having a wide range of sizes, the filter system usually consists of different types of filters--normally roughing filters, absolute filters, and charcoal filters.

Roughing filters usually consist of a fibrous material and can usually remove all particles larger than ~100-microns diameter. Absolute filters usually consist of asbestos-impregnated paper and can remove 99% of the particles of greater than 0.3-micron diameter. Charcoal filters usually consist of 6-14 mesh charcoal particles and can usually remove more than 99.99% of the elemental iodine. Figure 1 summarizes these commonly accepted filter efficiencies.

Apparently there is a particle size range for which no type of filter is completely effective. The range is that below the absolute filter (0.3 microns) and above the charcoal filter (elemental iodine). At first glance, this gap might appear to be relatively unimportant since this range is such a very small percentage of the total. As previously stated, though, it is the main point of this paper to show that this range may be a very critical one that influences considerably the over-all efficiency of a reactor air-handling filter system. As can be seen from Figure 2,[5] several processes produce particles in this size range; for example, smoke from various sources and chemical mists.

Model Used in Calculations and Comparison with Actual Filter Efficiency Measurements

The model used in the calculations is quite simple. Essentially it assumes the following:

1. The air stream passing through the filter is composed of two components:

    a. Iodine in elemental form, and

    b. Iodine associated with particles less than 0.3 microns in diameter.

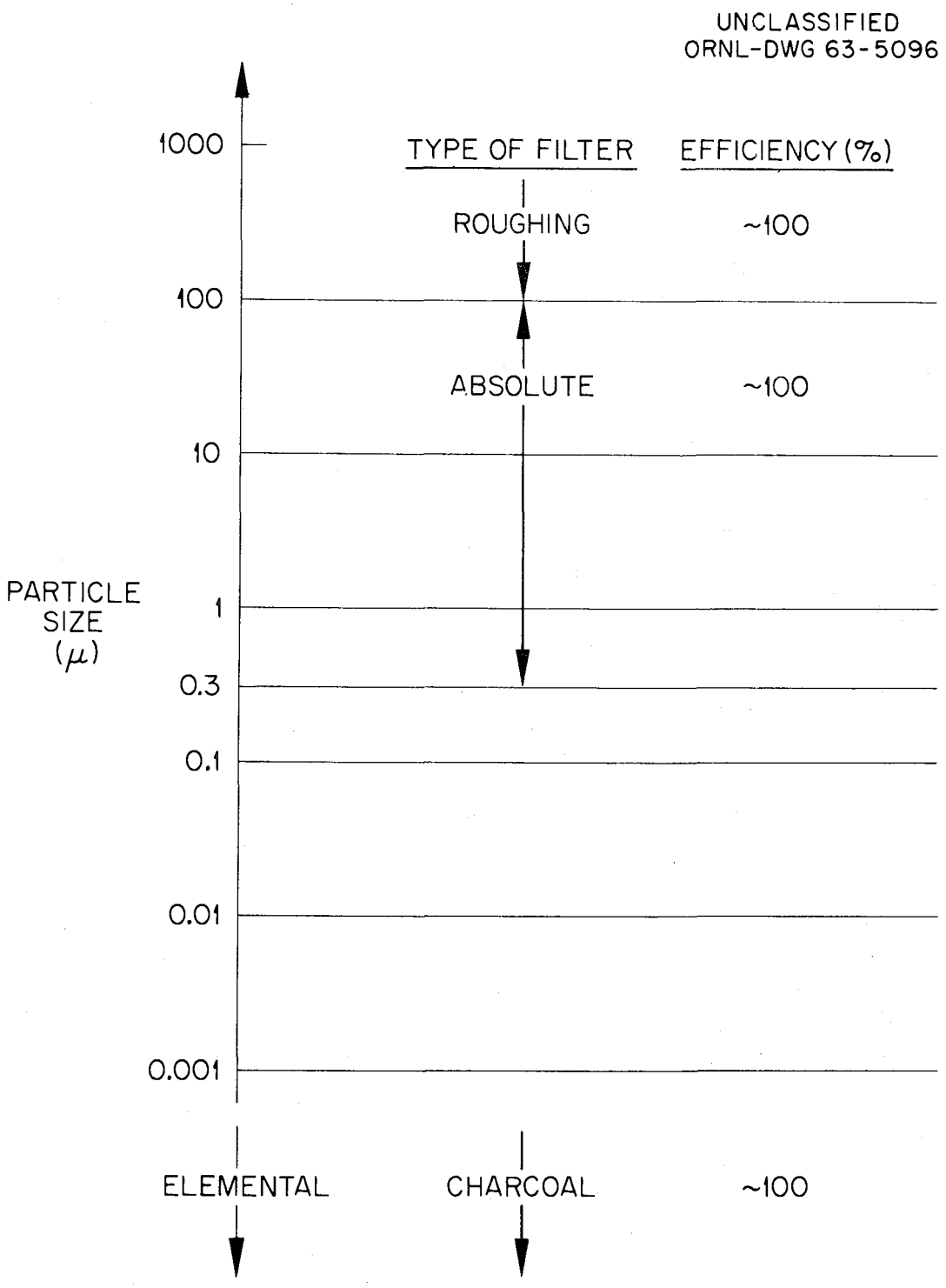
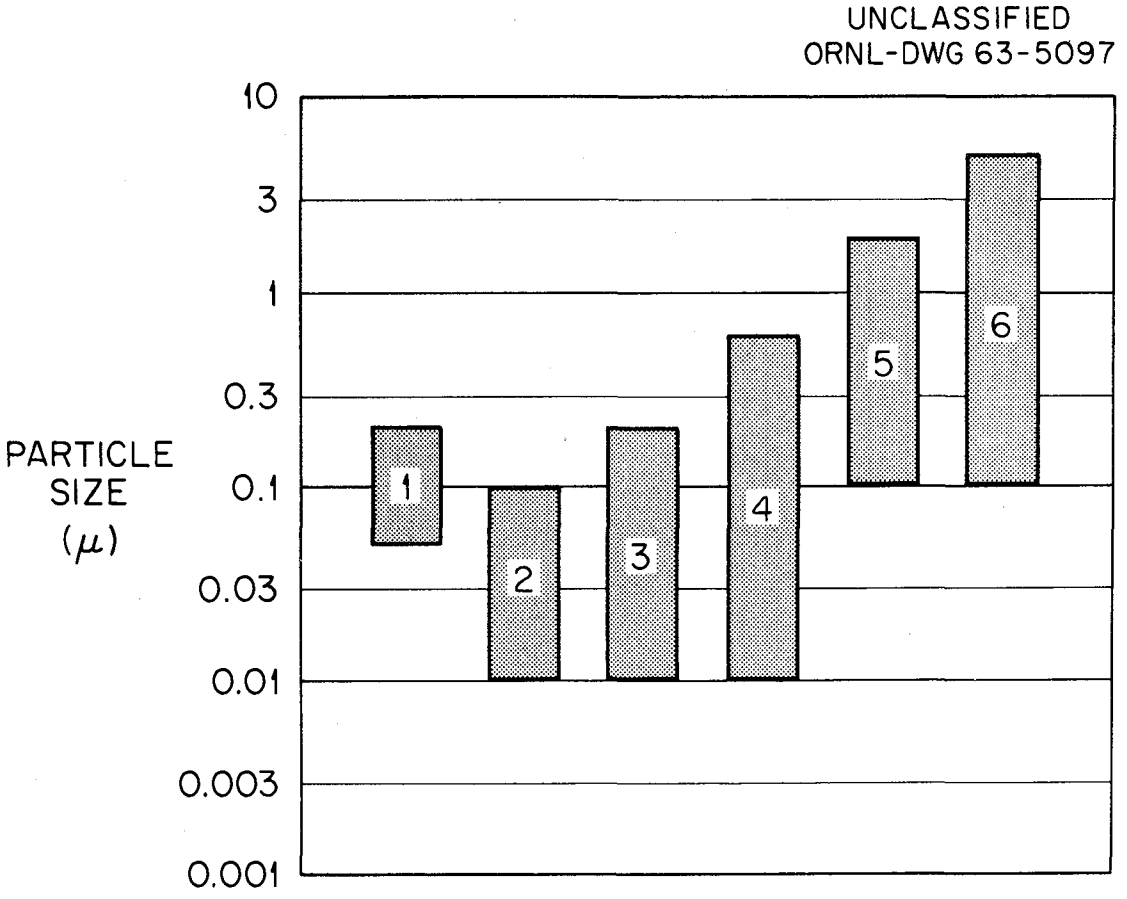


Fig. 1. Efficiency of Various Types of Filters for Range of Particle Sizes.



1. EXHAUST FROM AUTOMOBILE ENGINE (REF 11)
2. EXHAUST FROM BESSEMER CONVERTER (REF 10)
3. TOBACCO SMOKE (REF 5)
4. MAGNESIUM OXIDE SMOKE (REF 5)
5. AMMONIUM CHLORIDE FUMES (REF 5)
6. ALKALI FUMES (REF 5)

Fig. 2. Sizes of Selected Types of Particles.

2. Each of these two components is removed with a distinctive efficiency (it might be called a "partial efficiency" or "component efficiency"). In the case of elemental iodine the efficiency is 99.9%, for iodine associated with particles something much less.(b)

3. The distinctive efficiency of each component remains unchanged for subsequent filters of the same type in series.

The air stream could be separated into more than two components, each of which could be filtered with a particular efficiency. However, it is believed that this is a refinement that is not justified on the basis of present experimental data.

As was pointed out by Browning and Ackley,(6) the ability of a charcoal filter to remove particles smaller than 100 Å is considerably less than its ability to remove elemental radioiodine. For example, they reported efficiencies for a 3/4-in.-thick charcoal bed of 75% for 60 Å particles.

Based on these reported values it is interesting to calculate the combined and individual efficiencies of three charcoal filters in series for an air stream that contains, for example, radioiodine, 99.95% of which is elemental radioiodine and ~0.05% of which is associated with particles smaller than 0.3 micron. To arbitrarily choose workable numbers for the calculation, suppose that the exhaust stream has 10,000,000 arbitrarily-sized activity units of elemental iodine and 5,000 units associated with particles smaller than 0.3 micron. Further, suppose that the charcoal filter removes elemental iodine with an efficiency of 99.9% and the particles with an efficiency of 10%.

By using these efficiencies, we find that 10,000 units of elemental activity and 4,500 units of particulate activity penetrate the first charcoal filter (Figure 3a). The efficiency of this filter in removing radioiodine from the stream, regardless of its form, is

$$\text{Efficiency} = 1 - \frac{10{,}000 + 4{,}500}{10{,}000{,}000 + 5{,}000} = 99.9\%.$$

If these same efficiencies are assumed for the two iodine-131 components for the second filter, 10 activity units of elemental iodine and 4,050 activity units of particulate will penetrate (Figure 3b). The efficiency of this second filter is then calculated to be

$$1 - \frac{10 + 4{,}050}{10{,}000 + 4{,}500} = 72.0\%.$$

If this stream now passes through a third charcoal filter with the same efficiencies, 0.01 activity units of elemental iodine and 3,645 activity units of particulate will penetrate (Figure 3c). The efficiency of this third filter is

$$1 - \frac{0.01 + 3{,}645}{10 + 4{,}050} = 10.1\%.$$

These calculated efficiencies are compared in Table I with those reported by Browning and Adams.(7)

(b) The thickness of the charcoal and nominal velocity of the air stream passing through it need not be rigorously specified for the calculations, since the general method will be applicable to a wide range of thicknesses and velocities. A 3/4-in. thickness of charcoal and velocity of 25 fpm are reasonably typical to use for the efficiencies in the calculations.

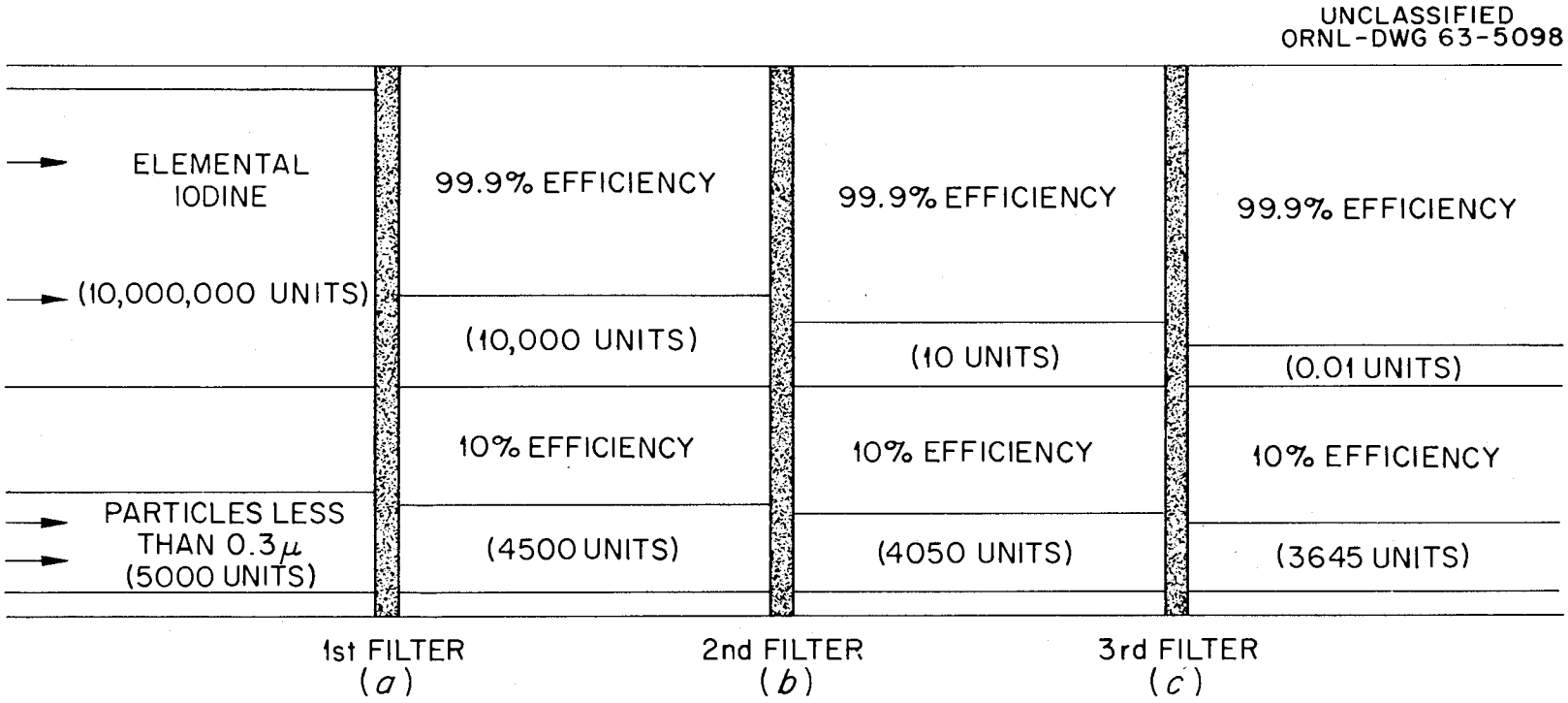


Fig. 3. Calculated Efficiencies of Three Charcoal Filters in Series for Approximately 0.05 Percent of the Total Amount of Iodine Associated with Particles Less than 0.3 Micron Dia.

Table I. Comparison of Calculated Filter Efficiencies with Measured Efficiencies

	Browning-Adams	This Paper
1st filter	99.99%	99.9%
2nd filter	74.6%	72.0%
3rd filter	14.5%	10.1%

The comparison between the two is striking!

The calculated combined efficiency of the three filters then is

$$1 - \frac{0.01 + 3{,}645}{10{,}000{,}000 + 5{,}000} = 1 - 3.64 \times 10^{-4} = 99.96\%.$$

Moreover, if the relative amount of iodine associated with particles is greatly changed, the efficiency of each individual filter and of the filter combination is changed greatly, too. This is shown in the next section.

Admittedly, the model used in the preceding calculation is quite crude, and the quantities of activity and efficiencies which were assumed are quite arbitrary and fortuitous. Nevertheless, the general idea is demonstrated adequately.

Calculated Filter Efficiency for Air Stream Containing Approximately 10 Percent of Total Iodine-131 Activity Associated with Particles Less Than 0.3-Micron Diameter

Since the efficiencies calculated by the proposed model compared favorably with experimental data, it would seem of interest to use the model for other situations. One interesting situation is that of an air stream which has a fairly high percentage of activity associated with particulate in the range 0.001 to 0.3 microns.

For example, suppose that the exhaust stream has 10,000,000 arbitrarily-sized activity units of elemental iodine and 1,000,000 units associated with particles smaller than 0.3 micron. (The actual percentage of activity associated with the particles is 9.1% of the total activity. The 10,000,000 and 1,000,000 were chosen for convenience.)

For the first charcoal filter, 10,000 activity units of elemental iodine and 900,000 units of particulate iodine penetrate (Figure 4a). The efficiency is

$$1 - \frac{10{,}000 + 900{,}000}{10{,}000{,}000 + 1{,}000{,}000} = 91.7\%.$$

For the second filter the efficiency is (Figure 4b)

$$1 - \frac{10 + 810{,}000}{10{,}000 + 900{,}000} = 11.0\%.$$

For the third filter the efficiency is (Figure 4c)

$$1 - \frac{0.01 + 729{,}000}{10 + 810{,}000} = 10.0\%.$$

The over-all efficiency for the three filters in series is

$$1 - \frac{0.01 + 729{,}000}{10{,}000{,}000 + 1{,}000{,}000} = 93.4\%.$$

This over-all efficiency would probably not be acceptable for many installations.

Based on the preceding calculations an important conclusion can be drawn; namely, if a fairly large percentage of iodine activity is associated with particles, or behaves as particles, in the range 0.001 to 0.3 microns, the efficiency of a charcoal filter may not be acceptable.

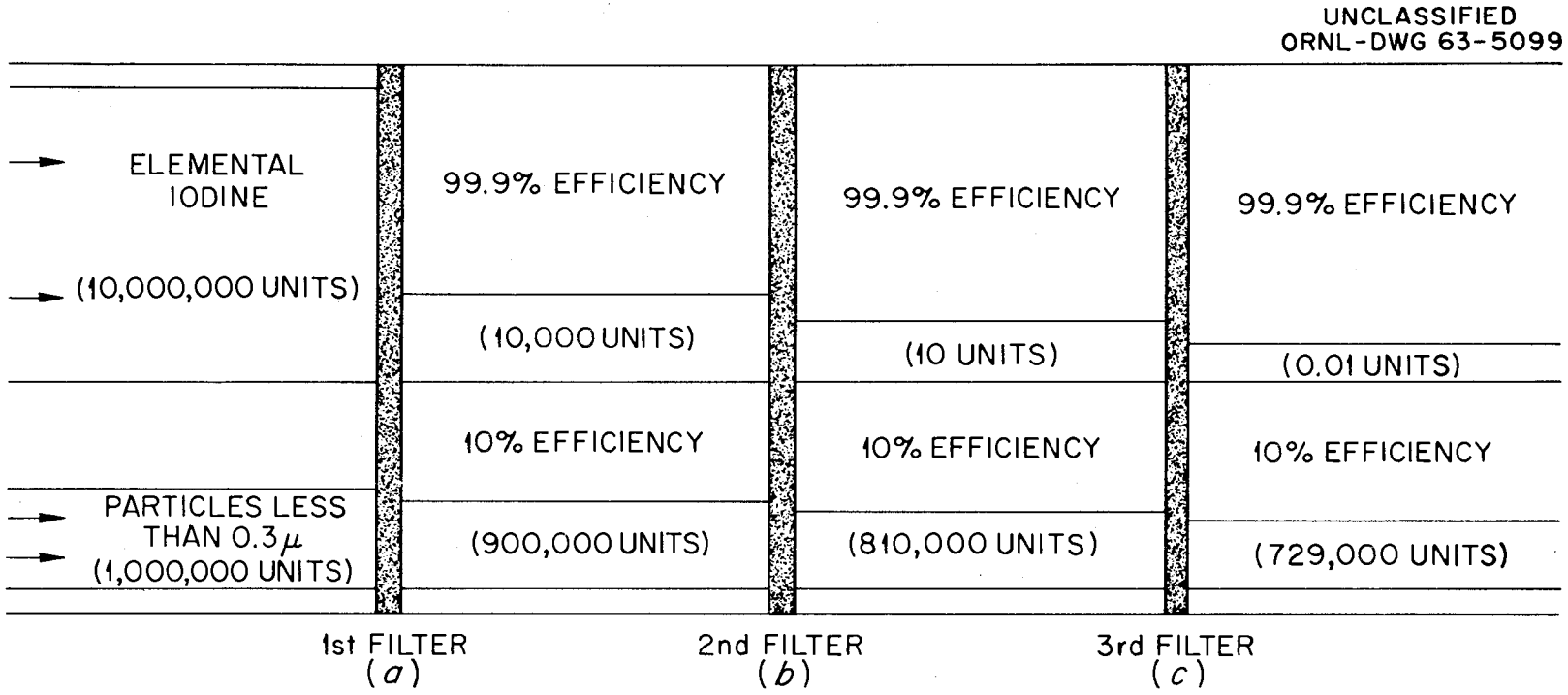


Fig. 4. Calculated Efficiencies of Three Charcoal Filters in Series for Approximately 10 Percent of the Total Amount of Iodine Associated with Particles Less than 0.3 Micron Dia.

It is natural to speculate on conditions when an air stream, especially in a full-sized plant, contains iodine-131 activity a large fraction of which is associated with particles in the size range 0.001 to 0.3 microns. Several conditions which could lead to this situation are:

1. Certain types of fuel elements when melted under certain conditions produce particles in this size range.

2. The atmosphere contains, at all times, particles in this size range.

3. Fuel-reprocessing plants and isotope-recovery plants in their normal operation produce chemical mists in this size range.

Regarding the first condition, particles in this size range have been observed to be produced by the melting of some types of fuel elements. For example, Parker[8] measured the size distribution of particles produced when UO_2 was melted in several different atmospheres. He found that in air 3% of the particles produced were less than 0.0250 microns, in helium 15% were less than 0.007 microns, and in carbon dioxide 30% were less than 0.040 microns. (This is not to imply, however, that all types of fuel elements or conditions causing melting are likely to produce particles of these sizes.)

It can be postulated that a certain fraction of iodine-131 released in elemental form somehow becomes associated with these particles. (We leave unsettled the question of what percentage of the original amount of iodine-131 in the fuel element was released upon melting.) These particles will not be removed by any of the three types of filters with a high efficiency.

If the total amount of iodine-131 activity associated with these particles is quite small, say 0.05%, the situation may not be serious. On the other hand, if the amount associated with the particles is higher, say 10%, the situation could indeed become serious.

Regarding the role of naturally occurring particles in the atmosphere, it has been found that the atmosphere contains at all times particles in a wide range of size and of chemical form. As shown in Table II,[9] the amounts and types of particles depend very much upon locality.

Table II. Occurrence of Particles in the Atmosphere for Various Localities During 1957 to 1958

Locality	Maximum Quantity of Suspended Particulate Observed ($\mu g/m^3$)	Maximum Quantity of Benzene Soluble Organic Matter Observed ($\mu g/m^3$)
Akron, Ohio	431	40.0
Gary, Indiana	945	46.8
Knoxville, Tennessee	245	33.7
Minneapolis, Minnesota	722	18.1
Los Angeles, California	361	56.1
Baldwin County, Alabama	49	7.6
Butte County, Idaho	56	3.8

Unfortunately, the sizes of the particles were not listed; however, we can gain knowledge on the probable sizes of many of these from other sources. For example, the size of many particles emitted from a Bessemer converter has been found to

be in the range from 0.01 to 0.1 micron.[10] Also, particles exhausted from automobile engines have been found to be in the range from 0.05 to 0.1 micron.[11]

These numbers are not meant to imply that the quantities quoted in Table II consist entirely of particles from steel mills or automobile engines; they are meant to imply, however, that some of the particulate matter most likely consists of particles in this size range.

The air which is drawn through the reactor containment system will contain these particles even if the inlet air to the reactor building is filtered with roughing and absolute filters which, for practical reasons, is usually not the case anyway.

Thus any elemental iodine released to the containment system may readily become associated with some of these particles. Therefore, even though a particular type of fuel element, upon melting, may not produce small particles there is still the distinct possibility that iodine-131 will become associated with difficult-to-remove particles and thus be transported through the filter system to the atmosphere. The seriousness of such a situation depends, in part, upon the quantity and type of contaminants existing in the atmosphere.

Contaminants in the atmosphere have been suggested[12] as contributing to the difference in efficiencies measured by various workers for the same type of filter under apparently the same test conditions.

Furthermore, even if an extremely pure atmosphere is used in laboratory tests the fact remains that the ultimate users of filter systems (namely, reactors, isotope-recovery plants, and fuel-reprocessing plants), for practical reasons, may be unable to use anything except the unfiltered, or only slightly filtered, natural atmosphere. For example, the ventilation system at the Oak Ridge Research Reactor is designed to exhaust about 6,000 cfm of air during an emergency. To achieve this flowrate an equivalent quantity of air must also enter the building. The major portion of the air enters through two intake ducts which contain roughing filters; a smaller portion enters through various leaks, such as around the doors, and is not filtered.

It is also suggested that there are factors that can cause concentrations higher than the maximums quoted in Table II. The exhaust from a specific source of the particles, a diesel-generator unit, for example, causes higher concentrations in its immediate area. If such a unit were used as the emergency power source for a reactor and if the exhaust of the unit were discharged near the intake of a reactor containment system, then even more particles than normal would be available. It is likely that some of the iodine-131 would become associated with these particles.

The third situation, where more than the normal amount of particles less than 0.3-micron diameter are likely, is in a fuel-reprocessing plant or in an isotope-recovery plant (in the latter case, especially, recovery of iodine-131). Of course, if the fuel at a fuel-reprocessing plant had decayed for a sufficiently long time, the iodine-131 presents no problem. However, in the case of the isotope-recovery plant, there is a problem since iodine-131 is often an important product. During portions of the recovery process at the ORNL Iodine-131 Processing Facility, certain chemicals are used. Among these are NaOH, HNO_3, and H_2SO_4.[13] It is likely that in this process chemical mists containing particles of less than 0.3-micron diameter are produced, as can be seen by referring to Figure 2.

Such particle production could be a major contributor to the lower-than-expected efficiencies of charcoal filters in the iodine-131 isotope-recovery plants.[13] Specifically, it is likely that more than 0.05% of the total iodine-131 activity is somehow associated with particles of less than 0.3-micron diameter.

Effect of Adding Elemental Iodine to an Air Stream In an Effort to Increase Filter Efficiency

The efficiency of a charcoal filter is often low when the iodine concentration in the air stream is low. Since the low efficiency is suggested to be caused somehow by the low iodine concentration, it seems reasonable to attempt to increase the efficiency of a filter by adding more iodine to the air stream.

However, it is believed by the author that iodine concentration per se cannot completely account for the low efficiency. The proposed model of the filter can be used to show that injecting iodine in elemental form upstream from a filter does not improve the efficiency of the filter. Figure 5, an extension of Figure 3c, shows this situation.

Assume that the iodine is injected between the third and fourth filters as elemental iodine only and that there is no increase in the amount of activity associated with the particles. The efficiency of the fourth filter is then (Figure 5)

$$1 - \frac{1{,}000 + 3{,}280}{1{,}000{,}000 + 3{,}645} = 99.6\%.$$

This is a tremendous increase over the 10.1% efficiency of the third filter. However, we have merely succeeded in releasing more iodine from the system, as tabulated below:

Leaving third filter; $0.01 + 3{,}645 = 3{,}645$ units.

Leaving fourth filter; $1{,}000 + 3{,}280 = 4{,}280$ units.

Granted, we need not have injected as much as 1,000,000 elemental units nor need it have been radioiodine. However, the calculation does show that simply injecting elemental iodine to increase the concentration of iodine-131 in the air stream probably produces no increase in the efficiency of the filter. This calculation further illustrates the main purpose of this paper; namely, that the form of the iodine must also be specified.

Of course, if the injected elemental iodine did somehow cause the iodine associated with the particulate to escape and become elemental iodine or did cause the particulate to agglomerate to particles larger than 0.3 micron, the efficiency of the fourth filter would be improved.

CONCLUDING COMMENTS

This paper is not, and was not intended to be, a complete and extensive review of the problems in achieving high efficiencies with filters in removing contaminants, especially iodine-131, from an air stream. Its only purpose is to focus attention on the role that particles in the size range from about 0.001 to 0.3 microns apparently play in the efficiency of filter systems, particularly in full-size operating plants.

It naturally follows, then, that the usual method of expressing the concentration of iodine-131 in an air stream (namely, mg/ft^3) is not sufficient if one is to take these smaller particles into account properly. Rather, as has been suggested by others, it is necessary that information on the particle-size distribution and the amount of iodine-131 activity apparently associated with them should also be given when describing the efficiency of filters.

Further, this paper neglects the effect of deposition of iodine-131 on the walls of a duct. The main reason for doing so is that the percentage of iodine which deposits on the walls of the duct is probably not significant in comparison to

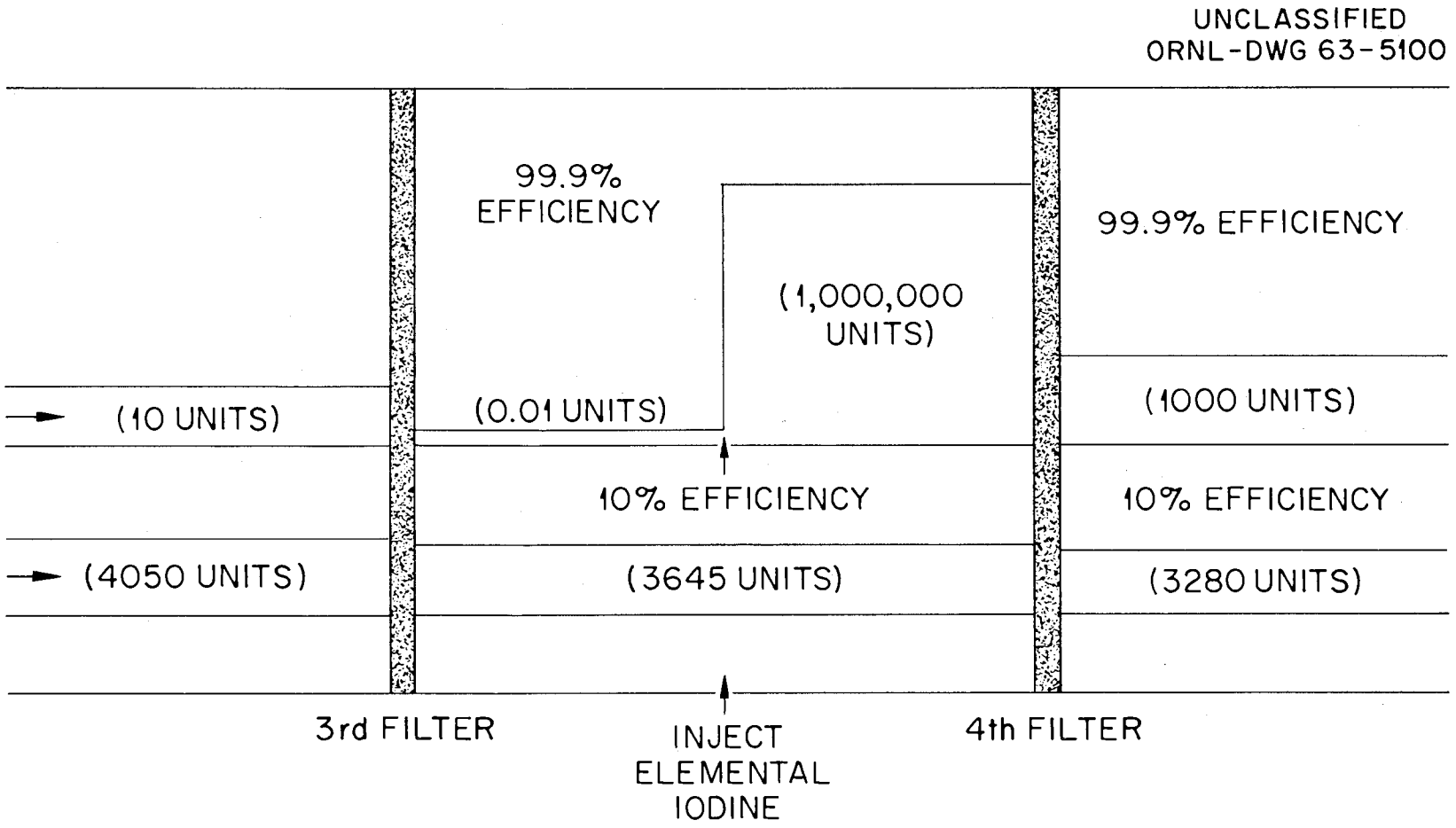


Fig. 5. Calculated Efficiency of a Charcoal Filter when Elemental Iodine is Injected into the Air Stream Ahead of the Filter (Extension of Fig. 3).

REFERENCES

1. Linderoth, C. E., Hilliard, R. K., and Healy, J. W.: Fission Product Release Studies--Status and Need, HW-59961, p 11 (April 10, 1959).

2. Dennis, R., Silverman, L., and Stein, F.: Iodine Collection Studies--A Review, Proceedings of the Seventh AEC Air Cleaning Conference held at Brookhaven National Laboratory, October 10-12, 1961, TID-7627, p 327, Division of Technical Information, Washington, D. C.

3. Browning, W. E., Jr., and Ackley, R. E.: Characterization of Millimicron Radioactive Aerosols and Their Removal from Gases, Presented at the Third Conference on Nuclear Reactor Chemistry held at Gatlinburg, Tennessee, October 9-11, 1962, TID-7641, p 130, Division of Technical Information, Washington, D. C.

4. Dennis, R., Silverman, L., and Stein, F.: Iodine Collection Studies--A Review, Proceedings of the Seventh AEC Air Cleaning Conference held at Brookhaven National Laboratory, October 10-12, 1961, TID-7627, p 347, Division of Technical Information, Washington, D. C.

5. Faith, W. L.: Air Pollution Control, pp 91 and 202, John Wiley and Sons, Inc., 1959.

6. Browning, W. E., Jr., and Ackley, R. E.: Characterization of Millimicron Radioactive Aerosols and Their Removal from Gases, Presented at the Third Conference on Nuclear Reactor Chemistry held at Gatlinburg, Tennessee, October 9-11, 1962, TID-7641, p 132, Division of Technical Information, Washington, D. C.

7. Adams, R. E., and Browning, W. E., Jr.: Removal of Radioiodine from Air Streams by Activated Charcoal, ORNL-2872 (March 17, 1960).

8. Parker, G. W., Creek, G. E., and Martin, W. J.: Fuel Element Decomposition Products, Proceedings of the Seventh AEC Air Cleaning Conference held at Brookhaven National Laboratory, October 10-12, 1961, TID-7627, p 282, Division of Technical Information, Washington, D. C.

9. Air Pollution Manual Part 1, Evaluation, p 20, American Industrial Hygiene Association, Detroit, 1960.

10. Orban, A. R., Hummell, J. D., and Cocks, G. G.: Research on Control of Emissions from Bessemer Converters, p 52-4, Proceedings of the Air Pollution Control Association, May, 1960.

11. McKee, H. C., and McMahon, W. A., Jr.: Automobile Exhaust Particulates--Source and Variation, p 20-7, Proceedings of the Air Pollution Control Association, May, 1960.

12. Dennis, R., Silverman, L., and Stein, F.: Iodine Collection Studies--A Review, Proceedings of the Seventh AEC Air Cleaning Conference heald at Brookhaven National Laboratory, October 10-12, 1961, TID-7627, p 347, Division of Technical Information, Washington, D. C.

13. Cox, W. C., Oak Ridge National Laboratory, Personal Communication.

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 RW 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

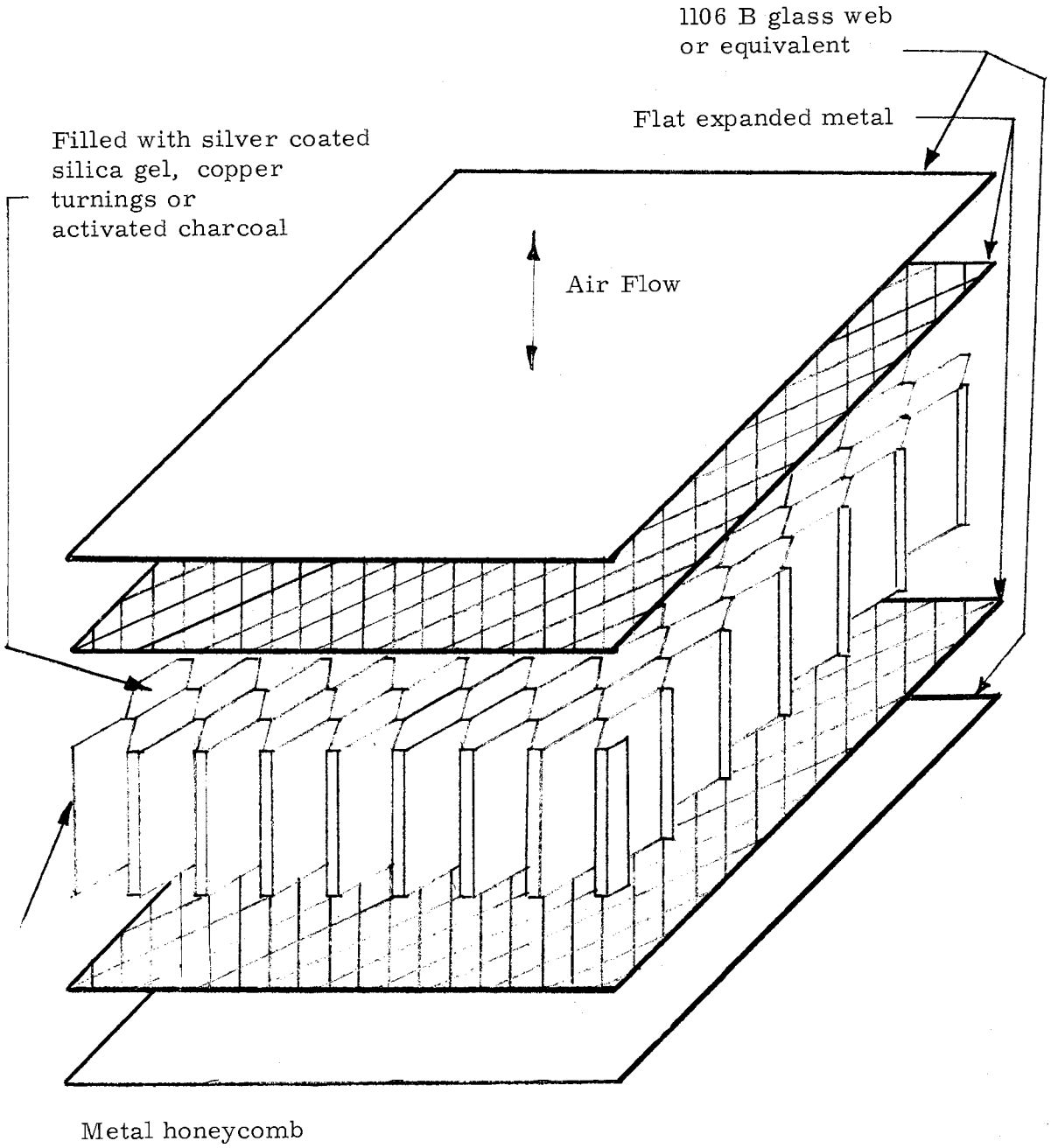

1106 B glass web
or equivalent
Flat expanded metal
Filled with silver coated
silica gel, copper
turnings or
activated charcoal
Air Flow
Metal honeycomb

FIGURE 1

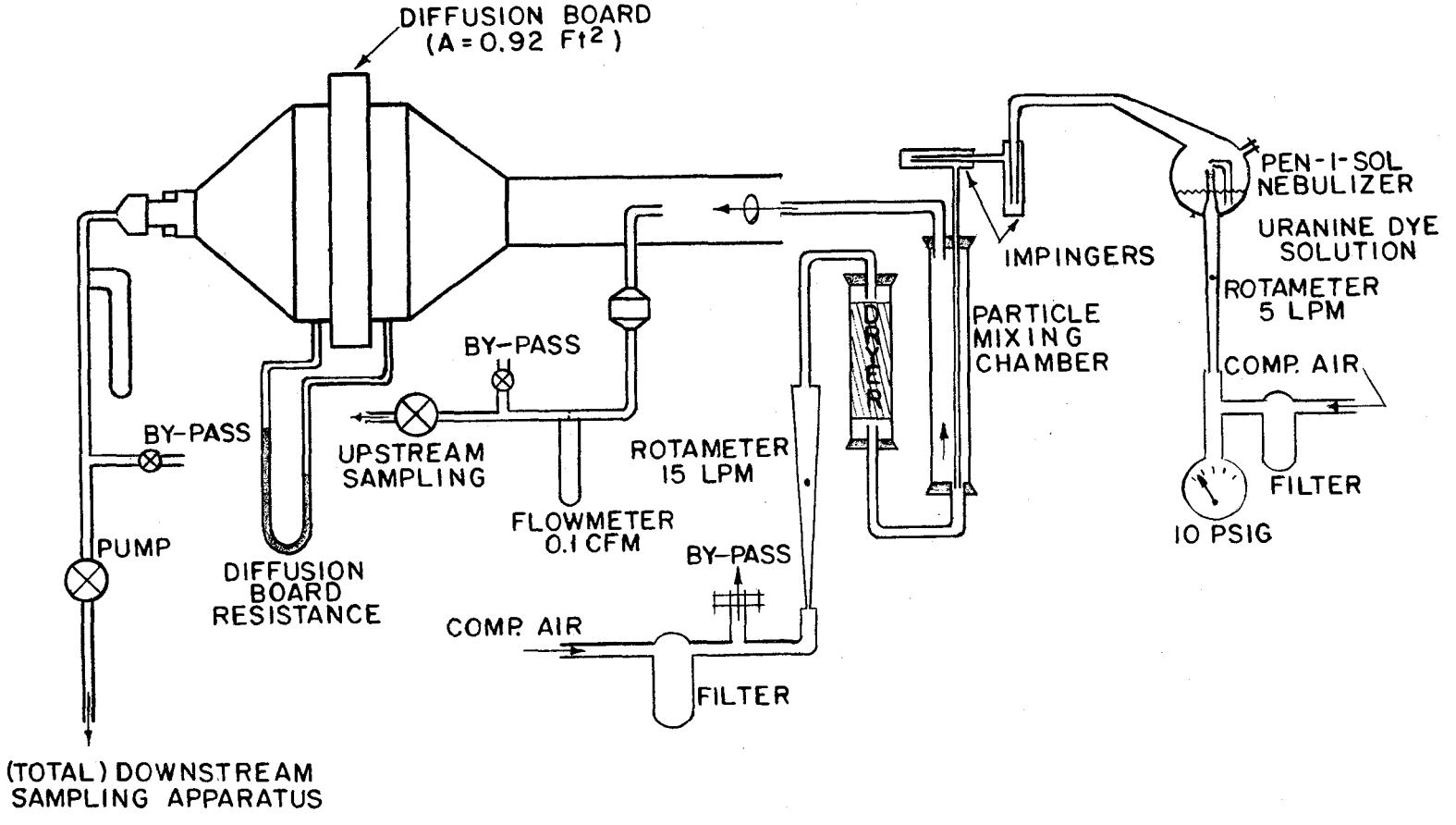


FIGURE 2. SCHEMATIC OF DIFFUSION BOARD TEST APPARATUS WITH URANINE GENERATOR.

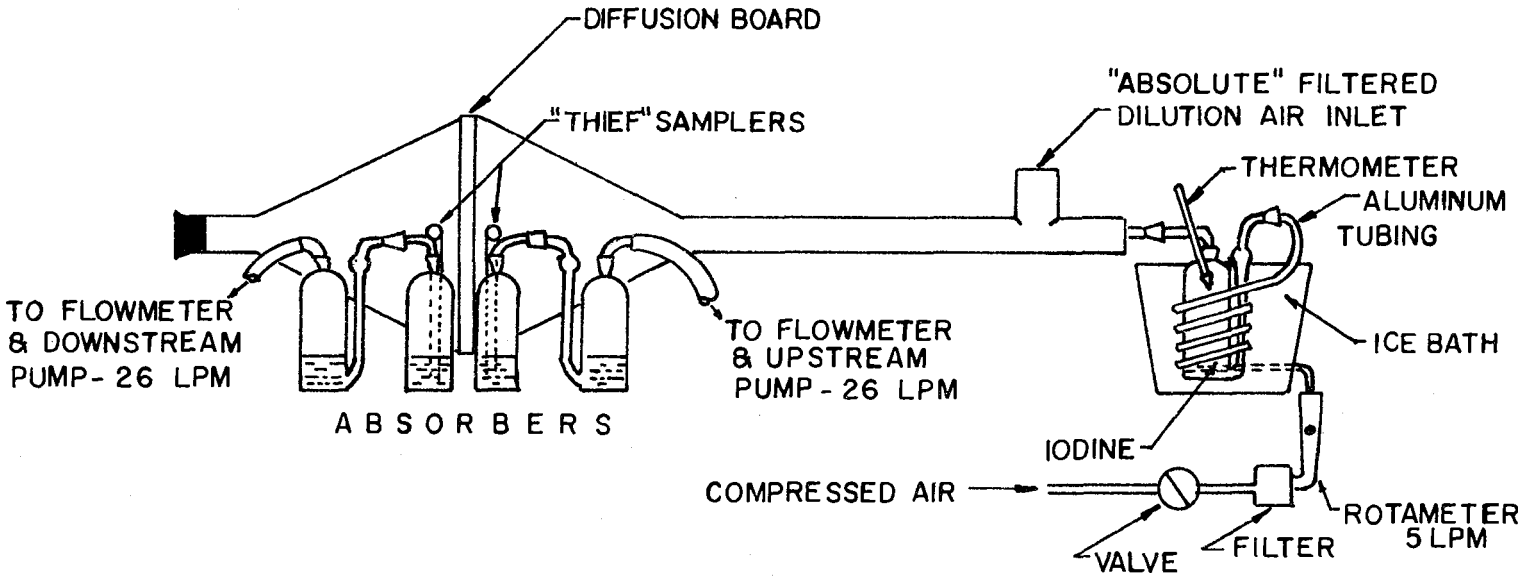


FIGURE 3. SCHEMATIC REPRESENTATION OF DIFFUSION BOARD TEST APPARATUS FOR IODINE COLLECTION EFFICIENCY STUDIES

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.

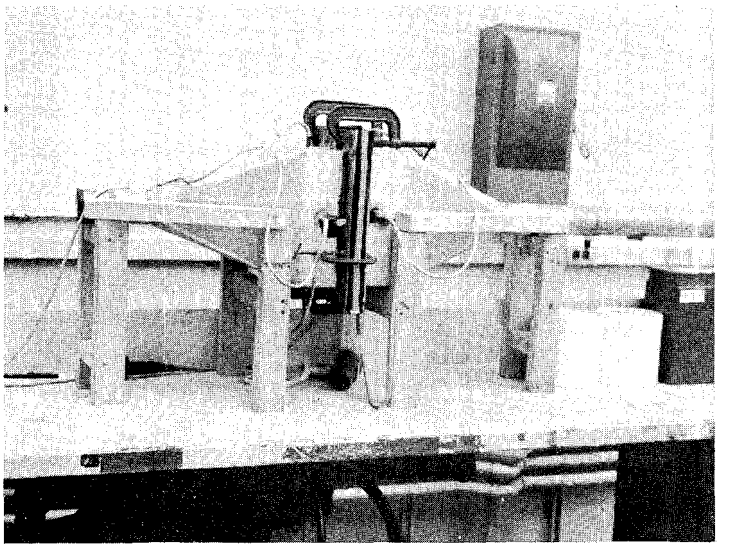
These boards were evaluated at velocities below 1 fpm up to the absolute filter range of 5 fpm.

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.

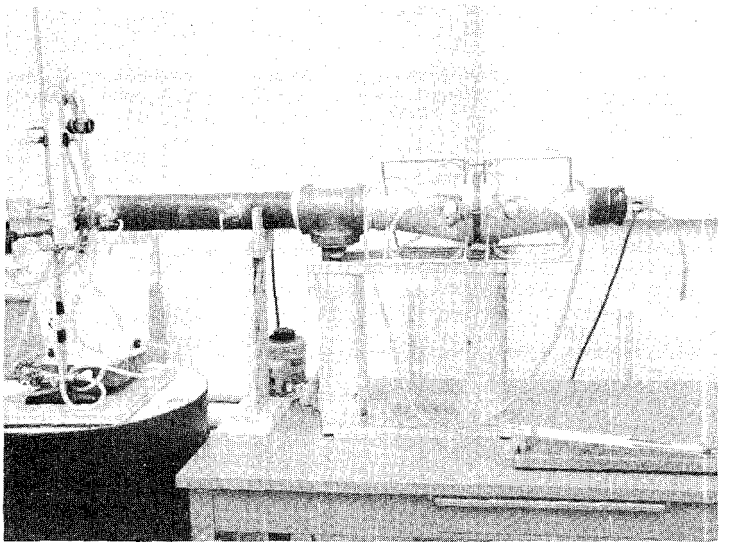
Table 4 shows the results of iodine removal for a board treated with ethyl silicate. Its elemental iodine removal was measured at one foot a minute. You will note the resistance has increased $2\frac{1}{2}$ times, due to the treatment. A gel probably formed at the surface of the fibers which caused a 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

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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 containing 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[2] (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.

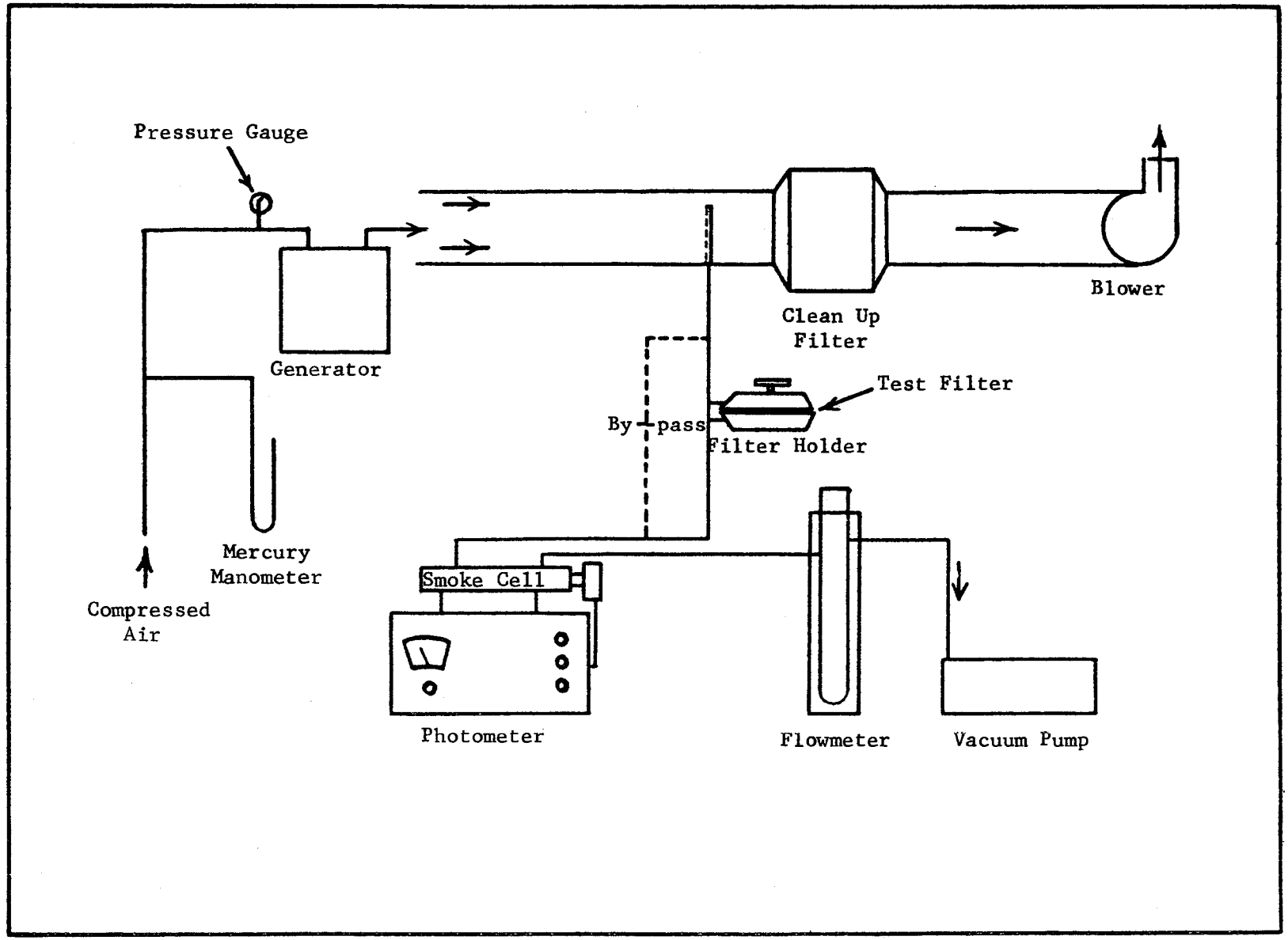


Figure 1. Filter Test Arrangement

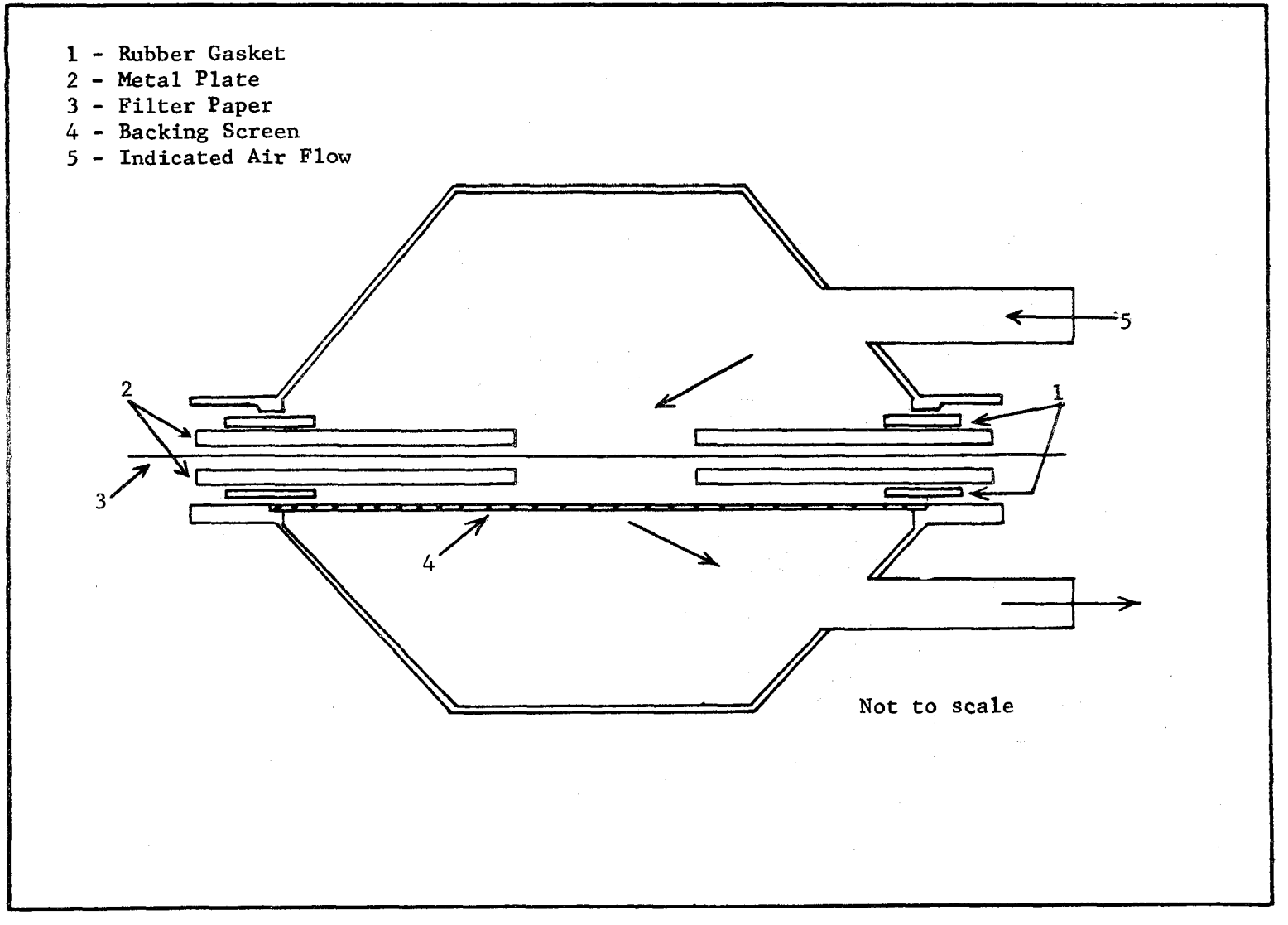


Figure 2. Filter Holder

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

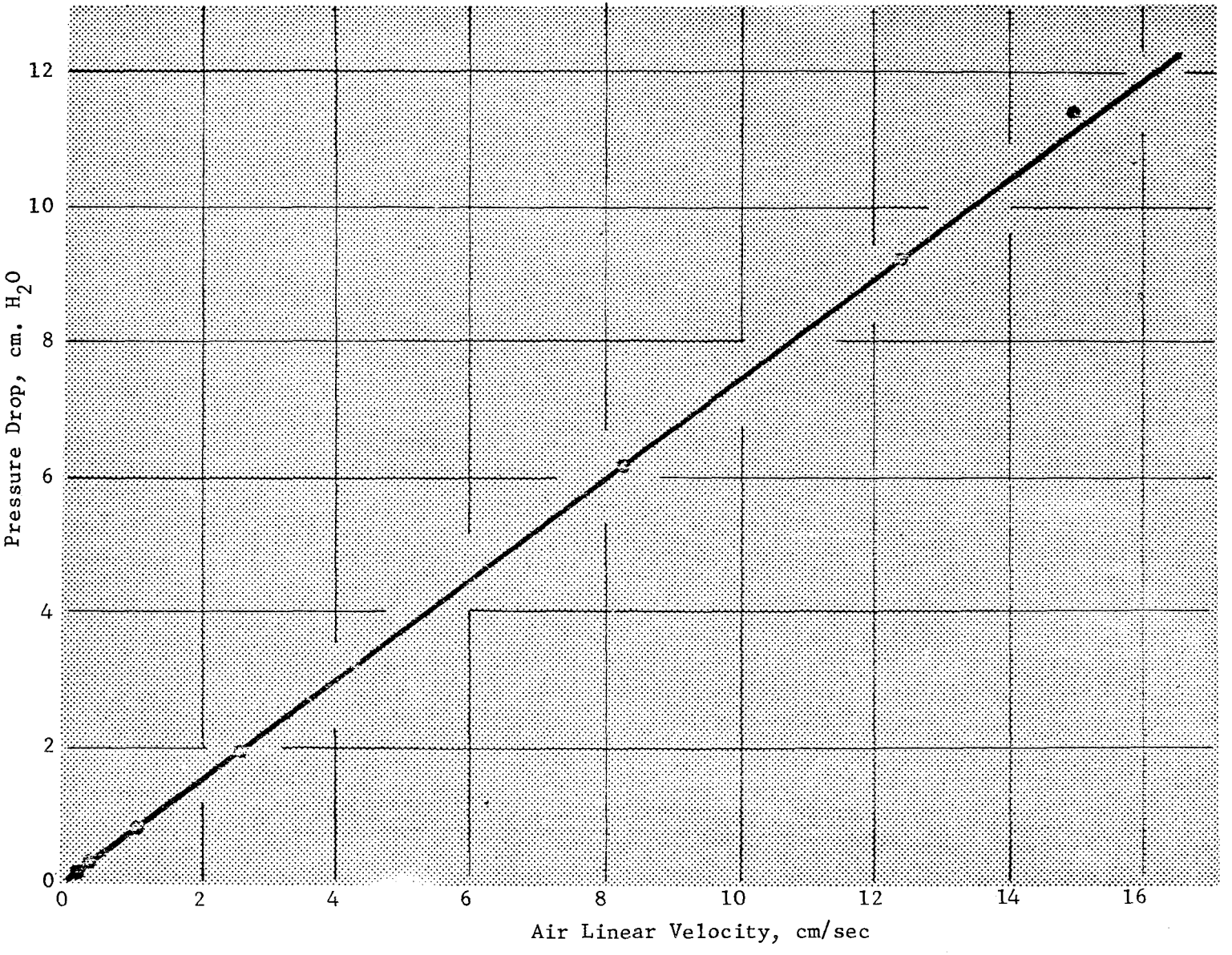


Figure 3. Pressure Drop of 9 mil HV-70 Paper

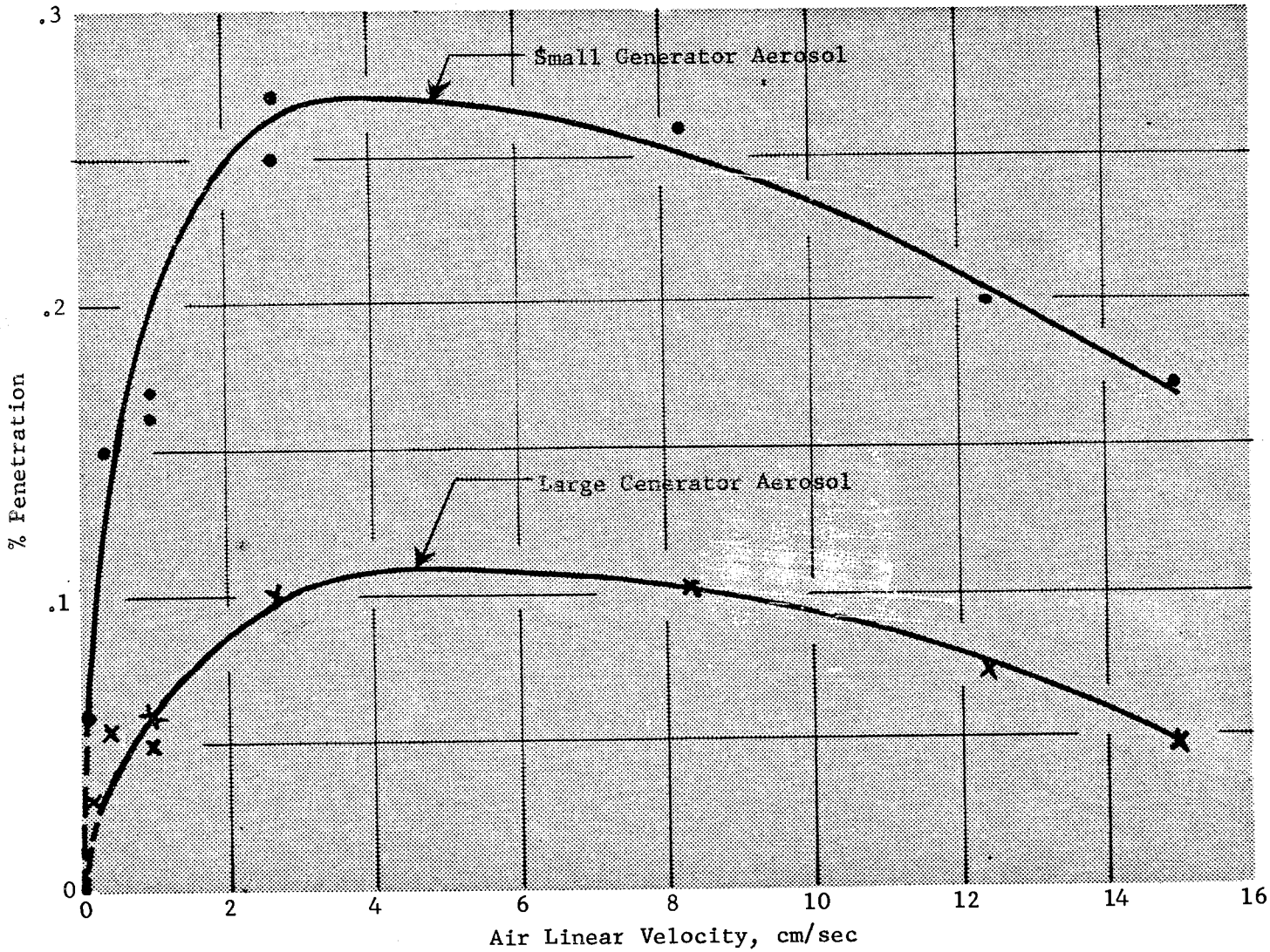


Figure 4. Aerosol Penetration Through Intact 9 mil HV-70 Paper

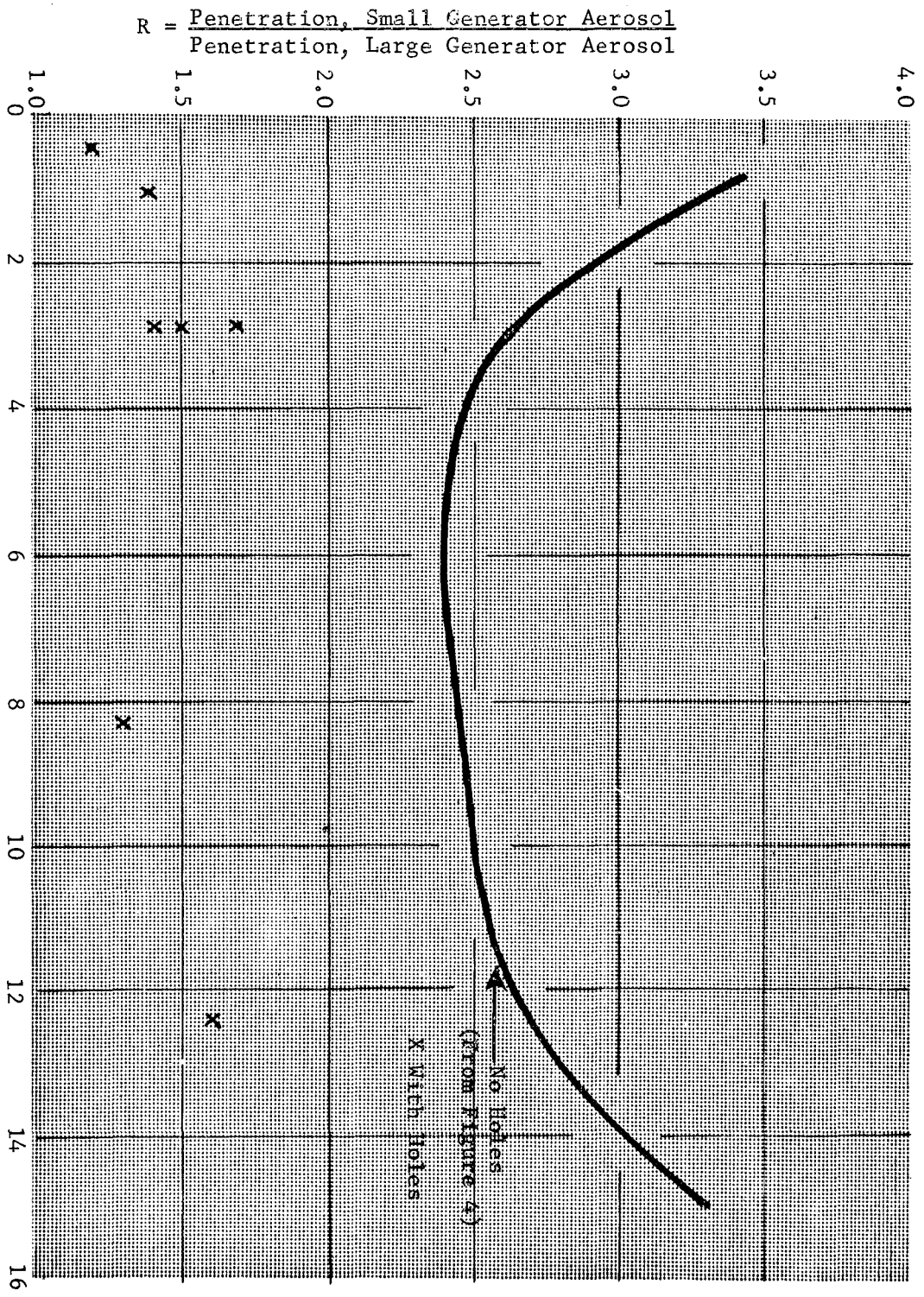


Figure 5. Aerosol Penetration Ratios

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

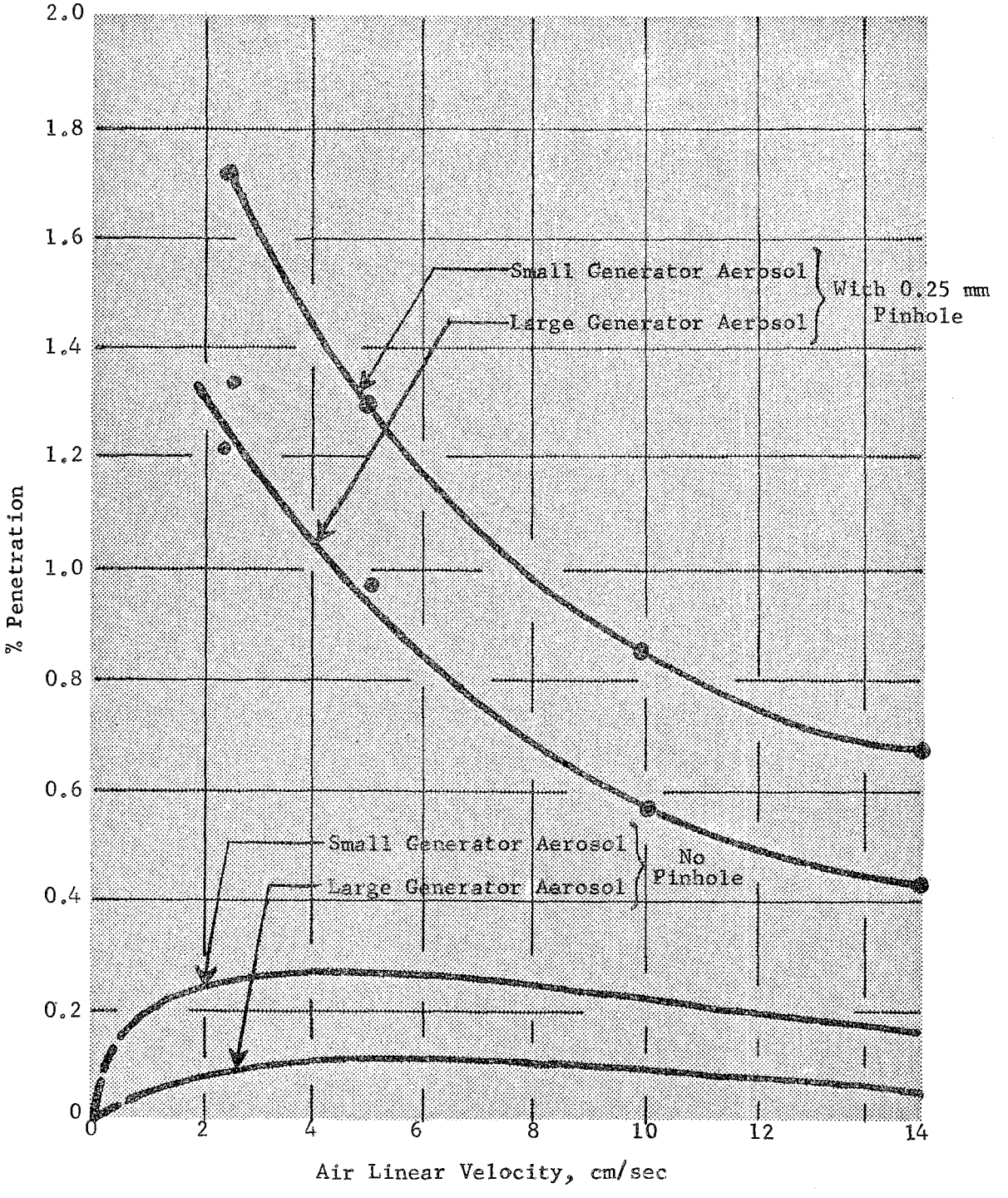


Figure 6. Aerosol Penetration of 9 mil HV-70 Paper, With and Without a Pinhole, as a Function of Air Linear Velocity

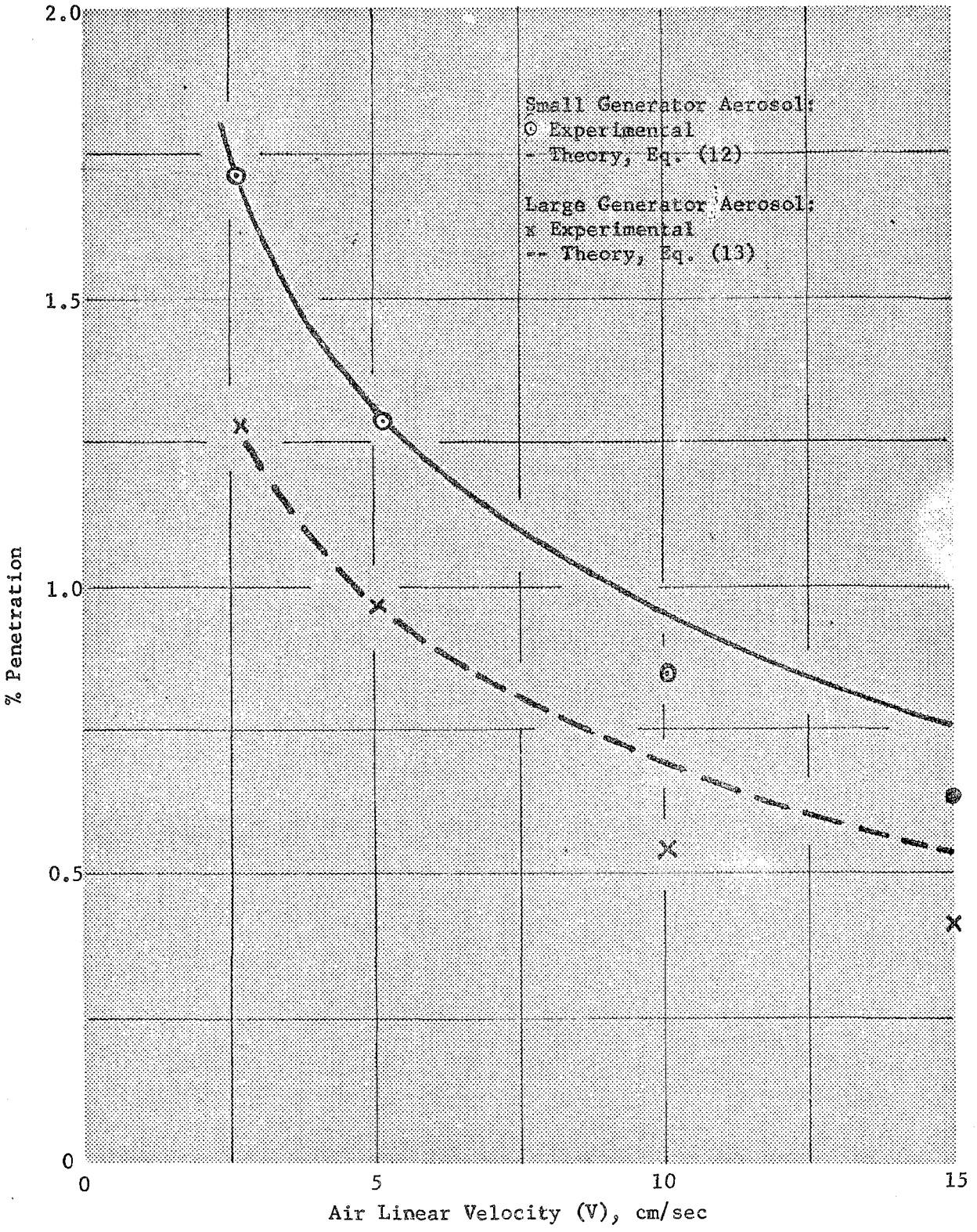


Figure 7. Test of Pinhole Effect Equation

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.

REFERENCES

1. Knudson, H.W., and L. White, "Development of Smoke Penetration Meters". Naval Research Laboratory, Laboratory Report P-2642, September 14, 1945.

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 radicactivity 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.

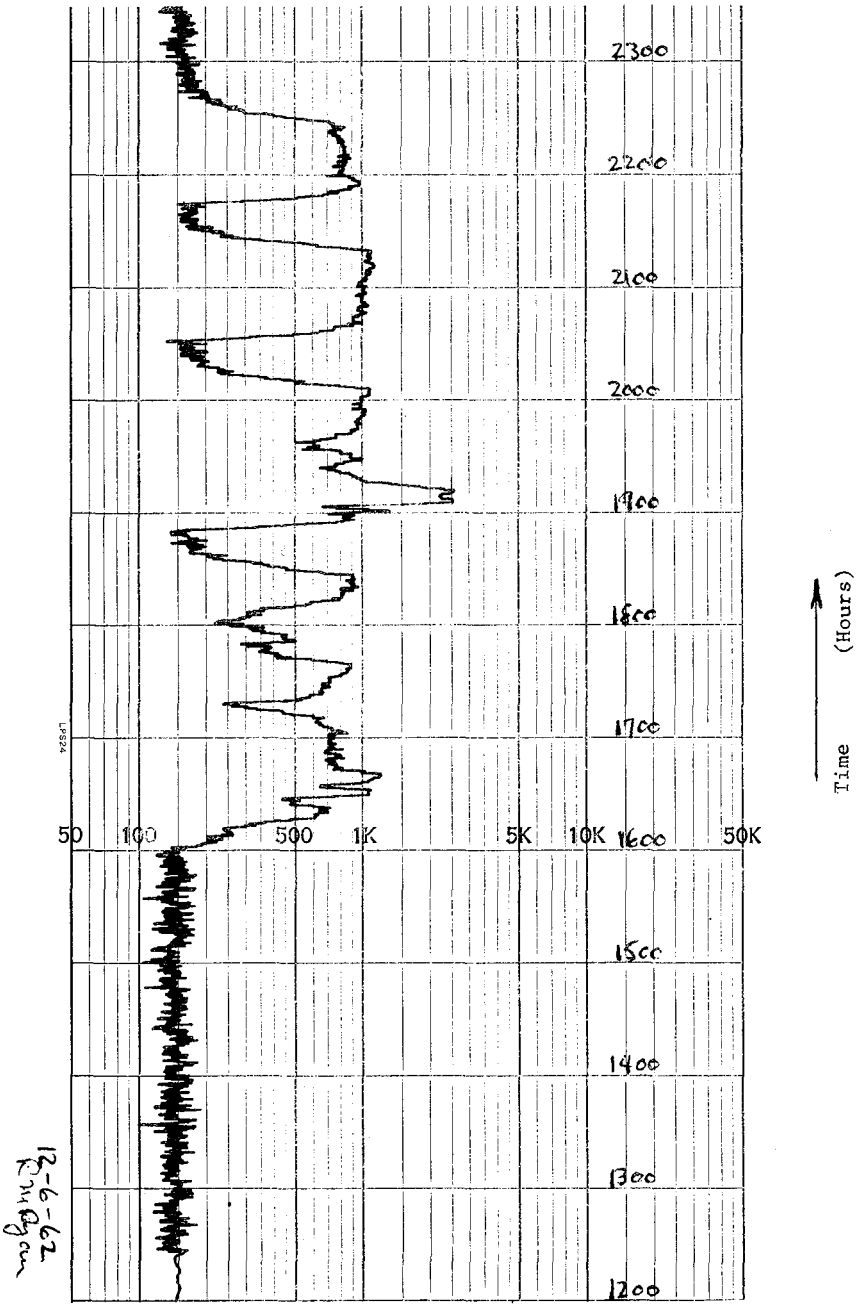
An investigation as to the various possible sources within the target room, and the half life and spectrum measurements indicated that the gaseous radioactivity was identifiable as nitrogen 13 and oxygen 15. Table 1 lists some of the physical characteristics of these two isotopes. Both isotopes decay 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

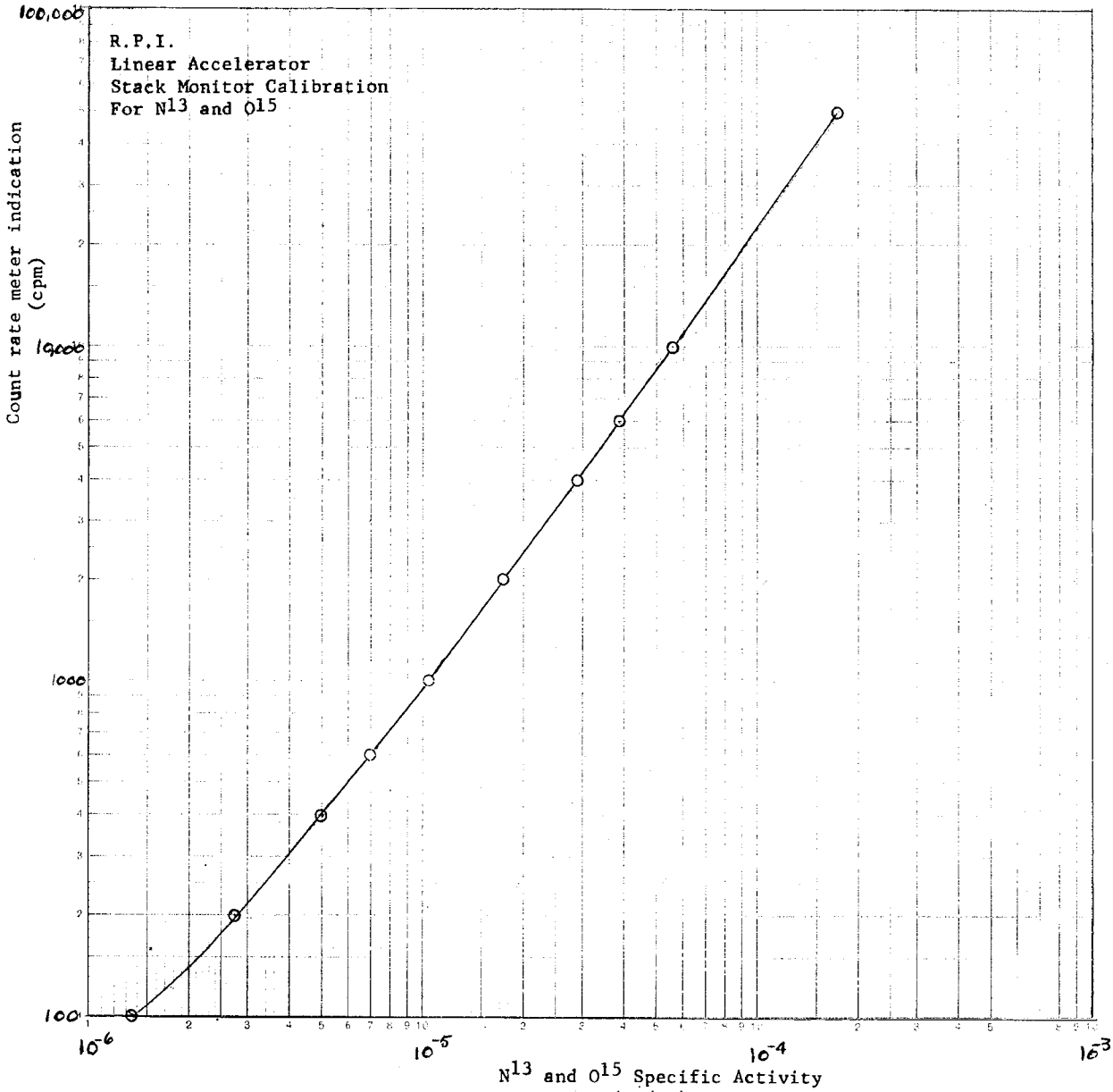

R.P.I.
Linear Accelerator
Stack Monitor Calibration
For N13 and O15
Count rate meter indication
(cpm)
100,000
10000
1000
100
10^{-6}
10^{-5}
10^{-4}
10^{-3}
N^{13} and O^{15} Specific Activity
(uc/cc)

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	(γ,n)	(γ,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)

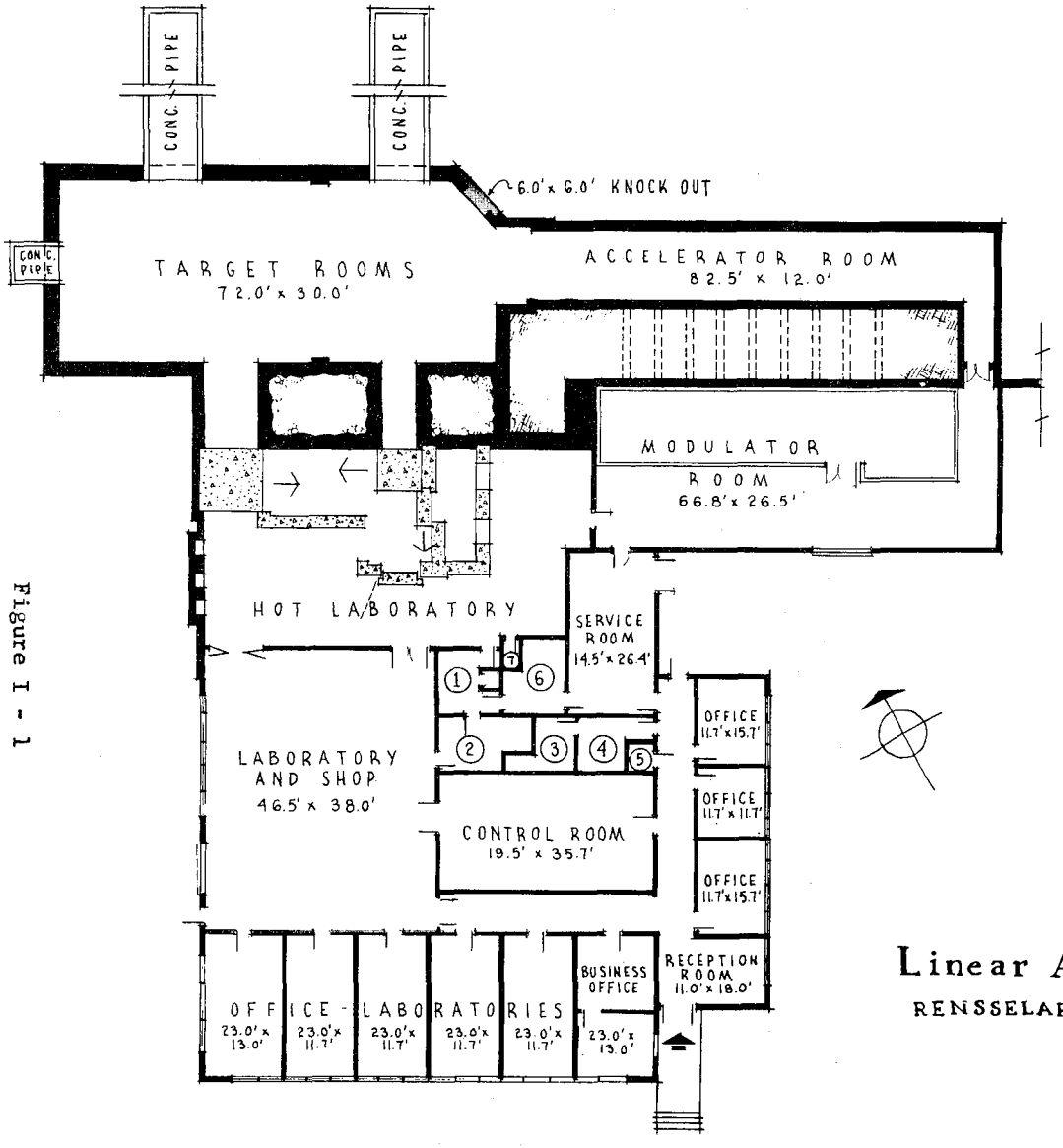
Session Chairman: We appreciate hearing your paper, Mr. Ryan.

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

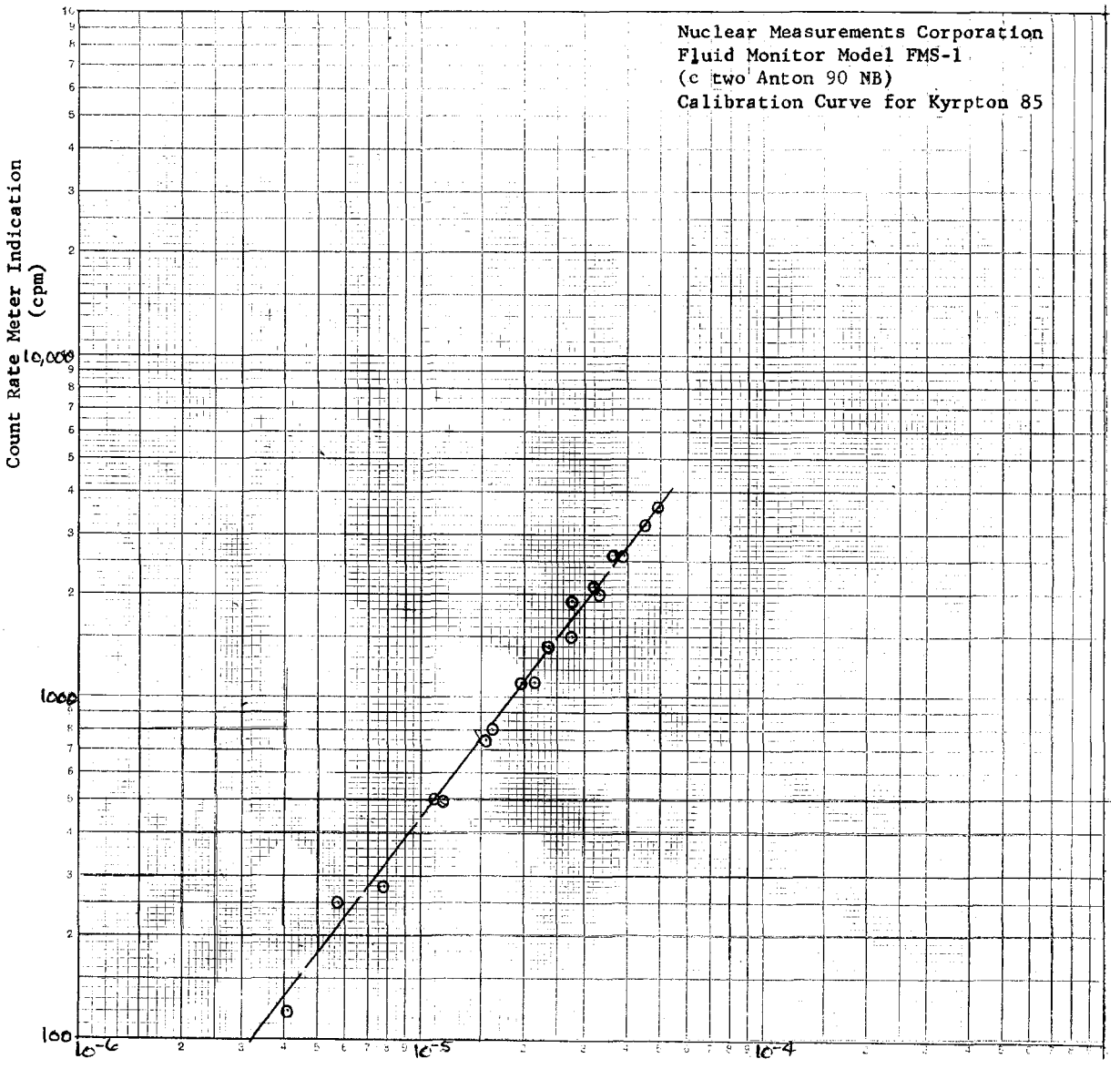

Nuclear Measurements Corporation
Fluid Monitor Model FMS-1
(c two Anton 90 NB)
Calibration Curve for Kyrpton 85
Count Rate Meter Indication (cpm)
10,000
1000
100
10-6
10-5
10-4
uc per cc as Krypton 85

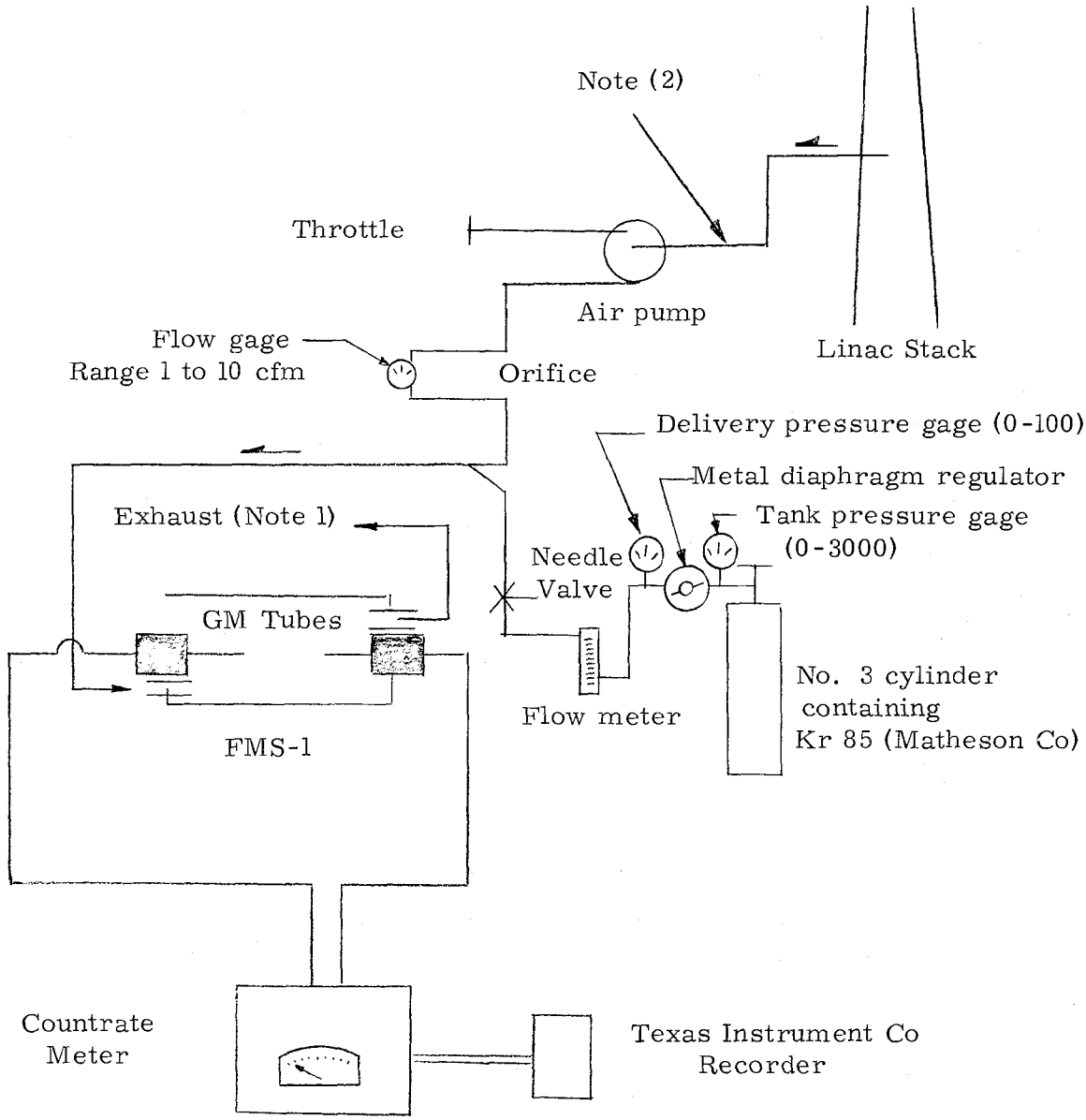
Figure II - 1

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

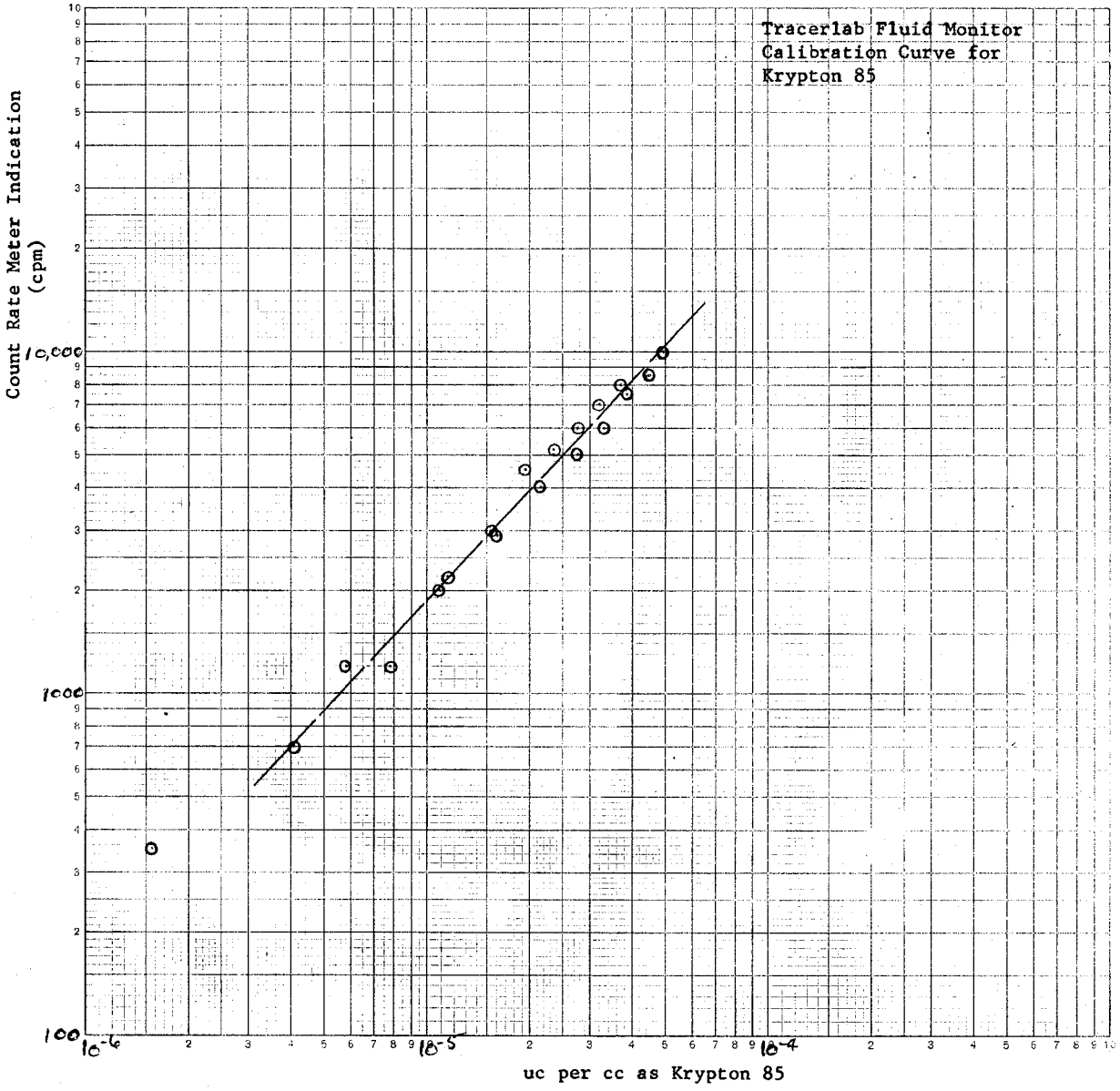

Tracerlab Fluid Monitor
Calibration Curve for
Krypton 85
Count Rate Meter Indication
(cpm)
10,000
1000
100
10⁻⁶
10⁻⁵
10⁻⁴
uc per cc as Krypton 85

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

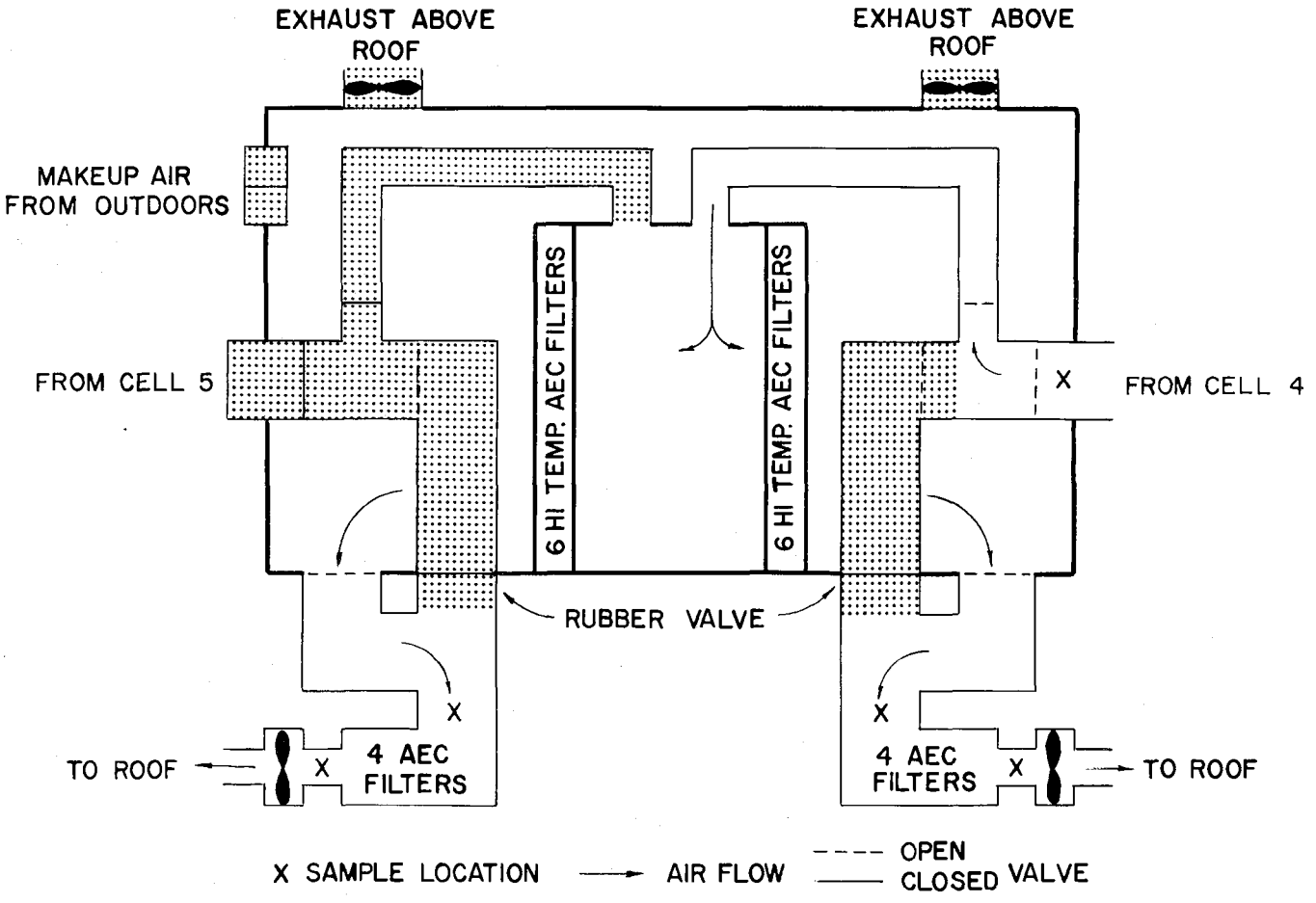


Figure 1

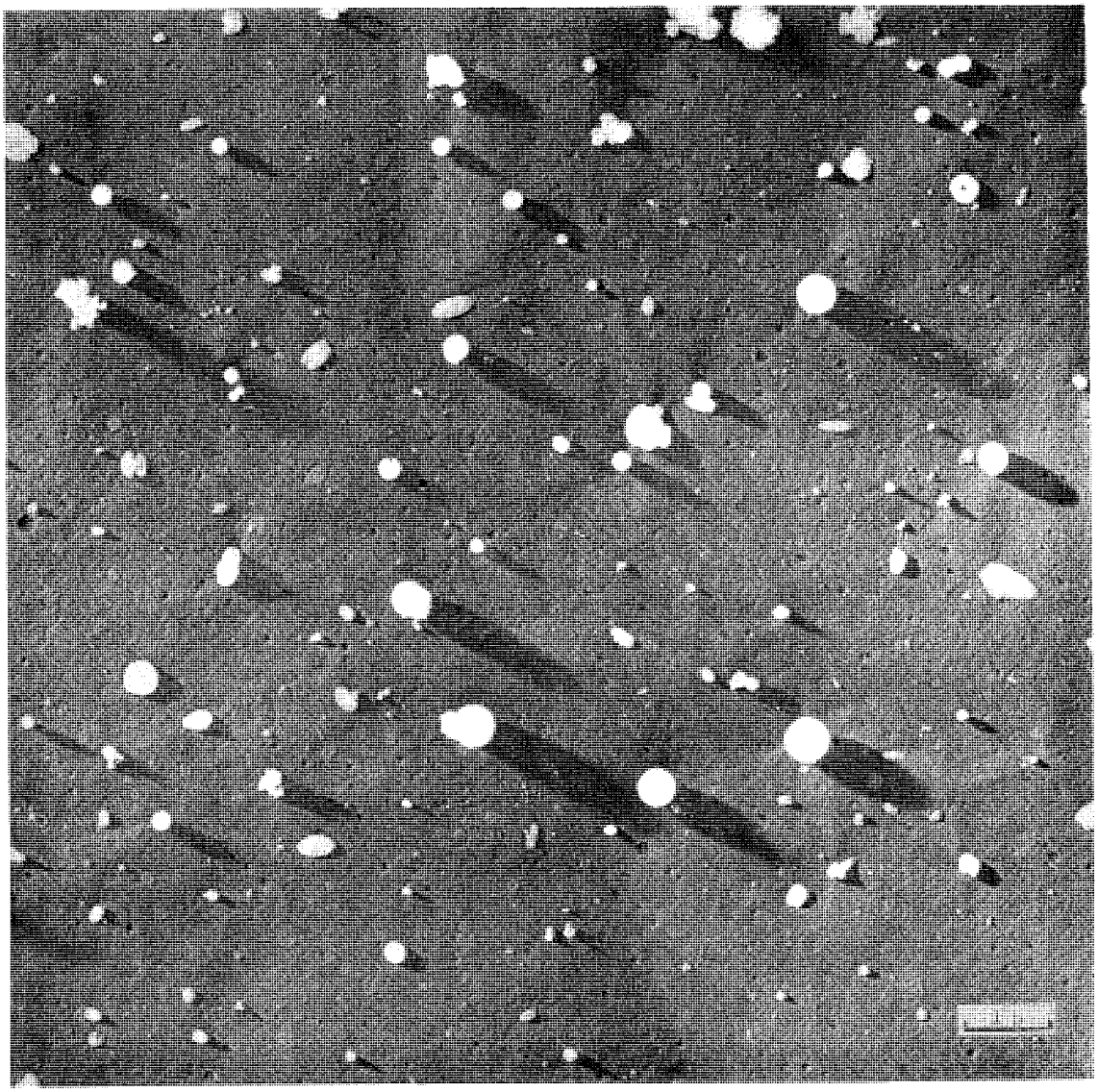


Figure 2

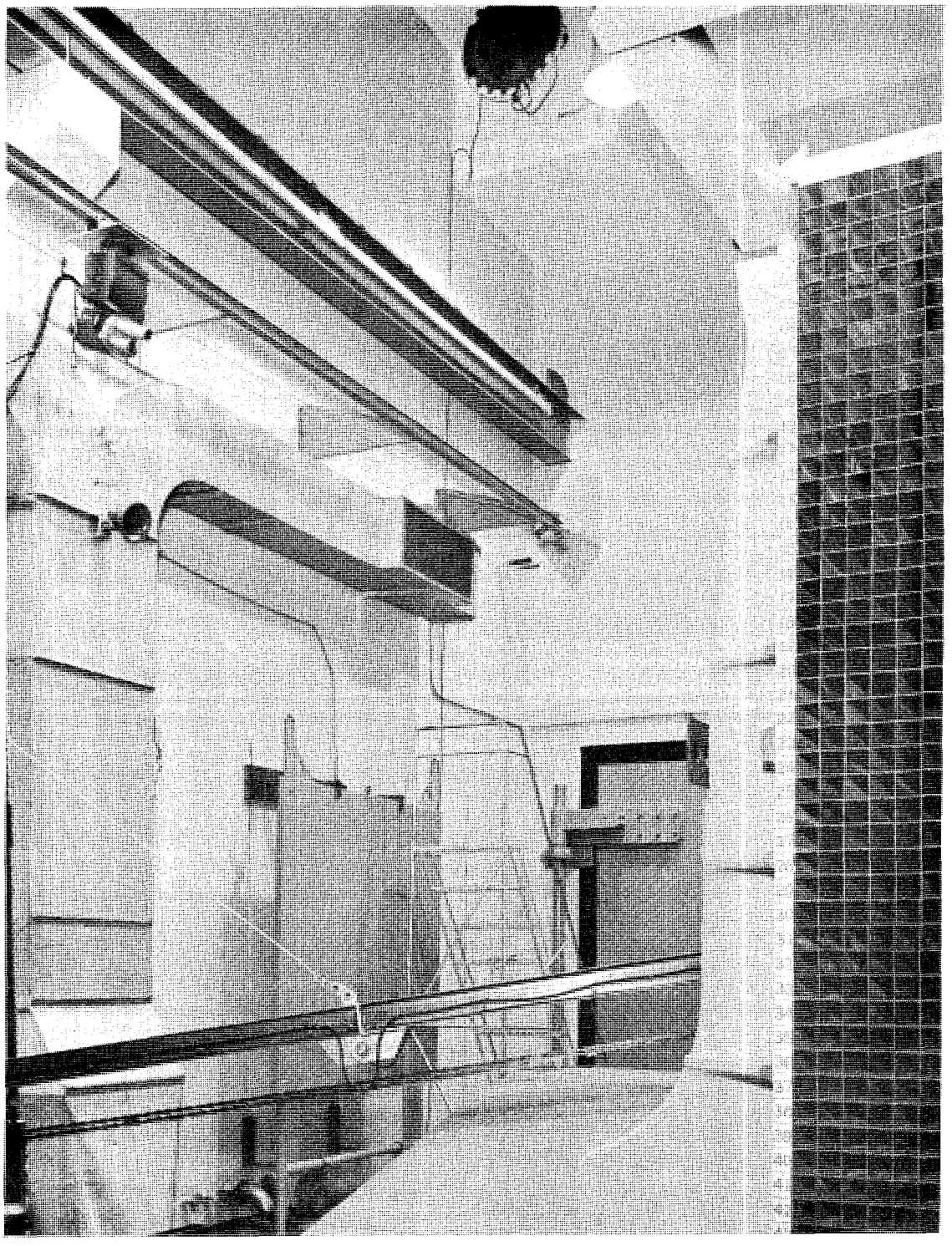


Figure 3

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

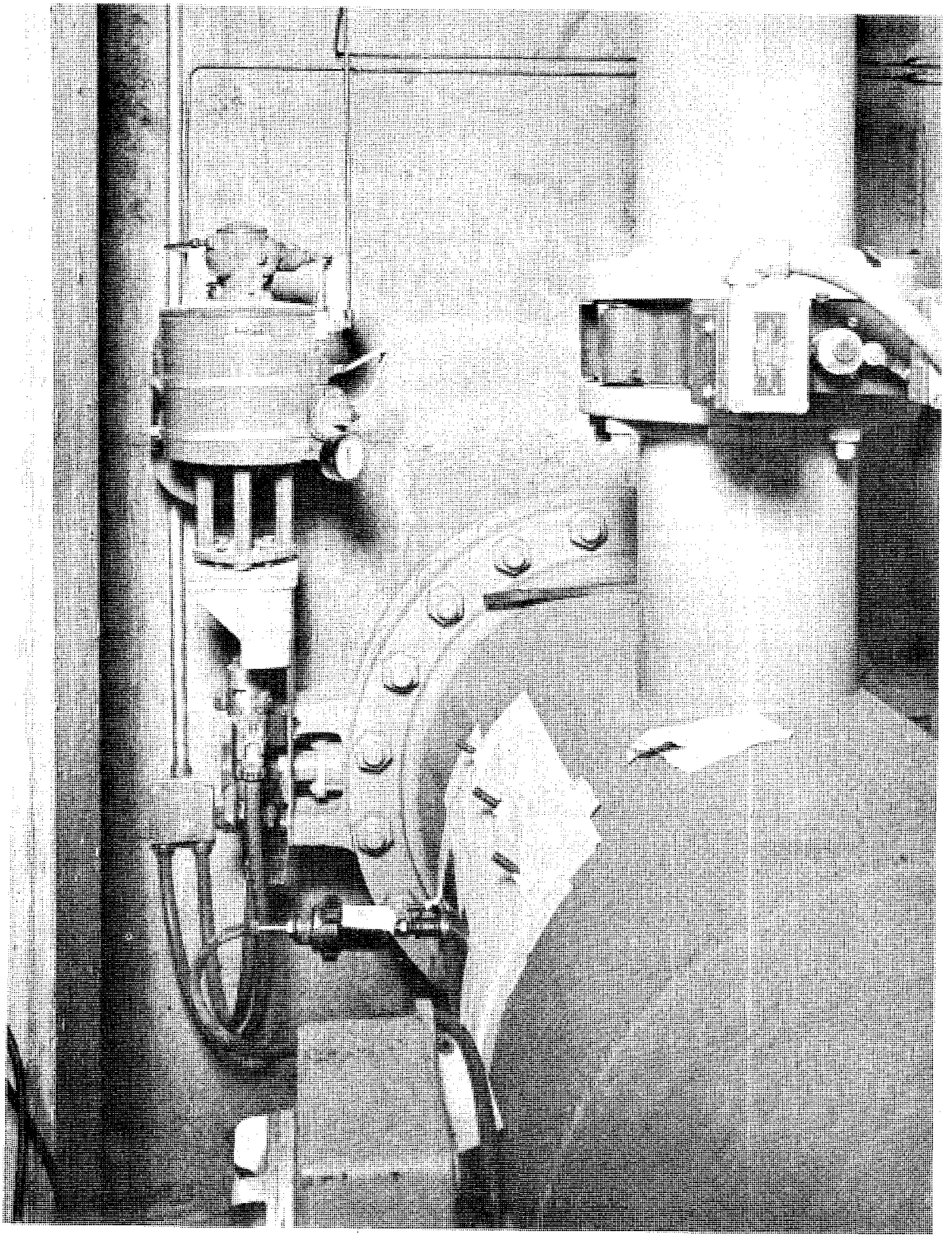


FIGURE 4

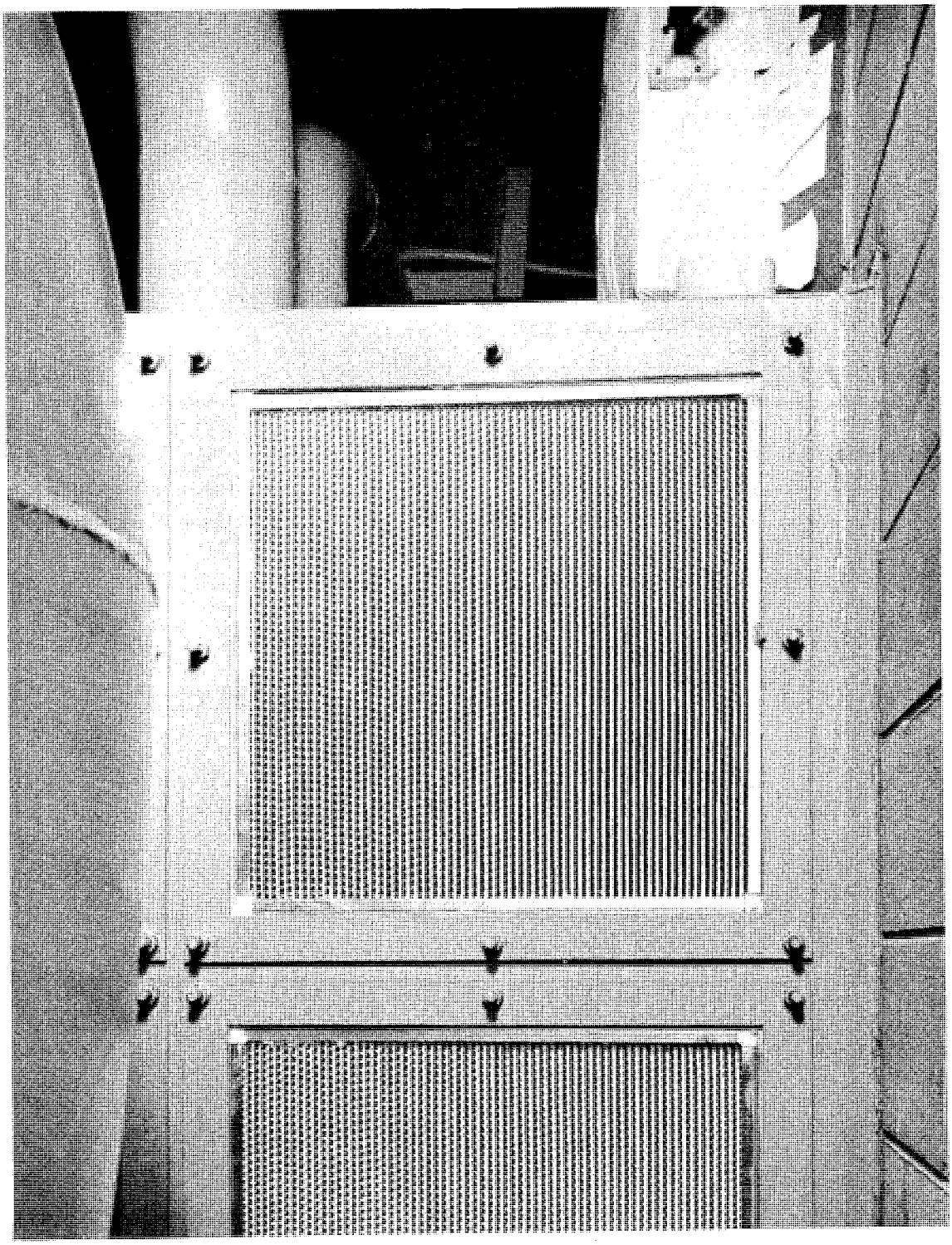


FIGURE 5

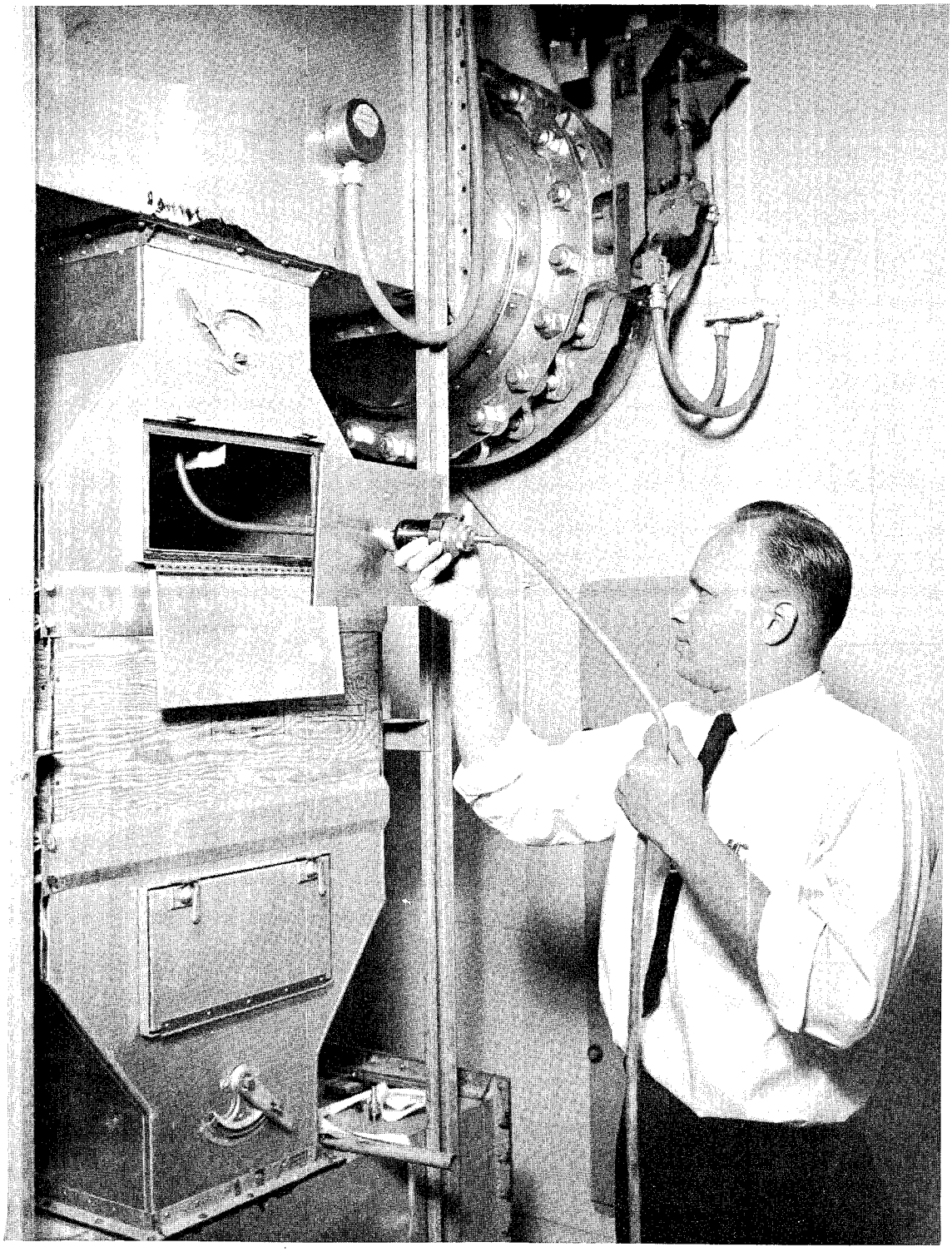


FIGURE 6

ANL D-205 CAVE EXHAUST FILTER SYSTEM

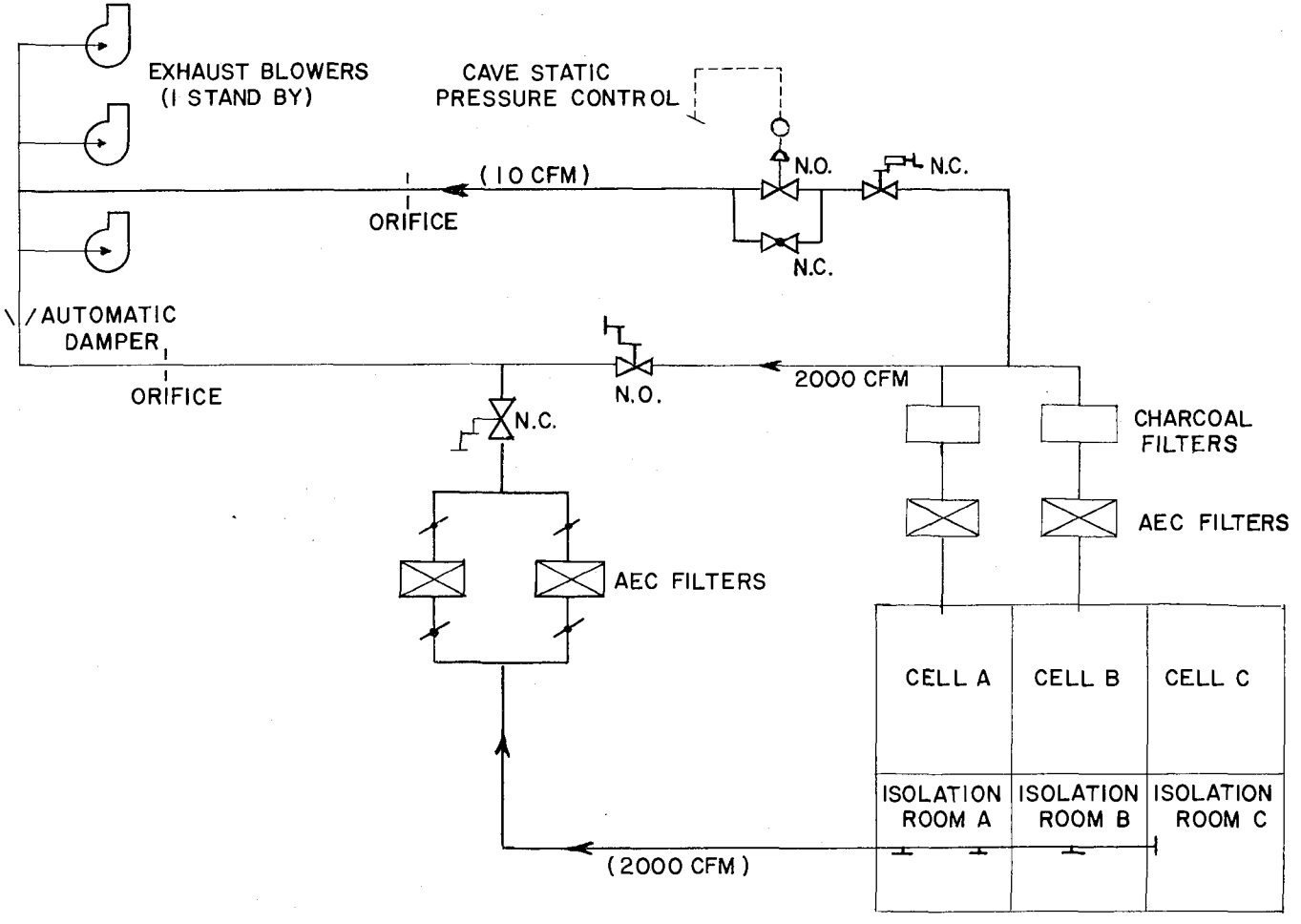


Figure 7

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."

THE HOLDUP EFFECT OF DOUBLE REACTOR-CONTAINMENT AND ITS INFLUENCE ON DOSE FROM AIRBORNE RADIOACTIVE MATERIALS

Truman D. Anderson
Oak Ridge National Laboratory

Introduction

Following a reactor accident the safety problem of greatest concern is the release of airborne radioactive materials to the environment. A design feature that would reduce such activity release is a second containment structure that surrounds the primary containment vessel. Specific examples of plants that utilize double containment are the Indian Point and the N.S. SAVANNAH Reactors. In these plants the space between the first and second containers is maintained at sub-atmospheric pressure by an exhaust blower connected in series with an air cleaning system. Thus, all material that leaks into the secondary containment space must pass through the air cleaning system before reaching the atmosphere.

Controlled activity release through an air cleaning system would result in a significant reduction in the release of those materials for which the air cleaning system is effective. An additional effect, which is the one of present interest, would be the time delay in release introduced by the second container. This time delay would result in a short-term reduction in the dose from all airborne radioactive materials; and, if decay of the isotope causing the dose were sufficiently rapid, a permanent reduction in dose would result. Even a temporary reduction in activity release following a reactor accident could be significant since the additional time available could be used for measures that would reduce the consequences of the accident. The double containment holdup effect could be especially important for ship reactors since it would be possible to move the system away from populated areas shortly after the accident.

The extent to which the holdup effect would alleviate environmental hazards resulting from a reactor accident would depend on the containment system parameters, the characteristics of the isotope causing the dose, and the manner in which radioactive materials were released from the reactor. The purpose of the present investigation was to evaluate the effectiveness of double-containment holdup in reducing environmental hazards associated with the release of radioactive materials after a reactor accident.

Containment Model

The containment model used in the present analysis is shown in Fig. 1. Basically the model is made up of three series-connected enclosures consisting of the reactor core and two containment structures. As may be seen from Fig. 1, an isotope can enter an enclosure by leakage from the preceding enclosure and by decay of the precursor isotope. Material can leave an enclosure by leakage and by decay to a daughter isotope. Deposition effects were not included in the containment model.

The leakage from a containment structure is normally characterized by a leak-rate constant which gives the fraction of the contained material that leaks out in unit time. The implication of this practice is that the rate of leakage of a given gaseous material is proportional to the total quantity of the material enclosed by the containment structure. This assumption forms the basis of the analysis given here.

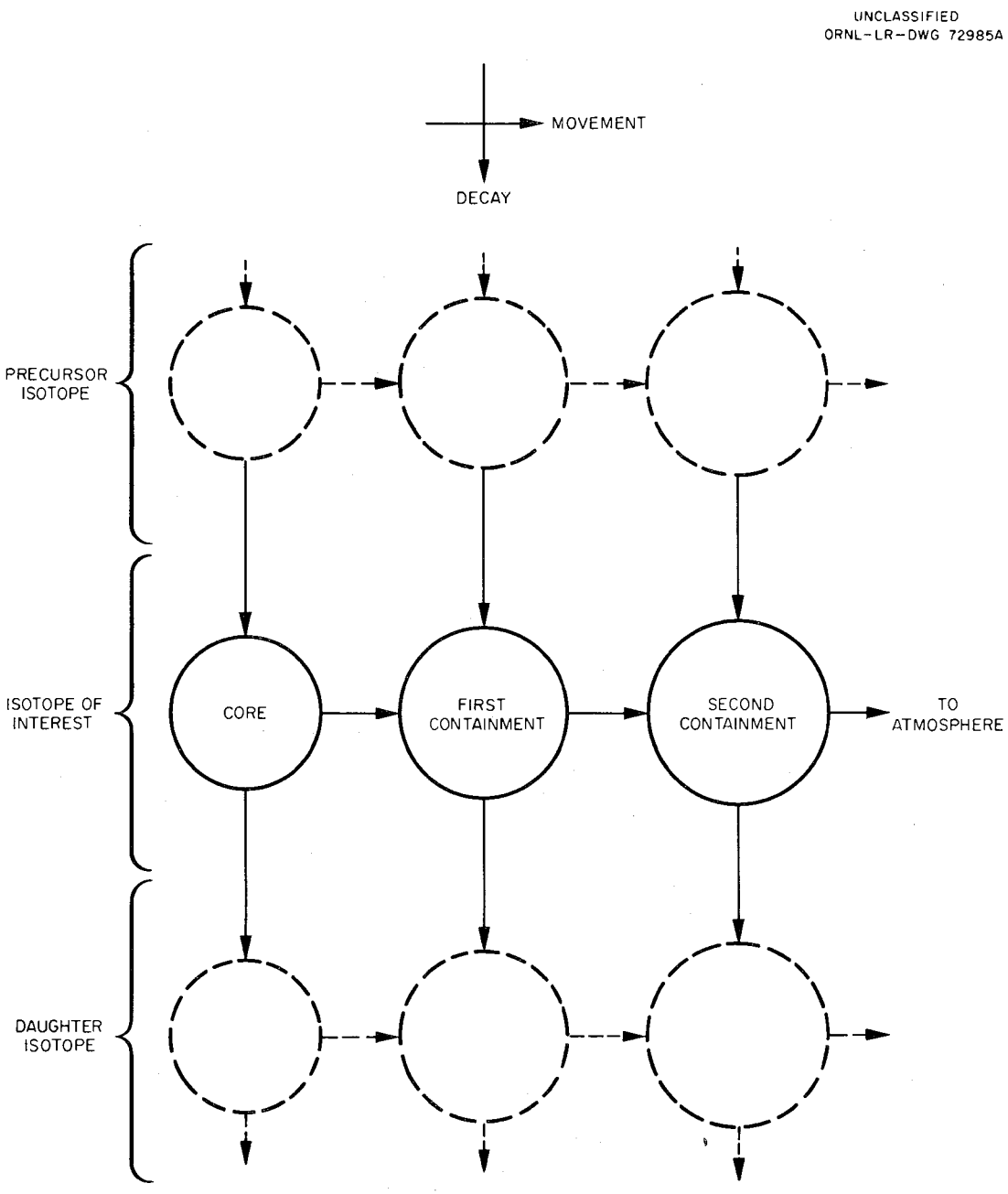


Fig. 1. Schematic of Containment System.

The containment rate processes for a given isotope are shown in Fig. 2. The symbols used in Fig. 2 are defined as follows:

$F(t)$ = fraction of the total quantity of the isotope that is outside the reactor core at time t,

l = leak-rate constant for first containment structure,

m = leak-rate constant for second containment structure,

$N(t)$ = total quantity of the isotope in existence at time t,

$Q(t)$ = quantity of the isotope held up in the first containment structure,

$R(t)$ = rate of release of the isotope from the reactor core,*

$U(t)$ = quantity of the isotope held up in the second containment structure, and

λ = decay constant of isotope.

The subscript, p, is used to denote the precursor isotope.

Leak-Rate Equations

A macroscopic material balance gives the following differential equations for the quantity of material held up in the containment structures:

$$\frac{dQ(t)}{dt} + (l + \lambda)\, Q(t) = N(t)\, \frac{dF(t)}{dt} + [F(t) - F_p(t)]\, \lambda_p\, N_p(t) + \lambda_p\, Q_p(t) \qquad (1)$$

and

$$\frac{dU(t)}{dt} + (m + \lambda)\, U(t) = lQ(t) + \lambda_p\, U_p(t) \qquad (2)$$

As is evident from Eqs. (1) and (2) the amount of an isotope in a given container depends on the amount of the precursor isotope in that container. There is, of course, a set of equations similar to Eqs. (1) and (2) for each precursor isotope. Thus, in general, the solutions to (1) and (2) can be obtained only after the solutions for the precursors are obtained. It can be shown,[1] however, that the solutions to (1) and (2) are considerably simplified if all precursor isotopes move through the system in the same manner as the isotope of interest. With this condition the problems of mobility and decay are separable, and the solutions to (1) and (2) are

$$Q(t) = \left[F(t) - l\, e^{-lt} \int_0^t e^{l\tau}\, F(\tau)\, d\tau\right] N(t) \qquad (3)$$

*The rate of release, $R(t)$, is related to the fraction released, $F(t)$, by[1]

$$R(t) = N(t)\, \frac{dF(t)}{dt} + [F(t) - F_p(t)]\, \lambda_p\, N_p(t) \quad .$$

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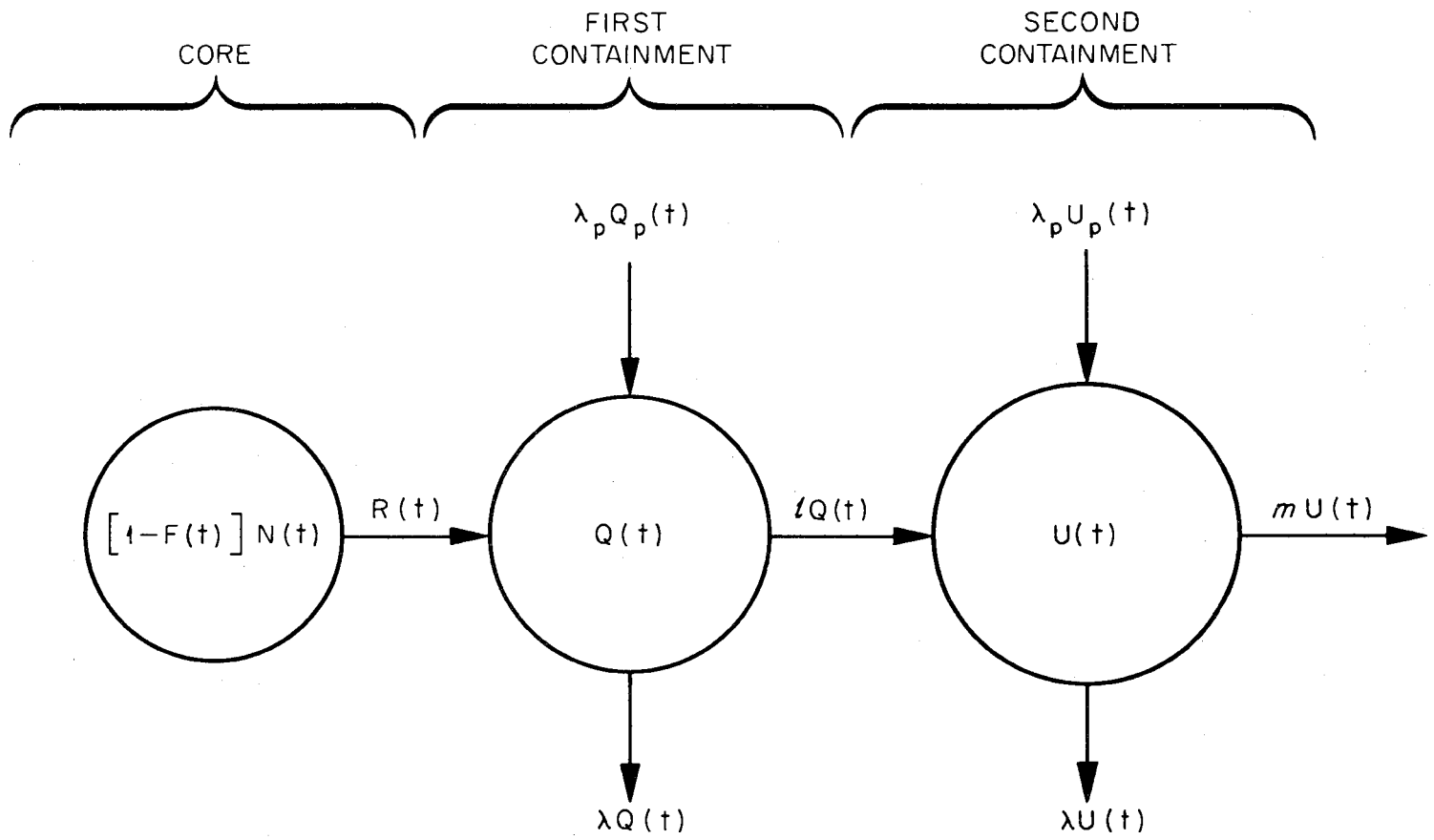


Fig. 2. Containment Rate Processes.

and

$$U(t) = \frac{l}{m - l}\left[m\, e^{-mt}\int_o^t e^{m\tau}\, F(\tau)\, d\tau - l\, e^{-lt}\int_o^t e^{l\tau}\, F(\tau)\, d\tau\right] N(t) \quad . \quad (4)$$

The rate of leakage from the first container, $S_1(t)$, is given by

$$S_1(t) = l\, Q(t) = l\left[F(t) - l\, e^{-lt}\int_o^t e^{l\tau}\, F(\tau)\, d\tau\right] N(t) \quad . \quad (5)$$

The leak rate from the second container, $S(t)$, is given by

$$S(t) = m\, U(t) = \frac{ml}{m - l}\left[m\, e^{-mt}\int_o^t e^{m\tau}\, F(\tau)\, d\tau - l\, e^{-lt}\int_o^t e^{l\tau}\, F(\tau)\, d\tau\right] N(t) \quad (6)$$

Leak-Rate with Step Release from Core

To evaluate the leak rates given by Eqs. (5) and (6) it is necessary to know the fraction of the isotope released from the core, $F(t)$. In safety analyses of power reactors it is normally assumed that some fraction, f, of the total quantity of a given fission product is released instantaneously from the core at time t_o after the start of the accident. With this core release model, $F(t)$ is given by

$$F(t) = \begin{cases} 0 & t \leq t_o \\ f & t > t_o \end{cases} ,$$

and Eqs. (5) and (6) become

$$S_1(t) = l\, f\, e^{-l(t - t_o)}\, N(t), \qquad t > t_o \quad , \quad (7)$$

and

$$S(t) = l\, f\, \frac{m/l}{m/l - 1}\left[e^{-l(t - t_o)} - e^{-m(t - t_o)}\right] N(t) \quad , \qquad t > t_o \quad . \quad (8)$$

For convenience in graphical presentation the leak rate to the environment given by Eq. (8) can be arranged in the dimensionless form

$$\frac{S(t)}{l\, f\, N(t)} = L(\theta) \quad ,$$

where

$$L(\theta) = \frac{\kappa}{\kappa-1}\left[e^{-\theta} - e^{-\kappa\theta}\right] ,$$

$$\theta = l(t - t_o) \quad ,$$

and

$$\kappa = \frac{m}{l} \quad .$$

The relative leak rate, $L(\theta)$, is shown graphically in Fig. 3 for a range of θ and for several values of the parameter, κ.

Connection Between Release-Rate and Dose

The dose rate from airborne radioactive material is proportional to the air concentration of the material at or near the receptor point. The air concentration is, according to atmospheric dispersion formulae, proportional to the release rate with the condition that negligible time elapses between release and arrival at the receptor point. The dose rate is, therefore, proportional to the release rate. For a given isotope the dose rate, $D(t)$, is

$$\dot{D}(t) = K\, S(t)$$

where $S(t)$ is the release rate to the atmosphere and K is a time independent quantity determined by the isotope under consideration, the atmospheric conditions, and the position of the receptor point relative to the release point. The dose, $D(t)$, up to time, t, is given by

$$D(t) = \int_o^t \dot{D}(\tau)\, d\tau = K\int_o^t S(\tau)\, d\tau \quad . \tag{10}$$

Using Eq. (7) in Eq. (10) it is found that the dose, $D_1(t)$, from a single containment system with step release of material from the core is

$$D_1(t) = lfK\int_{t_o}^t e^{-l(\tau - t_o)}\, N(\tau)\, d\tau \quad . \tag{11}$$

Similarly using Eq. (8) in Eq. (10) the double containment dose is seen to be

$$D(t) = lfK\,\frac{m/l}{m/l - 1}\int_{t_o}^t \left[e^{-l(\tau - t_o)} - e^{-m(\tau - t_o)}\right] N(\tau)\, d\tau \quad . \tag{12}$$

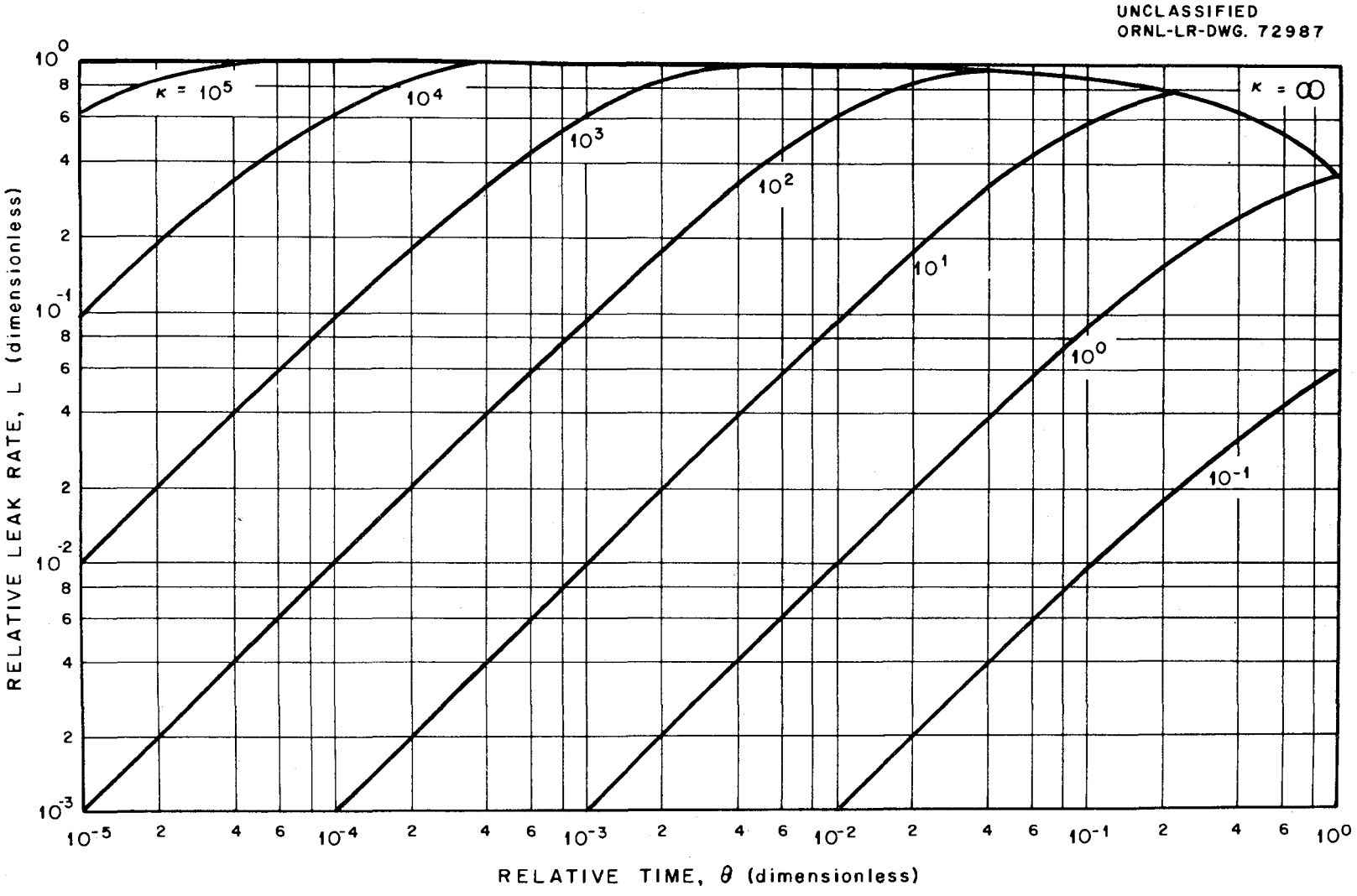


Fig. 3. Leak Rate from Double-Containment System With Step Release from Core.

Effect of Double Containment on Dose

The use of two series-connected containment structures can effect a reduction in the exposure dose arising from a reactor accident. The extent of this reduction can be determined by taking the ratio of the dose with double containment to the dose with single containment. Using the step model of core release, the dose ratio given by dividing Eq. (12) by Eq. (11) is

$$\frac{D(t)}{D_1(t)} = \frac{m/l}{m/l - 1}\left[1 - \frac{\int_{t_o}^{t} e^{-m(\tau - t_o)}\, N(\tau)\, d\tau}{\int_{t_o}^{t} e^{-l(\tau - t_o)}\, N(\tau)\, d\tau}\right]. \qquad (13)$$

From (13) it is seen that the reduction in dose depends on $N(t)$ as well as the leak characteristics of the containment structures. Because of precursor isotopes, the time dependence of $N(t)$ depends on the neutron flux level and the operating time of the reactor prior to the accident. The general character of the effect of double containment can be demonstrated, however, without introducing the reactor details. This is done by assuming simple exponential decay of the isotope causing the dose. For this case

$$N(t) = N_o\, e^{-\lambda t}$$

and Eq. (13) becomes

$$\frac{D(t)}{D_1(t)} = \frac{\kappa}{\kappa - 1}\left[1 - \frac{(1+\kappa\alpha)}{(1+\alpha)\kappa} \cdot \frac{1 - e^{-(1+\alpha)\kappa\theta}}{1 - e^{-(1+\kappa\alpha)\theta}}\right] \qquad (14)$$

where $\alpha = \frac{\lambda}{m}$ and the other quantities are as defined previously. For materials that undergo radioactive decay it would be expected that the holdup effect of the second containment would result in a permanent reduction in the exposure dose. The infinite-time dose ratio from Eq. (14) is

$$\left[\frac{D(t)}{D_1(t)}\right]_{t=\infty} = \frac{1}{1 + \alpha} \quad . \qquad (15)$$

Thus, the permanent reduction in dose because of double containment is dependent only on the ratio of the decay constant to the leak-rate constant for the second container. The infinite-time dose ratio given by (15) is shown graphically in Fig. 4. It can be seen that when the decay constant, λ, is small relative to the leak-rate constant, m, there is no permanent reduction in the dose. There is, however, a temporary reduction in dose even if there is negligible decay ($\lambda \sim 0$) of the isotope producing the dose. To illustrate this effect the time-dependent dose ratio given by Eq. (14) is shown in Fig. 5 for $\alpha=0$ (no decay, $\lambda=0$), for $\alpha=1$ ($\lambda=m$), and for two values of κ. It can be seen that the short-time effectiveness of double containment in reducing the dose is little affected

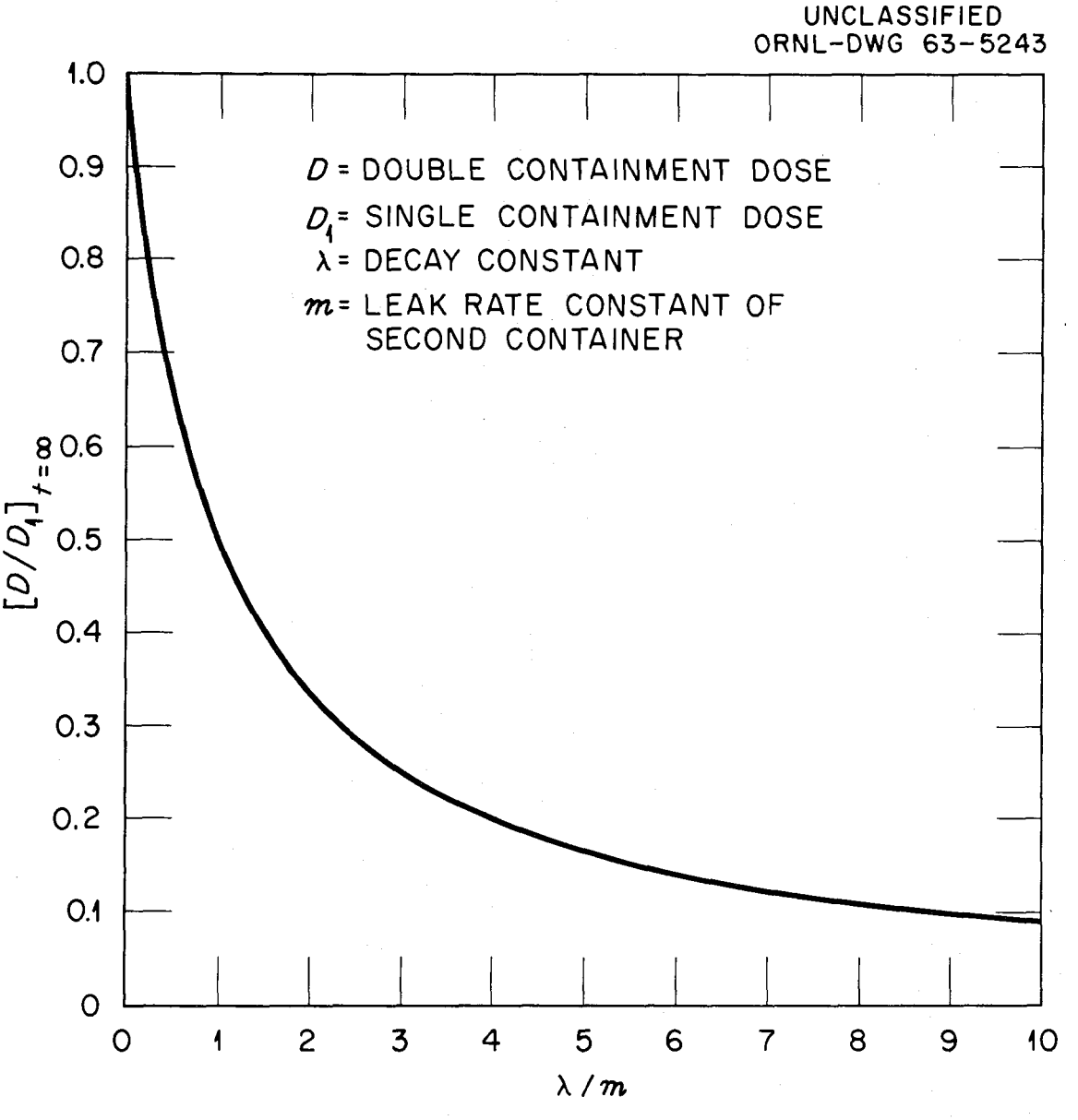


Fig. 4. Effect of Double Containment on Infinite-Time Dose from Isotope Decaying Exponentially.

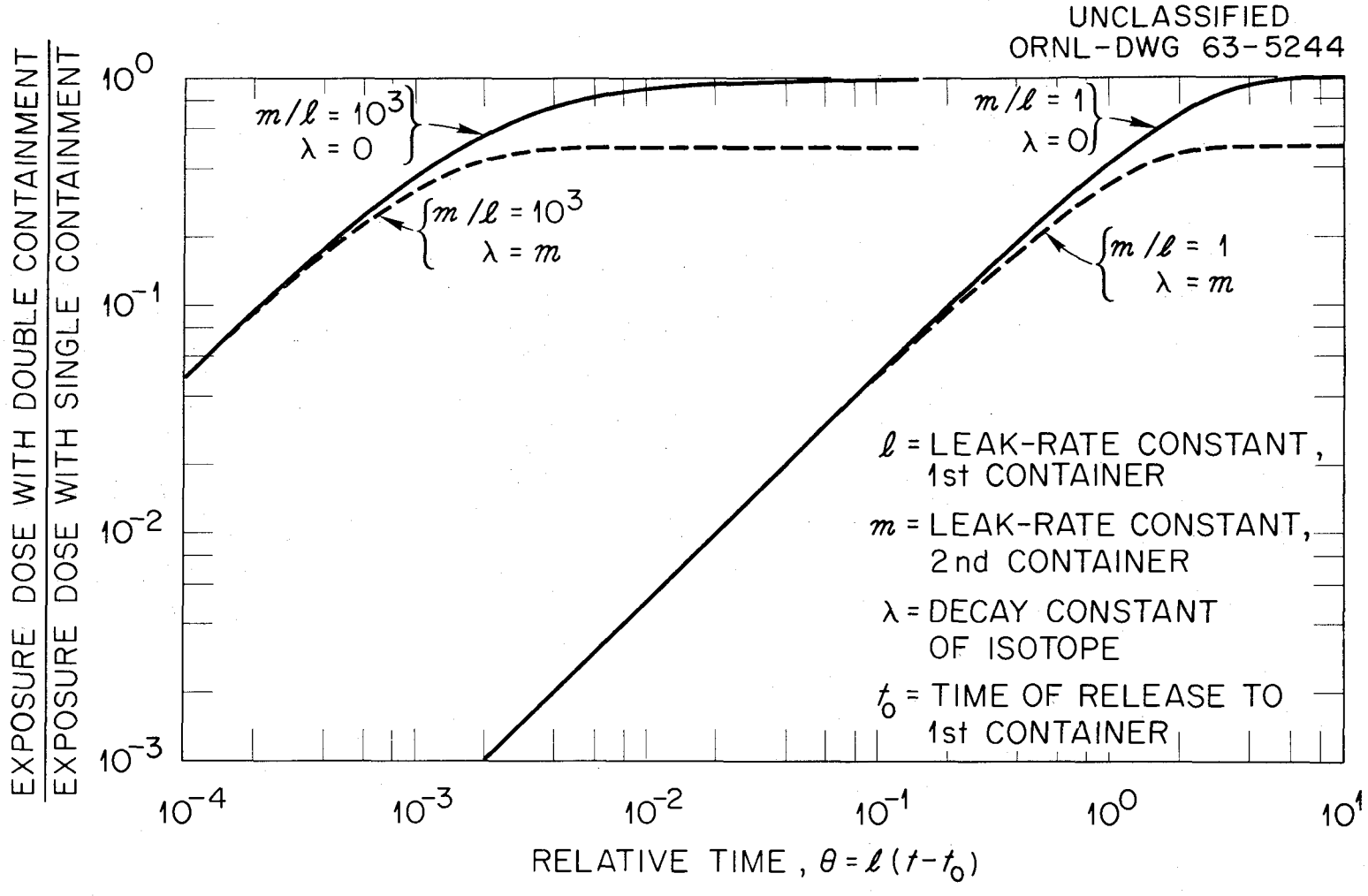


Fig. 5. Effect of Double Containment on Finite-Time Dose from Isotope Decaying Exponentially.

by radioactive decay of the isotope. Ultimately, however, the double-containment system gives no net reduction in dose if decay is negligible.

Application to the N.S. SAVANNAH

The N.S. SAVANNAH reactor system is enclosed in a conventional containment vessel that is, in turn, enclosed in the reactor compartment. The reactor compartment is maintained at slightly sub-atmospheric pressure by blowers that exhaust the compartment air through particulate filters and activated charcoal adsorbers.

The original purpose of the reactor compartment system was to reduce the release to the atmosphere of particulate fission products and radioiodine in the event of an accident. Further reductions in the release of all airborne material are provided by the holdup effect of the reactor compartment, although this effect has not been included in AEC safety justifications.

The noble-gas dose reduction resulting from compartment holdup was investigated using three different compartment exhaust rates, and the results are shown in Fig. 6. The data of Fig. 6 were calculated using Eq. (13). It was assumed that the gases would be released from the core instantaneously at the start of the accident ($t_o = 0$ in Eq. 13). The time-dependent amounts of the noble gases were calculated on the basis of reactor operation at full power for one year.[2] To account for possible non-uniform mixing in the reactor compartment, the compartment leak-rate constant, given by

$$m = \frac{\text{ventilation rate}}{\text{volume ventilated}} ,$$

was computed using approximately one-half the actual compartment volume. Figure 6 is valid for any primary containment leak-rate constant, l, in the range $0 < l \lesssim 0.025$ day^{-1}.

During initial operation of the N.S. SAVANNAH the emergency ventilation system was operated at an exhaust rate of 200 ft^3/min ($m = 9.6$ day^{-1}). At this exhaust rate the 2-hour dose from noble gases released to the atmosphere would be reduced 71% because of compartment holdup. The ultimate reduction in noble gas dose would be 20%. As can be seen from Fig. 6, a further reduction in noble gas dose could be effected by reducing the exhaust rate. At an exhaust rate of 40 ft^3/min the 2-hour dose would be reduced 93%, and the ultimate dose would be reduced 50%. There is, of course, a lower limit on the exhaust rate because the reactor compartment must be maintained at sub-atmospheric pressure to assure effective operation of the filters and charcoal adsorbers. The results of this analysis show, however, that it would be desirable to reduce the compartment exhaust rate to the lowest possible value consistent with the negative pressure requirement.

References

1. Truman D. Anderson, "Time-Dependent Release of Gaseous Material from a Three-Barrier Reactor Containment System," USAEC Report ORNL-TM-397, Oak Ridge National Laboratory, November 16, 1962.

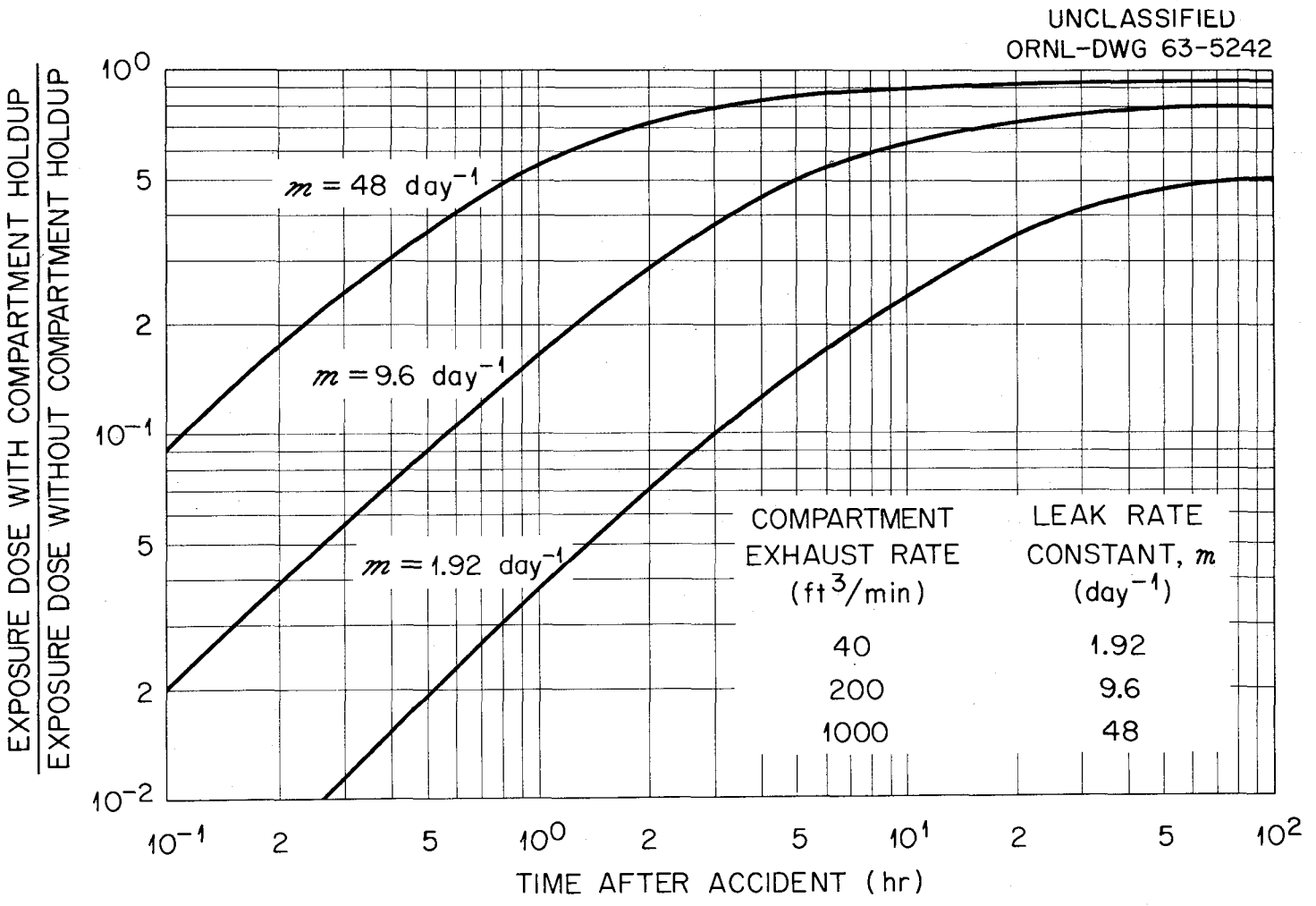


Fig. 6. Effect of Reactor Compartment Holdup on Dose from Noble Gases, N.S. SAVANNAH Reactor.

2. T. D. Anderson, J. R. Buchanan, W. B. Cottrell, M. H. Fontana, O. H. Klepper, and H. C. McCurdy, "Activity Release from the N.S. SAVANNAH in the Maximum Credible Accident," USAEC Report ORNL-3361, Oak Ridge National Laboratory, October 1, 1963.

DISCUSSION AND COMMENT

On the L and M values perfect diffusion is assumed within the containment vessel. In calculating, in particular, the M, one would do that by taking the flow rate out and dividing by the volume, and assume complete mixing of whatever it is you are interested in in the container. But one can adjust this M, get a hypothetical M, if experimental data were available, to show that there were not complete mixing.

Session Chairman: The Savannah River Plant will be represented by Mr. L. M. Arnett and Mr. B. C. Rusche with the presentation, "The Application of Iodine Absorber Units to the HWCTR Containment System." Mr. Arnett will deliver the paper.

THE APPLICATION OF IODINE ABSORBER UNITS TO THE HWCTR CONTAINMENT SYSTEM

by

L. M. Arnett and B. C. Rusche
Savannah River Laboratory

This report is an analysis of the extent to which the installation of iodine absorber units in the containment building of the Heavy Water Components Test Reactor (HWCTR) can be expected to reduce radiation exposures of personnel in the vicinity of the facility during a release of fission products from the reactor core.

Because the radioiodines contribute substantially to the whole body dose and constitute almost entirely the thyroid dose, any mechanism that eliminates these isotopes from the materials escaping from the building reduces considerably the radiation hazard outside the building. The recent development of highly efficient iodine absorbers[1] made consideration of their installation in HWCTR a logical step.

SUMMARY

This evaluation of the maximum credible accident reveals that the operation of efficient iodine absorbers reduces the radiation hazards to commonly acceptable levels even though the leak rates from the containment building are relatively high. At leak rates in the vicinity of 2% of the building contents per day, the whole body dose and the thyroid dose received by personnel at the Plant boundary three miles from the HWCTR will be less than 25 r and 30 rem, respectively, in 30 days. The effect of the iodine absorbers is to reduce the expected whole body dose by a factor of two and the expected thyroid dose by a factor of one hundred.

DETAILS

1. CONTAINMENT BUILDING

1.1 Brief Description of Building

The containment building, which houses the reactor and principal auxiliary equipment, is designed to withstand an internal pressure of 24 psig. This is slightly greater than the equilibrium pressure that would result from the maximum credible accident, which is a rupture of the pressurized system full of D_2O at an average temperature of 285°C. The maximum credible accident is defined in Section 2.1.

The building is 70 ft in diameter and 125 ft high; approximately half of the building is above grade. The enclosed volume is 420,000 ft^3 and the free volume is 320,000 ft^3.

The above-grade portion of the building is carbon steel (ASME Spec SA-212, Grade B); the remainder is prestressed, reinforced concrete. The steel shell of the building is anchored to the concrete substructure by high strength bolts that are tensioned to compress the joint. The building was constructed in accordance with interpretations of the 1956 ASME Boiler and Pressure Vessel Code, Section VIII, "Unfired Pressure Vessels".

Major structural characteristics of the building are listed in Table I.

Table I

STRENGTH OF THE CONTAINMENT BUILDING

	Internal Pressure, psig
Yield strength of steel shell	50
Yield strength of anchor bolts	63
Zero compression on main joint	50
Guaranteed[a] ultimate strength in girth cables used to prestress concrete	58
Minor cracks in concrete substructure	30

[a] Guaranteed by the manufacturer.

The building is designed to withstand an external pressure of 0.75 psig. A vacuum breaker prevents external pressure exceeding internal pressure by more than 0.25 psi. No relief is provided for internal pressure.

There are four floors in the building. The main floor at grade level is a single operating area. The minus 16-ft level is divided into two compartments, the minus 37-ft level into two compartments, and the minus 52-ft level into four compartments.

Building compartments are interconnected to equalize internal pressures. A 14-ft by 19-ft stairwell connects all levels of the building. Grating floors are used where structural and shielding requirements permit. The volume of the building is accessible to gases or vapors released from the reactor system.

Two air locks provide access to the building. One is reserved for emergency use. The normal access air lock, 10 ft in diameter and 16 ft long, contains two doors, both sealed by mechanically loaded gaskets. Interlocks prevent opening both doors at the same time. The emergency air lock is similar but is smaller.

Equipment is moved into and out of the building through a 7-ft wide and 7-ft high opening. During reactor operation this is sealed by a gasketed and bolted steel door.

Pressure-tight seals are provided where the building is penetrated by service piping and conduit. The largest penetrations are for the two air ducts of 24-inch diameter, one for fresh air, the other for exhaust air. These ducts are welded to the building shell. Each duct contains two air-operated butterfly valves that close in approximately 0.8 sec on signal from the control building. Service lines, through which any building pressure could be relieved, contain isolation valves that are operated from the control building. Electrical conduits enter the building through the substructure and terminate in junction boxes. A leakproof seal is installed in each conduit run.

1.2 Iodine Absorbers

Four iodine absorber units are provided within the building to remove radioactive iodine vapor released from ruptures of the process system. The units are installed in the following locations:

No. of Units	Level	Location
2	Zero	Platform at +22 ft
1	-16 ft	Right pump room
1	-37 ft	Left generator room

Each absorber unit, consisting of a moisture separator, activated charcoal filter, and fan, will filter 1000 cfm of building air. Provision is made on each unit for placing two inches of lead shielding across its top. The absorber fans will start automatically on a building "isolation" signal. Manual "Stop-Start" buttons and operating signal lights are provided in the control room. The fan motors are on emergency power and can start and operate under a pressure of 24 psig, a temperature of 108°C, and during operation of the deluge spray. Separate circuits in separate conduits run from the electrical substation to each fan motor.

The absorber units are located and oriented to secure maximum mixing of the building air. Six 1000-cfm portable fans, which operate continuously, assist in mixing the air. The motors of these fans are on emergency power and can operate at 24 psig, at 108°C, and during deluge spray.

The entrainment separators in the absorber units will remove 99% of the entrained liquid in steam-air mixtures drawn through the unit as determined by experiments reported in Reference 2.

The carbon filter cells in the absorber unit are activated coconut shell charcoal packed to a density of 35 lb/ft^3. Each filter cell contains 56 lb of activated charcoal with an effective filter area of 14.6 ft^2. Tests have shown that under the anticipated operating conditions of the absorber, iodine is removed with an efficiency of 99.99%.(1)

The absorbers are designed as integral units to facilitate removal and replacement, thus minimizing exposure to personnel. Construction features prevent recirculation of air within the unit and prevent bypassing the charcoal filter. Gasket and adhesives are designed to maintain the integrity of the unit for a minimum of eight hours at 110°C.

2. COURSE OF ACCIDENT

2.1 Definition of the Maximum Credible Accident

The maximum credible accident is defined as follows. A major break occurs in the high-pressure D_2O system. The reactor core boils dry; the uranium metal in the test elements melts, breaks through the zirconium cladding, and ultimately reacts chemically with residual steam or air. The zirconium-uranium alloy in the driver tubes also reacts with steam and releases fission products. The hot D_2O flashes through the break, and the temperature and pressure of the containment building increase. This is followed by a slower migration of fission product activity through the break into the containment building. Finally, the pressure and temperature inside the containment building are reduced by the action of the H_2O spray system and by heat losses to the building structure and to the outside air.

2.2 Initial Conditions

The accident is assumed to occur after the reactor has operated for 365 days at a power of 70 MW. The average D_2O temperature is 285°C. The accident starts when the system breaks and D_2O flashes into the containment building at an assumed rate of 10,000 gpm. When 60 gal of D_2O has been lost (less than 1 sec), a scram is initiated by an 8% decrease in the reactor pressure. The containment building is evacuated (as for all scrams). The safety rods will be completely inserted about 4 sec after the break. About 3 sec after the break the reactor pressure will be reduced enough for boiling to start in the hottest portion of the system. Boiling will begin in the reactor effluent lines and spread to the bulk moderator and coolant channels as D_2O is lost. In one minute most of the D_2O will be ejected.

2.3 Core Temperature Rise

Once the core has boiled dry, the temperature of the fuel will increase rapidly due to the fission product afterheat. Upper estimates of the temperatures that might be reached were made with the assumptions that the only mechanism for heat loss is radiation and that the powers in the driver and test fuel are 2.2 MW and 1.5 MW per assembly, respectively.

The calculations were carried out as follows. Heat from the fuel radiates to the housings. Two-thirds of the housing surface of the inner six test elements radiates heat to other test element housings, and one-third radiates to the driver ring. One-third of the surface of the housings for the outer six test elements radiates to other test elements, and two-thirds radiates to the driver ring. The outer half of the driver housings radiates to the thermal shield. The small amount of heat conducted around the periphery of the housing tubes was taken into account. It was assumed that the core boiled dry 10 sec after the break. The entire core would not be dry at this time, but some of the fuel channels probably would. The initial temperature of the driver fuel was taken as 400°C, that of the test fuel as 700°C, and that of all housing tubes as 300°C. Table II lists some of the parameters used in the calculation.

The maximum temperature in the driver fuel is reached in two minutes and is about 1750°C, or 100°C below the melting point of zirconium.

The temperature of the uranium metal test fuel, on the other hand, reaches the melting point of uranium (1160°C) in one minute. The molten uranium is expected to break through the zirconium cladding and flow to the bottom of the test assemblies.

Table II
PARAMETERS IN CALCULATION OF CORE TEMPERATURES

Element	Heat Capacity, MW sec/(°C)(ft)	Area x Emissivity, MW/(ft)(°K)^4
Test fuel tube (thick-walled metal)	1.0×10^{-3}	1.0×10^{-15}
Test element housing	0.15×10^{-3}	1.4×10^{-15}
Driver fuel tube	0.47×10^{-3}	1.1×10^{-15}
Driver housing	0.15×10^{-3}	1.4×10^{-15}

At the elevated temperatures that will exist in the core, the zirconium and uranium will react chemically with residual steam. Tests on zirconium-steam reactions at temperatures up to 1750°C indicate that the reaction rate will be 1 to 5 mils/minute.(3) Thus, the driver tubes could be consumed in 15 minutes to one hour. The molten cores of the metallic uranium elements in the core will react more rapidly, but explosive reactions are not expected below 2200°C.(4) For the maximum credible accident, it is assumed that all of the uranium and zirconium in the fuel tubes react completely with water.

2.4 Heat Release

The heat released to the building consists primarily of the heat contained in 41,000 lb of liquid D_2O at 285°C. This heat content is about 7×10^6 pcu above that of water at 100°C, so this amount is available to boil the water into steam and heat the air in the building. The uranium-water reaction will add about 0.6×10^6 pcu for 12 metallic test elements, and the zirconium-water reaction will add about 1.5×10^6 pcu.

2.5 Pressure and Temperature Transients

The maximum values to which the pressure and temperature inside the containment building will rise were calculated from the equations that relate the heat available to the heat content of the components in the final state. In the calculations it was assumed that:

- the building is sealed completely as soon as the break occurs,
- all the air space in the building has the same temperature and steam content,
- heat transfer to the building and equipment is negligible, and
- the heat capacity of water vapor initially in the air and of helium from the reactor is negligible.

For the maximum credible accident, it is assumed that the chemical reaction is too slow to contribute sensibly to the maximum pressure in the building; thus Q is zero. The maximum pressure is 23 psig, and the maximum temperature is 108°C. The D_2O will flash out of the reactor in one or two minutes. The temperature and the partial pressure of steam will become fairly uniform throughout the containment building in a few minutes by spread of liquid D_2O and by convection currents set up in the air space. It is expected that the maximum values of the temperature and pressure will be reached in less than 10 minutes after the break occurs.

The maximum pressure is nearly equal to the 24-psig design pressure for the containment building, but is well below the 29 psig at which the building was test pneumatically. Even if the heat of reaction of the uranium and zirconium with water is immediately available ($Q = 2.1 \times 10^6$ pcu), the maximum pressure will be 28 psi.

After the accident, the pressure and temperature inside the building are reduced by two main mechanisms: (1) the liquid D_2O transfers its heat to the building structure and equipment, and (2) the H_2O spray system is started by a high pressure signal to cool the air and condense the D_2O vapor.

Figure 1 shows the calculated pressure as a function of time after the spray is started. The spray flow is 1000 gpm, and it is assumed that the H_2O, the D_2O vapor, and the air are in equilibrium at all times. The spray alone will reduce the pressure from 23 to 10 psig and the temperature from 108° to 80°C in 15 minutes.

After the spray has stopped, the pressure and temperature will continue to drop slowly as heat is transferred to the building and equipment. It is estimated that 12 hours after the accident the pressure will be about 3 psig, and the temperature will be about 50°C. Additional H_2O can be supplied to the spray system from the wells at 120 gpm.

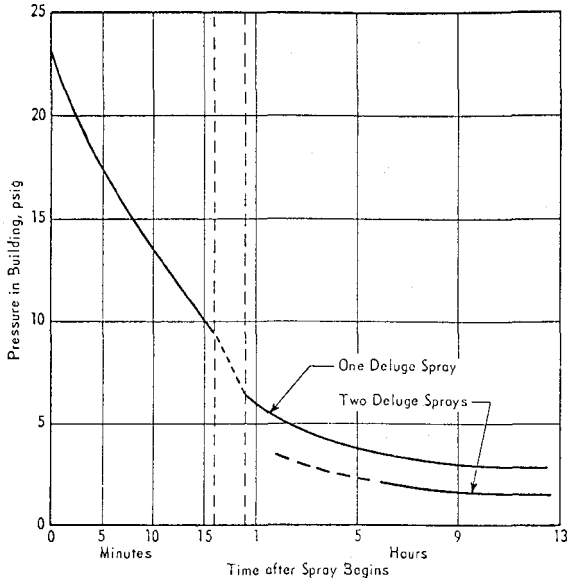


FIG. 1 - PRESSURE REDUCTION BY SPRAY SYSTEM

3. RADIATION HAZARD

3.1 Basis of Hazard Evaluation

The calculated dose for all radiation hazards is based on a fission product inventory equivalent to operation for 365 days at 70 MW. The accumulated exposure is about 25,000 MWD. Reactivity will limit exposure for the first few charges to about 15,000 MWD, but subsequent charges may operate up to 25,000 MWD exposures.

The commonly accepted assumptions and techniques[5] were used to calculate the doses for ingested radiation hazards. Similar assumptions, but slightly different techniques, were used to calculate the whole body dose from the cloud.[6] In both cases the dispersion of radioactivity in the atmosphere was estimated from the Sutton equation for a continuous point source at ground level. Therefore, many of the assumptions and parameters are common to both calculations.

The common form of the Sutton equation is:

$$C' = \frac{2Q}{\pi C_y C_z V D^{2-n} T} \exp\left[-\frac{Y^2}{C_y^2} - \frac{Z^2}{C_z^2}\right]\left[\frac{1}{D^{2-n}}\right]$$

where

C' = concentration of radioactive material in the air, curies/meter^3
Q/T = release rate of radioactive material, curies/hour
n = turbulence index
C_y = dispersion coefficient in the horizontal plane, meters$^{n/2}$
C_z = dispersion coefficient in vertical plane, meters$^{n/2}$
V = wind velocity, meters/hour

D = downwind distance from source, meters
Y = crosswind distance from cloud axis, meters
Z = vertical distance from cloud axis, meters

The dose from a ground level cloud can be obtained with appropriate forms of the equation. The parameters used in these calculations for inversion conditions are given in Table III and are typical of those used in Reference 5.

Table III

ATMOSPHERIC DISPERSION PARAMETERS

Parameters	Value
n	0.5
C_y	0.4 meters$^{\frac{1}{4}}$
C_z	0.07 meters$^{\frac{1}{4}}$
V	3200 meters/hour

The following assumptions were made concerning the release, leakage, and dispersion of fission products:

a. The maximum credible accident releases to the building the following percentages of the fission product inventory:

noble gases	100% (1.25×10^7 curies)
halogens	50% (6×10^6 curies)
solid products	1% (3×10^4 curies Sr)
equivalent gross fission product release	15%

b. Fifty percent of the iodines in the containment vessel remain available for release to the atmosphere. The other 50% is removed by absorption, settling, or adherence to internal surfaces. As the building atmosphere is quite humid after operation of the deluge system and release of steam, the moisture serves as a trap for the iodine. This assumption is conservative.

c. The internal iodine absorbers described in Section 1.2 remove the iodine with an efficiency greater than 99%,(1) at an effective removal rate of 5×10^{-5} sec^{-1}. This assumption is based on 1000 cfm circulation.

d. The release rate from the containment building is constant for the duration of exposure. The deluge system will reduce the building pressure to 10 psig before the fuel melts 15 minutes after the break. In 12 hours the building pressure is calculated to be less than 3 psig.

e. The wind direction does not shift for the duration of exposure. Since the wind direction at Augusta, Ga., in 1957 was never constant for as long as 24 hours, this assumption is conservative.

f. Atmospheric dispersion occurs under severe inversion conditions which persist for the course of the accident. Since measurements at Charleston, S. C., and Atlanta, Ga., indicate that the maximum frequency of day-long inversions is about 60% in June and 10% in January, this assumption is conservative.

g. Cloud depletion or fallout does not occur during cloud travel. This assumption is conservative.

h. Fission products do not decay in transit. Decay and removal by filtration is assumed while the fission product mixture is in the building.

i. Only the gamma activity contributes to the whole body dose from the cloud. The cloud is assumed to be large with a uniform source distribution. The absorption coefficient (μ) for the air is 0.00003 cm^{-1}.

3.2 Direct Radiation from Building

If all the radioactivity listed in Section 3.1 is released in fifteen minutes, the radiation dose rate in the vicinity of the containment building will be as shown in Table IV.

Table IV

RADIATION FOLLOWING MAXIMUM CREDIBLE ACCIDENT

Distance from Bldg, ft	Dose Rate, r/hr, at the Indicated Time after the Accident							
	15 min	1 hr	3 hr	10 hr	1 day	3 days	10 days	30 days
330	620	360	120	48	32	12	7.2	0.80
660	160	84	24	8.0	5.0	2.0	1.2	0.08
1300	13	7.2	2.0	0.80	0.40	0.16	0.08	0.01
2000	1.8	1.2	0.32	0.08	0.04	0.02	0.01	--
3300	0.07	0.04	0.01	0.01	--	--	--	--

3.3 Thyroid Dose from Cloud

The release rate of radioactive isotopes to the atmosphere is calculated from the equation

$$Q(t) = \frac{1}{P}\left[\frac{\lambda_1 F q}{\lambda_1 + \lambda_R + \lambda_f}\right]\left[1 - e^{-(\lambda_1 + \lambda_R + \lambda_f) t}\right]$$

where

$Q(t)$ = the activity from a specific isotope released from the building to the atmosphere during the interval t, curies/MW
q = the reactor inventory of a specific isotope, curies
P = reactor power, MW
F = fraction of a specific isotope available for release from the building
λ_1 = release rate from building, sec^{-1}
λ_R = isotope decay constant, sec^{-1}
λ_f = removal rate by the iodine absorbers, sec^{-1}
t = time, sec

The Q(t) is the source term for the atmospheric dispersion equation that is derived from the Sutton equation

$$A(t) = \frac{2R\ Q(t)\ P}{A\ C_y\ C_z\ D^{1.5}}$$

where

$A(t)$ = amount of radioactivity inhaled from the cloud during an exposure of t seconds, curies
R = breathing rate, $meters^3/sec$

Other terms are the same as defined previously.

The thyroid dose was calculated as the sum of the doses from the isotopes I-131, I-132, I-133, I-134, and I-135. The values of the parameters used were the same as for the whole body doses except as listed below.

Parameter	Value
F	0.25
q	Saturated activities at reactor power = 70 MW
λ_f	5×10^{-5} sec^{-1} (this corresponds to a circulation rate of 1000 cfm in a building volume of 320,000 ft^3)
t	Infinity (i.e., until all iodine isotopes have decayed)
R	20 $meters^3/day$ = 2.3×10^{-4} $meters^3/sec$

Calculations, on the above basis, show that the thyroid dose will be less than 30 rem at the Plant boundary, which is three miles from the reactor, for leaks of less than 3% of the building contents per day. This dose is less by a factor of 10 than the permissible dose of 300 rem and is less by a factor of 100 than the dose that would be experienced if the iodine absorbers were not installed. When maintenance is adequate to ensure operability of the iodine absorbers and to minimize the leakage from the building, the hazard from the thyroid dose is largely eliminated.

3.4 Whole Body Dose from Cloud

The whole body dose received by a person who remains at the centerline of the cloud for 30 days was estimated from the following equation, which was derived from the Sutton equation for the atmospheric condition described in Section 3.1.

$$r = \frac{1.84 \times 10^5 \; p \; f \; a \; t}{V \; D^{1.5}}$$

where

- r = dose, roentgen
- p = reactor power, MW
- f = release rate, fraction/hour
- a = fraction of gamma power from noniodine fission products averaged over the exposure time
- t = exposure time, hours
- V = wind velocity, miles/hour
- D = downwind distance, miles

The values of the parameters used in the calculations were

- t = 720 hours (30 days)
- a = 5.1×10^{-4}
- p = 70 MW
- V = 2 miles/hour

Calculations on the above basis show that the dose will be less than 25 r in 30 days at the Plant boundary for average leakage rates of less than 1.6% of the building contents per day.

The evaluation of the hazards from both the whole body dose and the thyroid dose shows that relatively large leakage rates are permissible. In fact, leakage rates as high as these persisting for 30 days are not physically attainable when the leakage of significant amounts of fission products begins at an initial pressure of 5 psig. After a leakage of 25% of the building contents, the pressure in the building is zero psig, and this leakage corresponds to a leakage rate of 0.83%/day for a total of 30 days. Therefore, the calculation of a permissible leakage rate greater than 0.83%/day for a period of 30 days implies that there is no limit on the leakage rate. Obviously, this implication is not correct since at high leakage rates the assumptions in the above calculations are not valid. If the bulk of the fission products were to escape in a short period after the maximum credible accident, the average activity of the fission

products would be greater than the activity averaged over 30 days, and in an extreme case the iodine absorbers would not have time enough to remove an appreciable fraction of the iodine.

The assumptions used in the calculations of the whole body dose were modified to permit the calculation of a physically more meaningful limit on the leakage rate. Assumption d in Section 3.1 was modified to: the release rate from the containment building is constant for the duration of the exposure, and the integrated leakage is 25% of the building contents. Calculations with this modified assumption show that the dose at the Plant boundary would be 25 r for a leakage rate of 4.5%/day lasting for a period of 5.6 days. The use of the modified assumptions has only a negligible effect on the thyroid dose, since the iodine absorbers remove iodine in a very short time compared to five days. This evaluation, therefore, shows that, even with very conservative assumptions, no exposures greater than 25-r whole body dose and 300-rem thyroid dose will be expected beyond the Plant boundary if the leakage rate from the building is less than about 2% of the building contents per day when the initial pressure is 5 psig.

REFERENCES

1. Prigge, G. H. Application of Activated Carbon in Reactor Containment. E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, S. C. USAEC Report DP-778 (1962).

2. Peters, A. H. Application of Moisture Separators and Particulate Filters in Reactor Containment. E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, S. C. USAEC Report DP-812 (1962).

3. Lustman, B. Zirconium-Water Reaction Data and Applications to PWR Loss-of-Coolant Accident. Westinghouse Electric Corp., Bettis Plant, Pittsburgh, Pa. USAEC Report WAPD-SC-543 (1957).

4. Chemical Engineering Division Summary Report for January, February, and March 1960. Argonne National Laboratory, Ill. USAEC Report ANL-6145(1960).

5. DiNunno, J. J., et al. Calculation of Distance Factors for Power and Test Reactor Sites. Division of Licensing and Regulation, AEC, Washington, D.C. USAEC Report TID-14844 (1962).

6. Menegus, R. L. and H. F. Ring. Accidental Dispersion of Reactor Poisons and the Controlled Distance Required. E. I. du Pont de Nemours & Co., AED, Wilmington, Del. USAEC Report DP-105 (Rev. 2) (1958).

DISCUSSION AND COMMENT

While the material is still in the reactor, we assume for each isotope, 132, 133, 134 and 135, that while it is in the building, it decays by natural radioactive decay, and we also assume that the iodine absorbers were removing the iodine from the atmosphere at the circulation rate of 1,000 cfm through the filter, and we assume that that was 99% effective.

Although we do have four filters in the building, we assume that actually only one was operative. Of the 320,000 cubic feet of air in the building, 1,000 cfm, was being circulated through this absorber unit. So there are two processes for elimination of the iodine; radioactive decay and absorption in the iodine units.

We test halogen removal capabilities by a freon test. We circulate air to these units, and air entering the unit contains freon, and we then measure the freon that is present in the air that passes through the filter, and from this we get the efficiency.

The experimental results of atmospheric values we did use, we took directly from this reference that I cited, which is 14844, a document put out by the AEC Division of Licensing and Regulations in Washington, and it is entitled, "Calculation of Distance Factors for Power and Test Reactor Sites."

We are concerned about how well these charcoal filters will maintain their efficiency over a two or three year span, and we do have testing programs under way, and Mr. List indicates we will take out individual units and test them from time to time, so in this way we will accumulate data. We also do have some work in progress in which we would actually test the efficiency of these filtration absorption systems actually in place. The best we can say is that we are still working on the problem, and hope to accumulate data which will serve as the basis for giving a better estimate of what the lifetimes of these units are.

Session Chairman: Hanford will be represented by the contribution, "Hanford Experience with Reactor Confinement," a paper by J. W. Green, W. V. Thompson and H. Copeland. Mr. Green will present the contribution.

HANFORD EXPERIENCE WITH REACTOR CONFINEMENT

by

J. W. Green, W. V. Thompson, and H. Copeland
Hanford Atomic Products Operation

INTRODUCTION

Hanford's experience with the reactor confinement system, in regards to its ability to perform the intended function, has been good. Although there have been no incidents since the installation of the confinement system wherein fission products would have been released to the atmosphere without a confinement system, extensive tests are conducted routinely to assure that the system will contain such fission products if called upon to do so. Before going into the details of these tests and the operational history of the various segments of the confinement systems, I would like to describe briefly what comprises the confinement system on a Hanford reactor.

The typical layout, shown in Figure 1, graphically illustrates the basic features of the confinement systems. Each system is composed of:

1. A ventilation system to force the air from the various zones surrounding the reactor block, through the filters before exhausting it through the stack to the atmosphere.

2. A filter facility that contains the particulate and charcoal filters.

3. A sample building, constructed above the ventilation ducts leading to and from the filter building, containing the instrumentation for monitoring for excessive radioactivity.

4. A dense, finely atomized, spray system within the rear face enclosure.

5. A stack which takes the air stream high above ground before exhausting it to the atmosphere.

I. VENTILATION SYSTEM

During normal operation, ventilation air is supplied to the building by two supply fans. A portion of this air is diverted to the confinement zones, while the rest of it is used in offices, shops, and storage areas within the reactor building. The air is then drawn into a common plenum which is connected to the suction side of the exhaust fans. Prior to installation of the confinement system, the fans discharged air directly to the stack without filtering. The plenum at the stack has been breeched, diverting the air flow through the newly constructed filter building before its release to the surrounding environment.

The confinement program improved the reliability of the existing ventilation system by modifying the existing exhaust fans and adding equipment to permit continuous flow of exhaust air from the confinement zone surrounding the reactor proper. A typical ventilation flow diagram

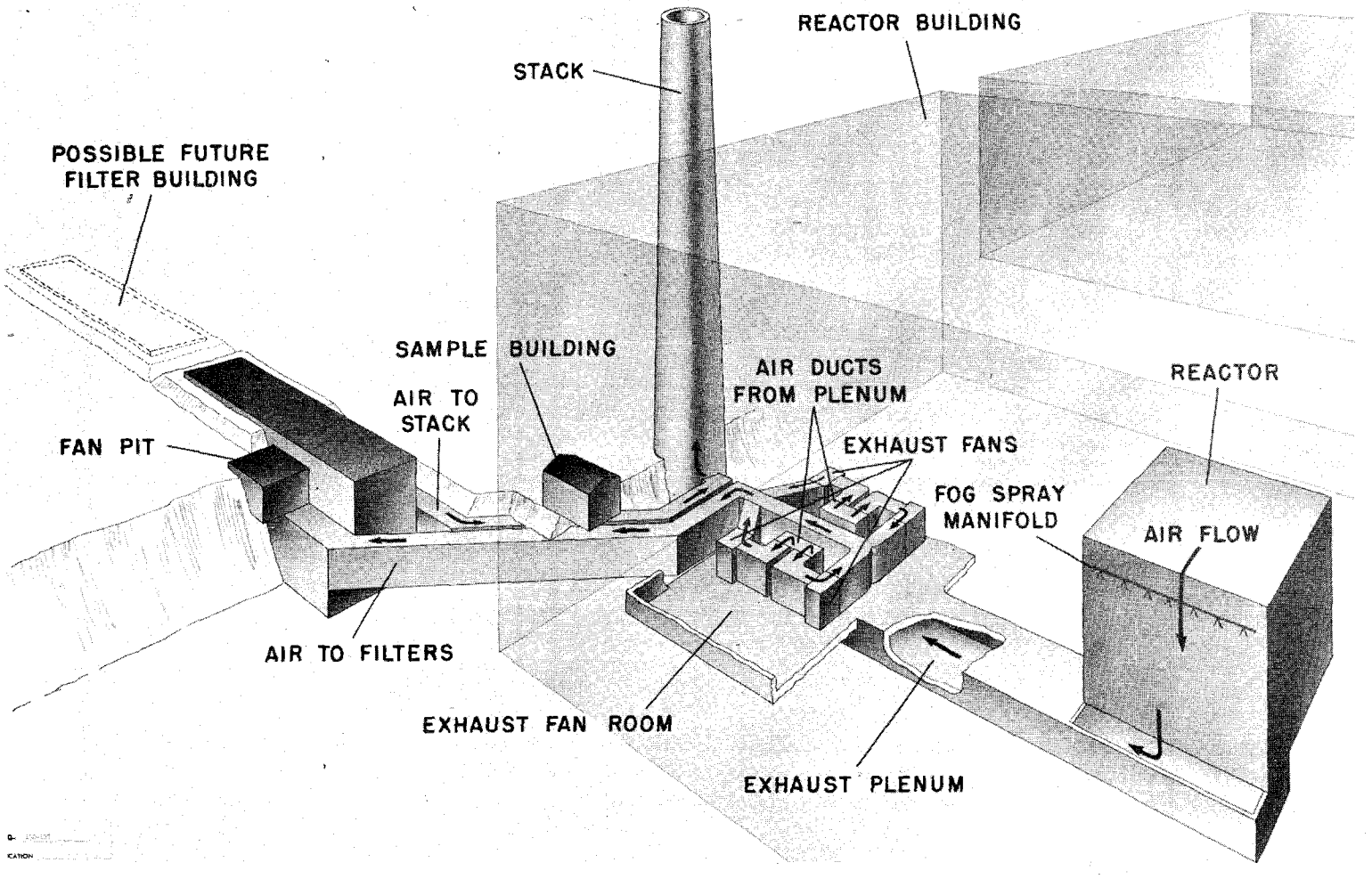


Figure 1 - FACILITY LAYOUT

is shown in the next slide (figure 2). The modifications to the system were as follows:

1. The electrically driven exhaust fans were upgraded to provide for the increased pressure drop of the new filter facility.

2. Emergency exhaust fans were provided with dependable steam or diesel engines in the event normal electrical power was lost.

3. Instrumentation was provided to automatically shut down the supply fans in the event of a reactor incident to insure that zone pressures are maintained negative with respect to atmospheric pressure.

4. Ventilation barriers were installed to permit the air balance crews to successfully balance the confinement zone pressures to slightly less than atmospheric pressure.

5. Alarms were provided to warn operating personnel of any significant change in ventilation balance.

Although the system functions well when responding to a simulated incident, certain problems have been experienced since the system has been in service.

Operating Experience

Pressures within the range of 0.02 to 0.06 inch water gage with respect to atmospheric reference within the confinement zone boundary have been impossible to maintain in a practical sense. Spurious trips of the confinement zone pressure alarms plague reactor daily operations. As yet, all causes of these spurious trips have not been fully resolved; however, programs are now underway to determine them. The reactor buildings are large and leakage rates high, which results in fluctuation of building pressures caused by varying wind velocities.

The automatic, spring loaded, valve installed on the emergency exhaust fan steam turbine drives failed to open in most instances after being turned over for operational use. The problems with this valve were solved by proper adjustment of the valve linkages, lubrication of the valve moving parts on a mandatory schedule and the installation of a strainer upstream of the valve. The operational experience gained by this type of valve in service indicates satisfactory performance is only obtained through special care and maintenance.

To ensure proper operation and performance of the equipment to maintain continuity of exhaust air from the reactor to the filters certain functional checks are mandatory.

System Testing

In order that the system will operate satisfactorily when required, these functional checks are made at intervals ranging from weekly to quarterly. Each week the ability of the emergency exhaust fans to assume the ventilation air load is checked, and the fans are run until bearing temperatures reach equilibrium. On a three month interval the overspeed trip mechanism on the emergency exhaust fans are checked for operability. The gravity vacuum relief damper which is installed in

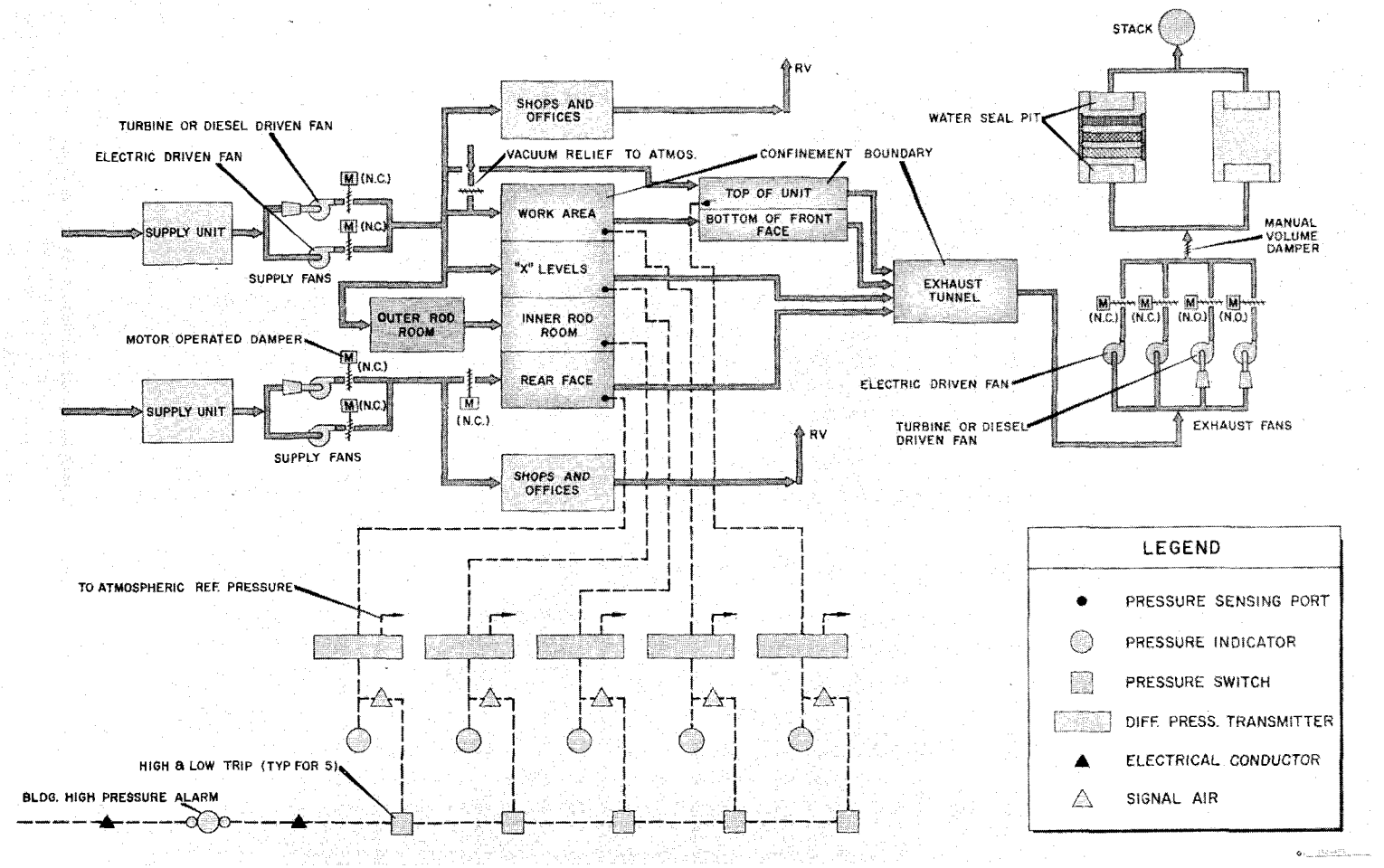


Figure 2 - TYPICAL FLOW DIAGRAM

the supply duct is manually checked for operability. This was installed to prevent collapse of the supply duct upon loss of supply air during an incident.

II. FILTER FACILITY

The confinement program at Hanford constructed a filter building approximately 59 feet long, 39 feet wide and 35 feet high, shown on the next slide (figure 3). The building is of reinforced concrete construction and is almost entirely below ground. It is connected to the existing stack breeching by two underground concrete ducts and metal breeching transition ducts above grade. The concrete intake and exhaust plenums in this building are provided with turning vanes to help streamline the flow of air to the filter cell. This lower section of the duct also doubles as a water seal pit when the filter cell is isolated for maintenance. All of the interior concrete surfaces located below ground level have been coated with a polyvinyl coating to seal any cracks in the concrete that could possibly be a leakage point in the event these surfaces be subjected to contaminated air.

Although normal radiation activity on the filters is quite low, the underground installation was used since (1) earth shielding is inexpensive, (2) abandonment in place would be simpler should this become necessary and, (3) the building and associated duct work causes less hinderance to moving vehicles and personnel.

There are two cells in this filter building that are separated by an operating gallery. Each cell contains provisions for three banks of filters in series and each bank provides for two aluminum filter frames which hold from 24 to 40 individual hi-efficiency or activated charcoal filters rated at 1000 cfm each. The volume of the reactor exhaust air of the plants varies from 85,000 to 150,000 cfm. The buildings were equipped with 96 filters for the lesser air flow and 160 filters for the greater air flow.

As a result of filter life tests, it was found that roughing filters added little to the effectiveness of the system and were nearly as expensive as the absolute filters. Upon completion of the filter building, the absolute filters were placed in the first bank and the activated charcoal filters in the third bank. This left the second bank unused.

Operational Experience

Installation of the absolute filters in the building started in early December, 1960 and was completed by late January, 1961. At this time the ventilation system was balanced; however, the final balance to confinement system requirements could not be completed until the activated charcoal filters were installed. The last activated charcoal filters were placed in service in October of 1961. These balances have proven to be tedious to make due to the magnitude of the system, the low pressure differential requirements within the zones and the fluctuations of building pressures caused by varying wind velocities. In April of 1962 the balancing of the system at each reactor plant was completed. The build-up on the filters since that time is shown in the next slide (figure 4). The two plants shown have 112 and 160 filters with average flow rates at 900 and 800 cfm and have a corresponding ΔP build-up at 2.4 and 1.5 inches of water. Other Hanford plants are located between these two curves. The wide spread of the curves is a

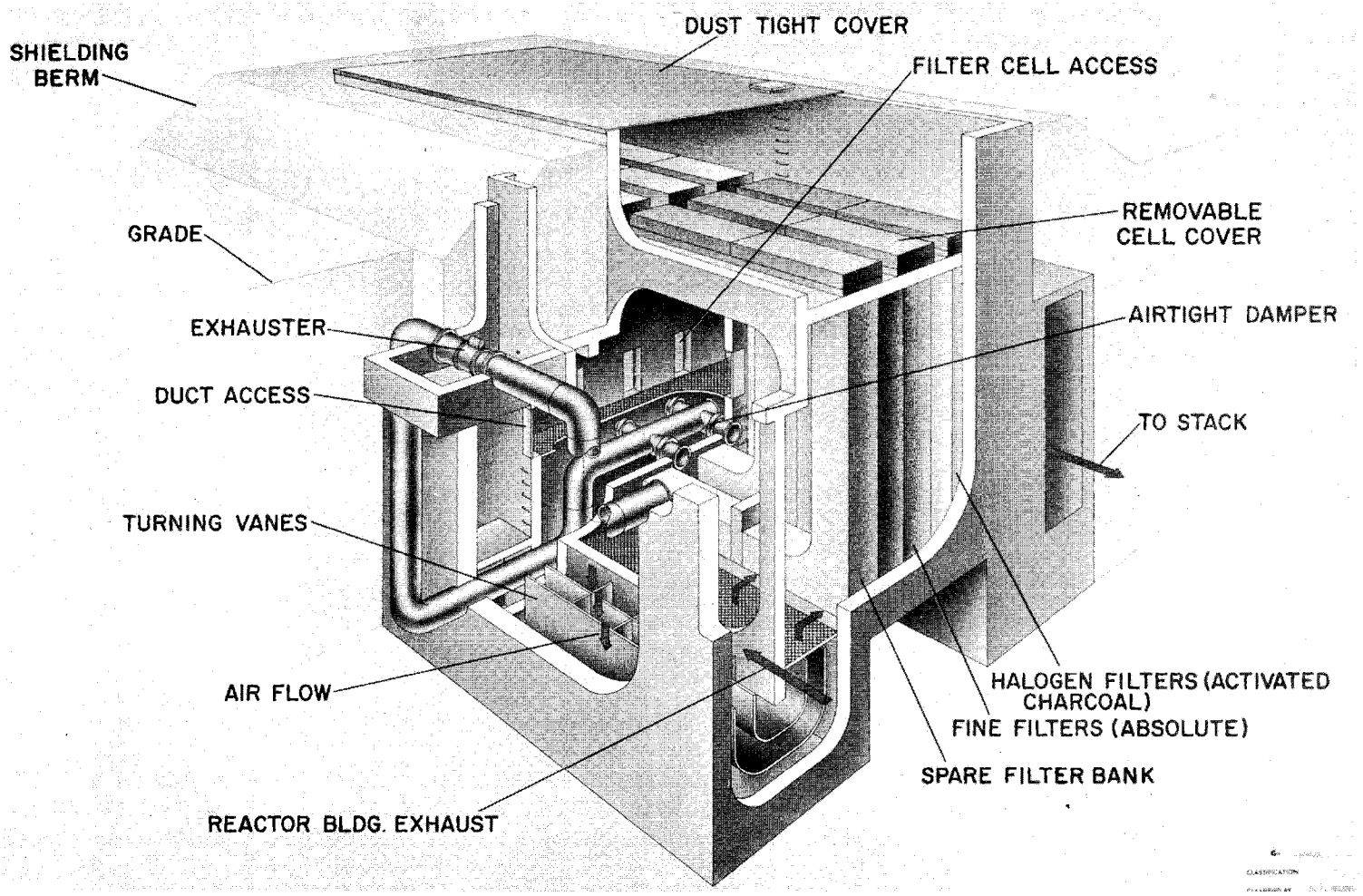


Figure 3 - FILTER BUILDING

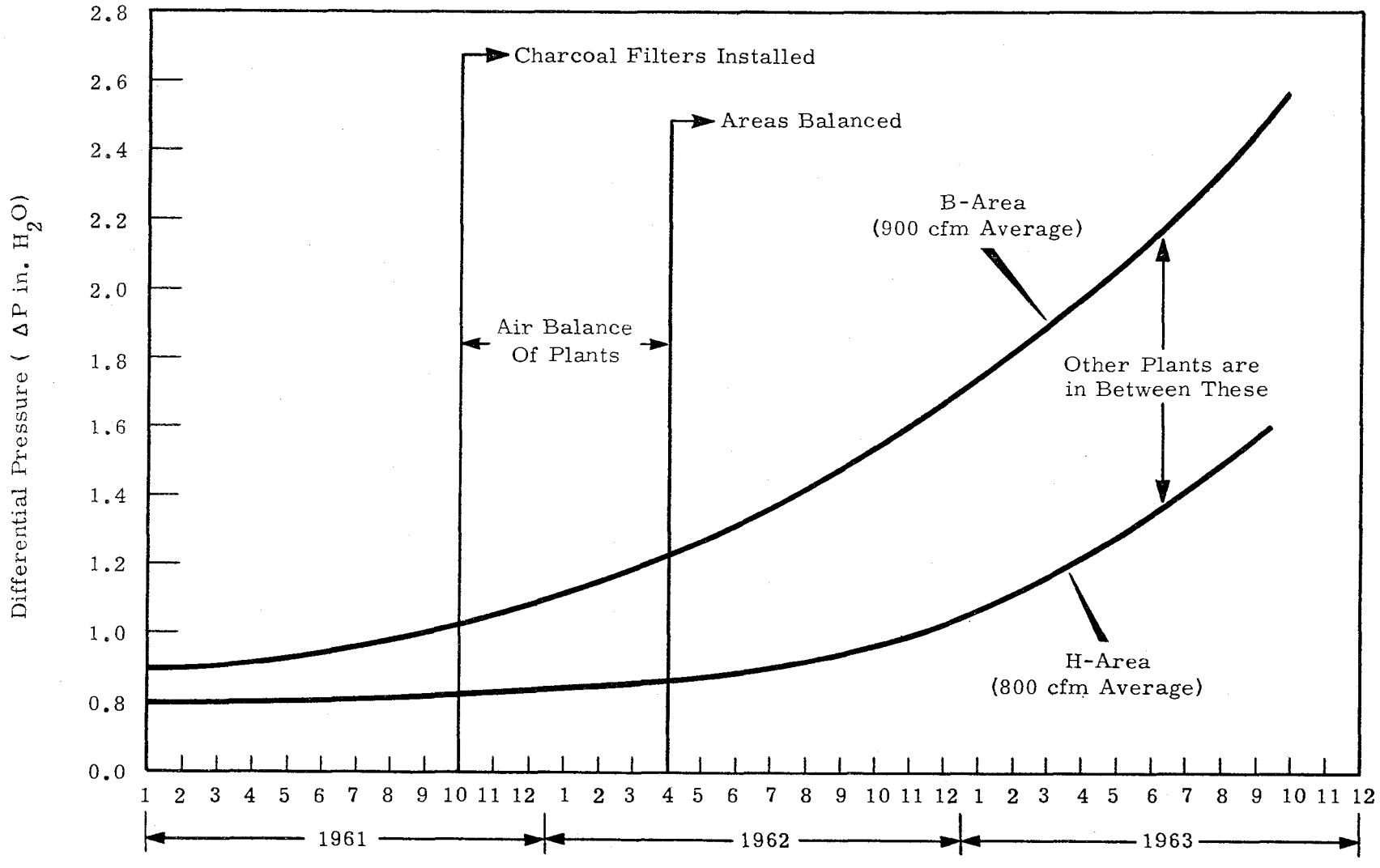


Figure 4 - LOADING HISTORY OF HIGH EFFICIENCY FILTERS (1961 - 63)

function of many variables which include heights of supply air inlet plenums from the ground, location from prevailing wind directions, particulate producing activity within the reactor building confinement boundary, control of closed doors, length and areas of exhaust air plenums, continuity of washing the supply air to the confinement zone, and preventive maintenance on the supply air filters. As mentioned before, the hi-efficiency filters have been in service prior to this time. These filters will experience three years, in January, 1964, in-line filtration. It is estimated that filter replacement will be required when the pressure drop across the filters reaches 2 to 4 inches water gage and appears that a likely replacement of some hi-efficiency filter banks will start somewhere between mid 1964 or early 1965. This indicates that the filters will exceed the anticipated three year life except for those filters that were replaced recently in the bottom rows in 11 out of a total 16 cells in the eight reactor plants.

During one of the plants routine removal of a charcoal filter test section, the hi-efficiency filter bank located upstream of the charcoal filter bank was visually examined for deterioration and damage. The examination disclosed that the bottom two rows of the absolute filter bank in this cell needed to be replaced. The next slide (figure 5) illustrates the damages to the first and second rows. As can be seen, the folding edge of the media has completely collapsed onto the inner separator and spread out between the outer separators. A closer look shows the inner separator to be completely exposed in many places on the bottom row. As a result of this examination the opposite filter cell in this plant and both filter cells in the other plants were inspected. As mentioned before, 11 out of 16 cells visually showed similar damage to either the bottom row or the bottom two rows. The actual phenomena that takes place is unknown but is believed to be the effect of water conveyed onto the filters. Referring back to the slide (figure 4) of the filter building, moisture in terms of humidity can get to the filters via the exhaust air stream, and the other possibility for water being carried to the filters exists when isolating a cell for entry. Upon entering the plants filter cells for visual inspection, it was discovered that in some plants the bottom two rows of filters were wet. Investigation, in each case, showed air flowing through the cell when the inlet seal pit was being filled with water. The result is water is blown onto the filters due to the greater air pressure on one side of the seal wall as compared to the water sealing heights on the other side. As a result of the investigation, the standard operating procedures for isolating cells have been revised to eliminate all possibilities of exhaust air flow through the cell while filling the inlet seal pit. Also, for further precautions the filters are being moved from the first stage to the second stage; thereby, giving additional distance between the filters and the seal pits.

Until the botton rows of the filters became damaged, engineering effort was directed towards providing a more reliable inflated neoprene filter frame seal on the halogen filter banks. Approximately half of the 56 seals in service have experienced leaks. In all instances the leak was located at the vulcanized joints. Recently, new seals have been purchased under more rigid specifications, and it is hoped that these seals will provide the expected three year life.

System Testing

To insure the high degree of filteration efficiency required of the confinement facilities the hi-efficiency filters are tested annually for leakage by in-place DOP testing and visually inspected quarterly for loading and damage. As mentioned before, each cell is supplied with

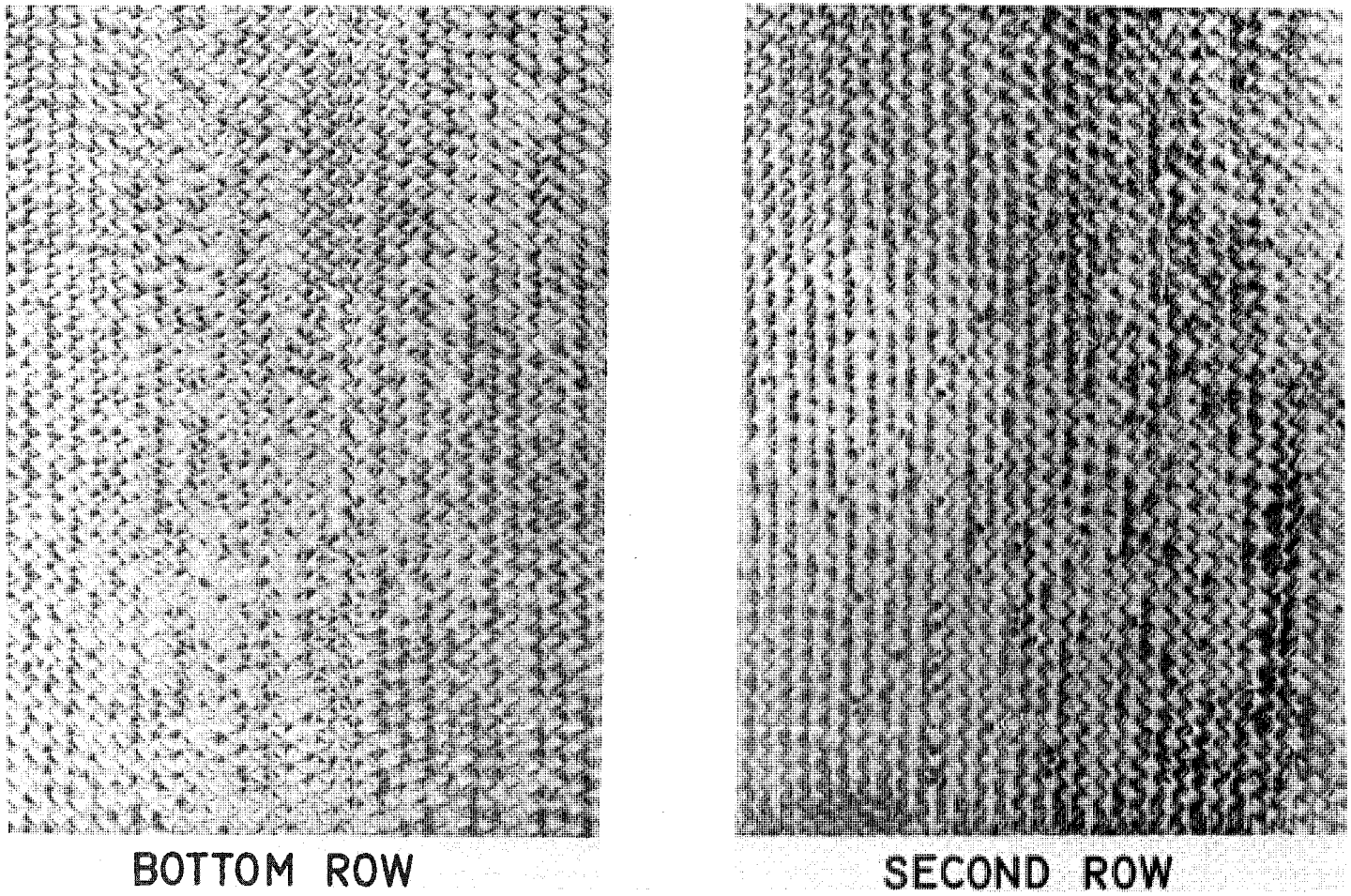


Figure 5 - DAMAGE ON LOWER ROWS - HIGH EFFICIENCY FILTERS

test sections (samples) which are representative of the in-service halogen charcoal filters. On an annual basis a sample is removed and tested to determine the absorptivity of the charcoal filters. These laboratory tests indicate the useful life of the filters. Further information on these charcoal filters is presented in Jerry McCormack's talk.

III. INSTRUMENTATION

A. Reactor Zone Static Pressure System

1. Description (Slide No. 6) The static pressure in each of five ventilation zones in the reactor building is monitored with sensitive differential pressure instruments. Each zone is connected to the measuring tap of a low range pneumatic differential pressure transmitter. A common atmospheric reference line is connected to the reference tap of each transmitter. The pneumatic output signal from each transmitter goes to a static pressure indicating gage, and to a pressure switch. When the static pressure in any of the zones reaches an unsafe level the pressure switch contacts actuate a warning alarm. The zone static pressures, with respect to atmosphere, established by balancing the ventilation system are:

   Inner Rod Room -.04 In. H_2O
   Work Area -.02 In. H_2O
   Experimental Level -.02 In. H_2O
   Top of Unit -.025 In. H_2O
   Discharge Area -.08 In. H_2O

2. Operating Experience During windy conditions the zone pressures fluctuate so as to actuate the warning alarm. Difficult has been experienced in locating the atmospheric reference to minimize the effects of wind direction changes.

3. System Tests The static pressure transmitters, indicating gages, and pressure switches are routinely calibrated. The zone static pressures are routinely checked and ventilation air balance adjustments made as necessary.

B. Gas Sampling and Radiation Monitoring System

1. Description The reactor building exhaust air is continuously monitored both upstream and downstream of the confinement filters for radioactive particulate matter, and for radioactive Iodine (I^{131}). Each filter-cell also has a gamma monitor for measurement of accumulated radioactive build-up on the filters.

   The particulate monitors draw a continuous air sample from the ventilation exhaust duct. The sample is passed through a continuously moving filter paper upon which any particulates are deposited. The filter paper is monitored with a beta sensitive radiation detector. The radiation pulses are counted with a log count rate meter and recorded on a six decade strip chart recorder which actuates an alarm upon high count rate.

   The upstream and downstream radioactive Iodine (I^{131}) monitors continuously monitor an air sample from the ventilation exhaust duct. The upstream sample is passed through a gas pig where a

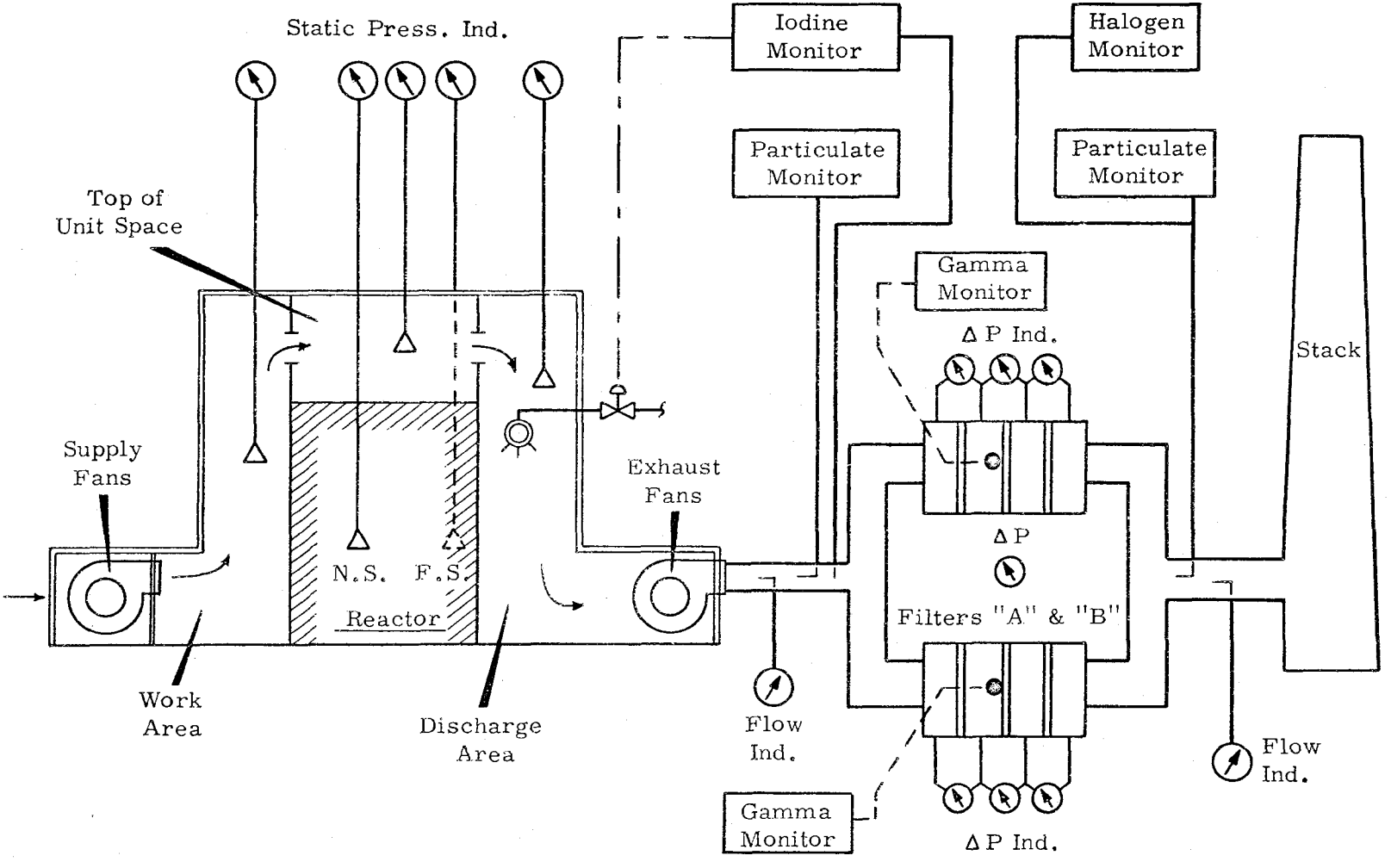


Figure 6 - CONFINEMENT SYSTEM

fixed volume is monitored for I^{131} with a scintillation type gamma detector. The downstream sample is passed through a charcoal filter within a pig where the accumulated I^{131} is monitored with another scintillation type gamma detector. The upstream pulses are amplified, discriminated for I^{131} energy level fed to a differential count rate meter and recorded on a strip chart recorder. The fog spray actuation and shut down of supply fans is initiated by a contact meter controller connected in parallel with the recorder. The downstream pulses are amplified, discriminated for I^{131} energy level, fed to a log count rate meter, and recorded on a strip chart recorder. Contacts in the recorder actuate a high activity alarm.

2. Operational Experience Considerable attention was required in setting up the instruments and performing the initial calibration. Filter paper drive failures have been experienced on the particulate monitors. Some overheating of electronic instruments required additional cooling. Day-to-day activity trends are noted on the recorders and changes correlated with processing activities in the reactor. No activity level has been high enough to actuate the fog spray system.

3. System Tests The response of these systems is routinely tested with radioactive sources. Initial response and calibration proof tests were run on the Iodine monitor s using an Iodine generator. Routine test and calibration of the electronic instrumentation is also performed.

C. Ventilation Flow and Filter Differential Pressure

1. Description A pitot tube is located in both the inlet and outlet ventilation ducts of the filter building. The pitot tubes are connected to flow indicating gages.

   The filter banks in each filter cell have upstream and downstream pressure taps connected to gages that indicate the pressure drop across each filter. Also, the total pressure drop across each filter cell is indicated on differential pressure gages.

   No abnormal performance of pitot tubes or gages has been experienced. The gages are routinely calibrated for accuracy.

IV. FOG SPRAY

The fog spray is a finely divided water spray system located within the rear face (fuel discharge) enclosure and is designed for automatic or manual operation. This is shown in more detail on the next slide (figure 7). Basically the system is a four inch stainless steel header mounted in the center of the ceiling in the rear face enclosure with spray nozzles attached at intervals that provide for optimum coverage by the water spray. When the system is in the automatic mode of operation, the valving to the fog sprays is activated by the scintillation detector system which continuously monitors the reactor building exhaust air. The manual operation of the fog spray is accomplished by either manual operation of valves at the valving station or by turning the fog spray switch located in the control room to the "emergency on" position which in turn operates the valves supplying water to the fog spray system.

Specifically the system is designed for the multiple purpose of:

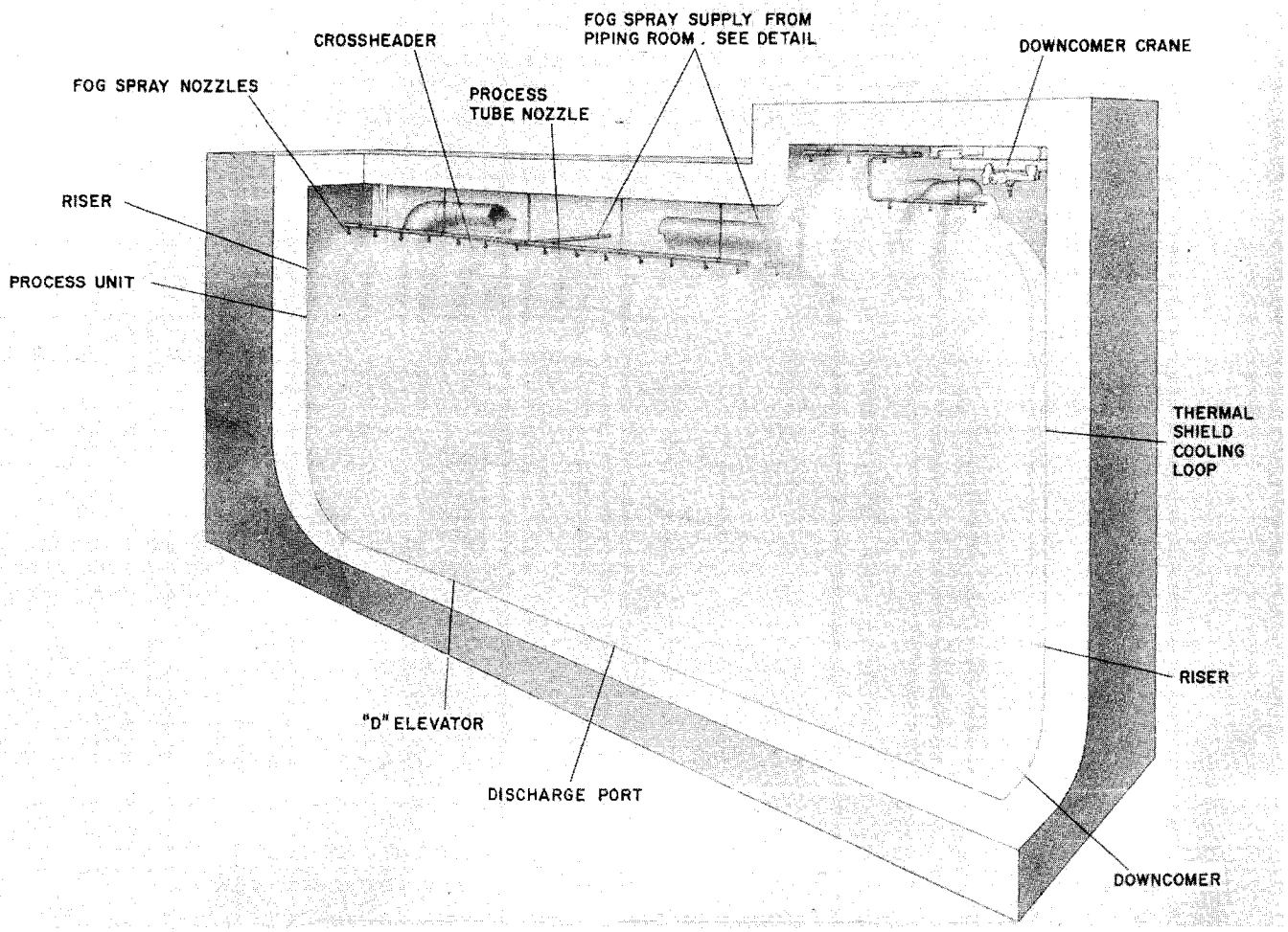


Figure 7 - FOG SPRAY SYSTEM

1. Absorbing a portion of the halogen vapors released during any uranium fires.

2. Settling out a portion of the airborne particulate matter released during fuel element fires.

3. Washing down exposed surfaces within the rear face enclosure for removal of contaminated particulates.

4. Providing some degree of thermal cooling to exposed fuel elements.

5. Condensing any steam that may be formed to prevent unnecessary pressure build-up within this area.

A reliable source of supply water to the sprays was provided by the addition of controls to automatically start back-up steam driven pumps in the event of electrical failure.

This component of the confinement system was the first phase of the work to be completed and was turned over to the reactor plants for use before completion of the rest of the system.

Operational Experience

Originally it was planned to activate the fog spray system by a signal from a scintillation detector that measured the concentration of radioactive Iodine in the exhaust air stream. This was proven to be unsatisfactory due to the background fluctuations and secondary radiation of Argon 41. The condition was corrected by the use of a linear differential amplifier that furnished the signal to activate the fog spray.

During the years of operation none of the reactor plants has had a credible incident that would activate the fog sprays when put on automatic operation; however, it has proven to be effective and of value in (1) reducing spread of contamination, (2) reducing air borne contamination during periods of reactor maintenance in the rear face, and (3) cooling exposed irradiated fuel. On these occasions the reactors were shut down and the fog spray system was activated by manual operation from the control room. Utilization of the fog spray system by manual activation during reactor outages has been advantageous as a source of water for rinsing off surfaces of the discharge area after chemical decontamination.

In no instance has the activation of the fog spray system failed when required. This reliability and performance of the equipment at the reactor plants is the effect of mandatory functional checks required by the process equipment standards.

System Testing

Each week the Iodine monitoring equipment which provides the trip signal for the fog spray system is functionally tested and calibrated against a known radiation source. The valving to this spray system is visually checked for operability each month, and automatic activation of the valving by tripping the Iodine monitoring equipment is operated at full flow and inspected for evidence of plugging and adequacy of water coverage of the sprays.

By: W. V. Thompson

THE SRP PRODUCTION REACTOR CONTAINMENT PROGRAM

by

J. A. List

E. I. du Pont de Nemours & Co.
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ABSTRACT

A program is under way at the Savannah River Plant to increase the containment facilities as much as practical in the existing production reactor buildings. The major features of the system are outlined, and the air cleaning portion of the installation is discussed in detail.

INTRODUCTION

Congressional authorization has been given to provide the Savannah River production reactors with additional facilities to minimize the escape of radioactivity in the event of a nuclear incident. This partial containment program will provide the maximum practical protection utilizing the existing building structures.

As I'm sure most of you are aware, the Savannah River reactors are cooled and moderated with heavy water. The reactor buildings are of heavy concrete construction designed to have a certain degree of resistance to an outside blast such as might occur during an enemy attack. The ventilation systems for the process areas are high capacity, once-through systems. The reactors are separated by about 2-1/2 miles and are 5 miles or more from the nearest plant boundary.

In order to decide upon the approach to be used in adding containment to the existing buildings, a great many potential accidents were analyzed. These analyses included not only the situation at the instant of the accident but also considered conditions following the accident up to the time no further operator attention or equipment functioning would be required. The results indicated that most accidents would be self-limiting and that the chance that the pressure capabilities of the building would be exceeded were very remote. On the other hand, many of the less severe accidents could deteriorate into serious situations if not properly handled.

Most of the potential accidents would result in limited fuel melting and a surge of contaminated steam into the Process Room at the time of the accident, possibly followed by additional fuel melting, steam generation, and release of fission products, depending on how well the decay heat was controlled after the incident.

DESCRIPTION OF THE SAVANNAH RIVER CONTAINMENT SYSTEM

A great many systems were considered during the early Savannah River containment studies. The usual approach of enclosing the reactors in a

containment shell was ruled out by the necessity of using the existing building. On the other hand, it was doubtful whether a filtration system could satisfactorily handle the radioactive steam and fog that could be generated by potential accidents. Decay heat removal also presented a problem, as an analysis of the heat transfer capabilities of the building indicated that very high temperatures would be reached if no means were provided for removing heat from the building. Many possibilities were considered and rejected before it was decided to install the best practical filtration system and, at the same time, to take all reasonable steps to prevent further fuel melting after the initial incident and thus minimize the load on the filters. The system that resulted consists of the following major items:

1. A filtration system to remove a high percentage of particulate matter and halogens from the ventilation exhaust.

2. A system for the control of decay heat to prevent fuel melting after an accident; the system should use the normal cooling system if possible and, if not, provide for direct addition of light water to the heavy water system.

3. Open earth basins to collect contaminated water generated by the addition of light water to the reactor.

4. Remote control facilities to operate certain critical equipment if evacuation of the area should become necessary.

5. Sealing of the Process Room to the extent practical to minimize escape of activity through passages other than the exhaust system.

6. Sprays in the Process Room to cool an irradiated element dropped during discharge from the reactor.

7. Numerous changes to make critical equipment or power supplies more reliable under incident conditions.

Although our interest here is primarily in air cleaning systems, I would like to say a few words about some of the other features before proceeding to a more detailed discussion of the filtration system.

The control of decay heat proved to be a difficult problem. The heat could not be removed by allowing the moderator to boil, as the fuel would quickly become blanketed with steam that could not escape. Recirculation systems handling hot contaminated water did not seem to offer the required degree of reliability.

The direct addition of light water was selected as the simplest and most reliable system; however, the addition of light water at rates sufficient to prevent boiling would generate large quantities of contaminated water that could not be allowed to escape to the Savannah River. Provisions were made to store this water in large open basins, which is definitely not a permanent solution; however, the activity will be retained on the Plant and can be dealt with after the incident is under control.

The remote control system supplies information on conditions in the building and permits operation of certain critical equipment in the building including the light water addition system. The existing system for remote control of the electrical distribution system was expanded for this purpose.

The other features of the system are largely self-explanatory.

THE AIR CLEANING INSTALLATION

The filtration system consists of high efficiency particulate filters and activated charcoal units. The use of such a combination in a containment system is not new, but the Savannah River system is unique because it is applied in exhaust streams containing mixtures of steam, air, and water droplets. It had been established at Hanford that such a system would handle air containing up to 100% humidity, but it was not certain that the system could survive in an exhaust stream containing steam and entrained water. As soon as the decision was made to proceed with containment at SRP, a program was undertaken to select the best available components for the filtration system and to evaluate its capabilities. The goal set for this program was a system which could:

1. Remove 99+% of the particulate matter and 99.9+% of the iodine from steam or steam and air mixtures;

2. Handle flows per filter unit (normal rating 1000 cfm) of wet steam at 7000 cfm for 30 sec. and 2000 cfm for 5 min. to be followed by a flow of steam and air at 1000 cfm with the amount of steam reduced in steps to follow steam rates characteristic of those produced from reactor decay heat;

3. Have a life of 3 months following an accident; and

4. Provide for remote removal and disposal of filter units.

I'm sure you will agree this is asking quite a lot of a filter system, and we were not at all sure it could be attained. Fortunately, only partial success was necessary to justify the installation. As it turned out we came closer to attaining these goals than was expected when the program was initiated.

Tests with filters quickly established that high quality water-repellent filters would withstand the flows given above as long as they were clean, but when a layer of dirt built up on the filter medium the dirt layer would "blind" with water and the desired flows could not be obtained. Since it was obviously impractical to make the dirt layer water repellent, a high efficiency entrainment separator was added up-stream of the filters. These separators are known as "Demisters" and are manufactured by the Otto H. York Company, Inc. The "Demister" used in the Savannah River system consists of a two-inch-thick mat woven from stainless steel wire wrapped with "Teflon"* fibers. The "Demisters" are installed at the rate of 5 "Demisters" for 8 filters in order to increase the superficial velocity and obtain a pressure drop of about 0.9 inch of H_2O across the "Demisters". With this combination, and with an accumulation of dirt on both the filters and "Demisters", flows would drop to 500-600 cfm after the initial steam burst but would recover as the amount of steam decreased. A temporary drop of this magnitude would not have a serious effect on the control of an incident, so these results were considered satisfactory.

Our application of activated charcoal units required high efficiencies in the presence of entrained moisture. The moisture proved to be no problem, as tests with small sealed carbon beds established that a one-inch-thick bed would consistently remove 99.99% of iodine vapor even when saturated with water from the first flow of steam and in the presence of entrained water up to 0.43 lb of H_2O/filter/min. The problems of obtaining high efficiencies were purely mechanical and consisted of the prevention of bypassing and the elimination of carbon dust which, of course, could carry iodine through the bed.

* Product of E. I. du Pont de Nemours & Co.

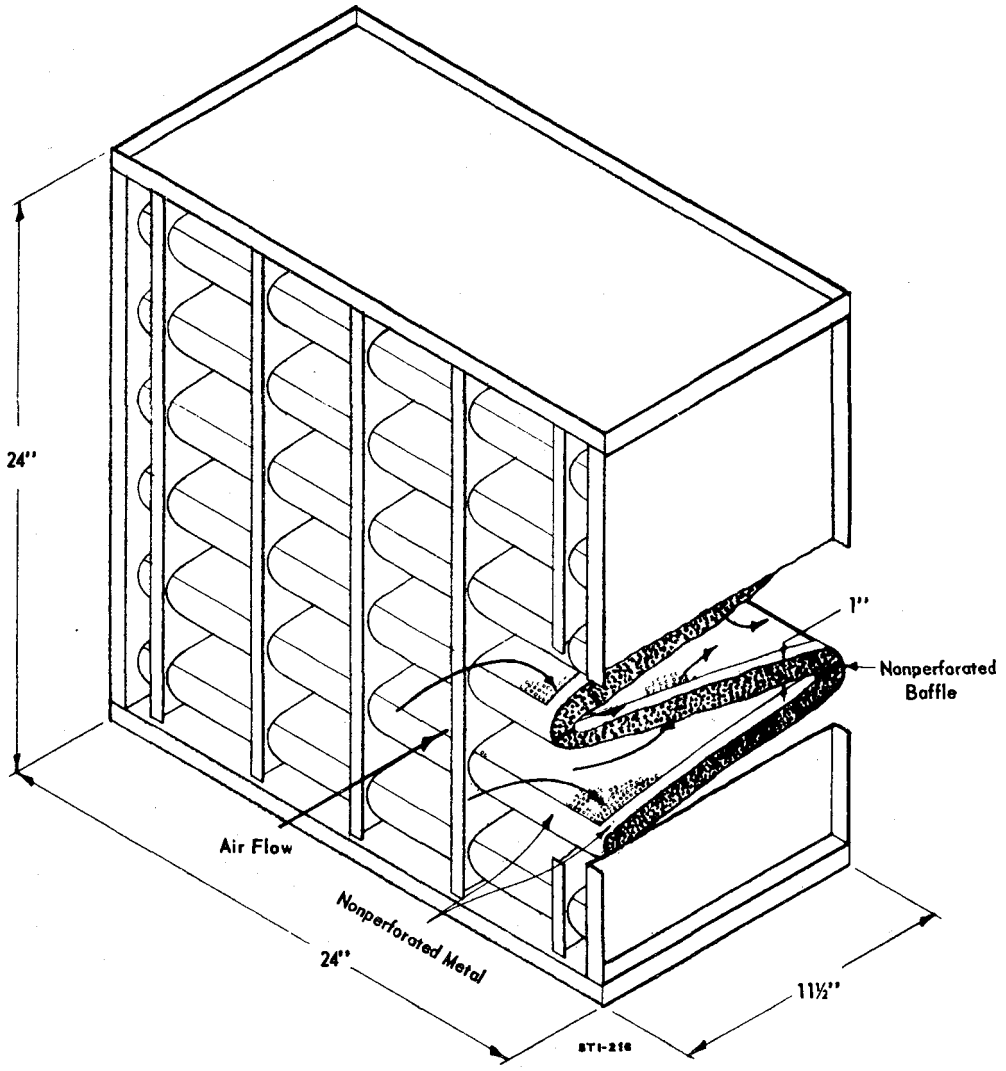
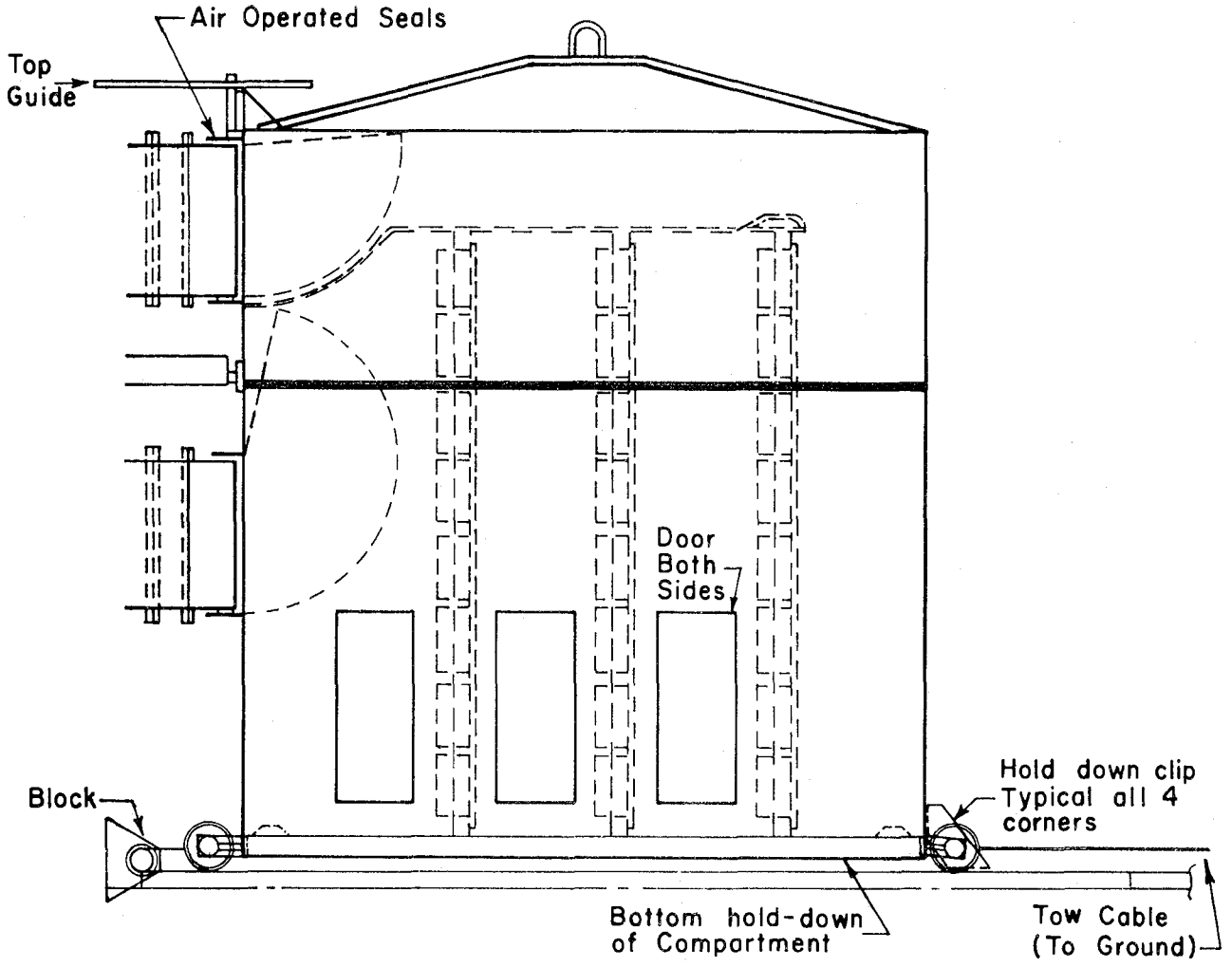


FIG. 1 ISOMETRIC DRAWING OF FULL-SIZE CARBON FILTER

Fig. 2

EXHAUST FILTERING SYSTEM
FILTER COMPARTMENT



Dusting was minimized by specifying a hard coconut shell carbon, and bypassing was minimized by careful design of the filter unit. Some of the features incorporated in these units are shown by the first slide. You will note that the edges of the screen are unperforated to avoid bypassing at the carbon-to-metal interface; the screen supports are all external for the same reason; the bends are not perforated to avoid high velocity areas; and a support plate is provided at the bends to minimize settling effects. When the carbon units are received, they are subjected to high air flows to detect dusting and to a "Freon" test to detect settling or bypassing. In the first shipment of 186 units no serious dusting was found, and only two units had removal efficiencies below 99.9%. The average of the other units was 99.99%. The two poor units were corrected by adding carbon to eliminate voids.

To avoid excess duct runs, the filter compartments were placed on a roof approximately 50 feet above ground level. Slide 2 shows the system that permits remote removal and disposal. The compartments are placed on dollies and both inlet and outlet are on one end so that the unit can be plugged into the system or unplugged much like plugging a toaster into an electrical receptacle. Contaminated units can be retracted to the edge of the roof, picked up by the shielded crane available on the plant, and hauled by rail to the burial ground. This system should permit disposal of the filters under any conditions permitting recovery of the building. Two other points regarding the compartments are that a space of four feet was allowed between filter banks to allow water drops to settle and to provide access for inspection, testing, and filter change; and that a small trough is provided under the front of each unit to prevent water removed by one unit from running down on the unit below it. To make provision of these troughs easier, the units are attached to the back of the support frame rather than the front as in normal ventilation practice.

A rigid testing and inspection program was followed for both filters and carbon units. A steam flow test was run on a filter fabricated from each lot of filter medium, and every filter was given the usual DOP test after completion. In addition, each installation was given an in-place DOP test, which will be repeated at least annually to ensure continued integrity of the filter system.

Procedures for filling and compaction of the carbon units were rigidly specified, and all units were filled in the presence of a Du Pont inspector. All units were also given an air flow and "Freon" test on arrival at the Plant.

As yet no in-place test for these units has been devised and periodic testing of sample units must be relied upon. However, an in-place "Freon" test is now being developed.

SUMMARY

The Savannah River containment filtration system is capable of reducing particulate matter by a factor of 100 and halogens by a factor of 1,000, even in the presence of substantial quantities of entrained water. Under incident conditions, the performance could be expected to be poorer because of such factors as the effect of radiation on gaskets and pneumatic seals, the possibility of overheating the filters or charcoal units, the presence of aerosols, and the possible loss of exhaust fans. However, the combination of the filtration system and provisions for control of decay heat should reduce by several orders of magnitude the probability of an accident affecting off-site areas.

DISCUSSION AND COMMENT

Savannah River operated about seven years without containment, and we have gone to it to provide an extra degree of protection since we are operating to closer limits. The cost has been in the range of eighteen million dollars for five reactors. The decision to go over was primarily an AEC one.

The de-misters are woven from stainless steel wire that are wrapped with teflon fibres; the weave is actually a combination of the two.

Session Chairman: R. D. Modrow, of Phillips Petroleum Company, has agreed to discuss the paper, "Removal of Particulates from the Waste Calcination Facility Off-Gas," by L. T. Lakey, J. A. Buckham and Mr. Modrow.

REMOVAL OF PARTICULATES FROM WASTE CALCINING FACILITY OFF-GAS

by

R. D. Modrow
L. T. Lakey
J. A. Buckham

SUMMARY

This paper discusses the removal of particulate matter from off-gas from the Waste Calcining Facility (WCF), a unit that will convert radioactive liquid wastes to granular solids in a heated, fluidized bed. Descriptions of the off-gas cleaning equipment employed are given together with data for each unit. Also discussed are sampling of the off-gas for particulate matter and other special techniques used in evaluating the system performance.

The overall decontamination factor for the off-gas cleanup system, consisting of a cyclone, a spray tower, a venturi scrubber and separator, silica gel beds, and AEC filters, was about 3.6×10^5. This resulted in a reduction of the solids loading from approximately 1.4 grains/acf to about 5×10^{-6} grains/acf; particulates in the final off-gas were essentially spherical and were less than 0.1 micron in diameter. This high degree of decontamination indicates that a noncondensing-type cleanup system can be used to reduce radioactive particulate contamination in a gas stream to a level low enough to permit the gas to be released safely to the atmosphere.

The use of a radioactive tracer in the system indicated the occurrence of a delayed-type of penetration of the AEC filters by the submicron particles. About ten days were required to reach an equilibrium value of penetration through the filters.

INTRODUCTION

The Waste Calcining Facility (WCF) utilizes the fluidized bed calcination process for the conversion of high-level aqueous radioactive waste solutions, resulting from reprocessing of aluminum-uranium alloy fuels, into compact granular solids. Treatment of the off-gas from the calciner to remove entrained fine solids is effected in a noncondensing-type system which does not result in the formation of additional liquid wastes. Initial development[1] of this continuous process by the Atomic Energy Division of Phillips Petroleum Company began in 1955 and led to the design[2] and construction of the WCF at the National Reactor Testing Station (NRTS) in the period from 1958 to 1960. Design and operating data in support of the WCF have been obtained from 6- and 12-inch diameter and two-foot-square pilot plant calciner units[3,4,5,7]. Early in 1961, cold testing of the WCF began with the use of a non-radioactive simulated aluminum nitrate waste solution, and was conducted intermittently over a total of 3700 hours of operating time. Late in 1962, cold testing was concluded with a continuous

month-long operating period during which a radioactive tracer was added to the feed to facilitate the quantitative determination of the effectiveness of the off-gas cleaning system.

In the fluidized bed calcination process, as exemplified by the WCF, waste solution is pneumatically sprayed at a nominal rate of 80 gph into a four-foot diameter by six-foot deep fluidized bed of alumina maintained at [illegible]°C. An inlet fluidizing velocity, based on the superficial cross sectional area of the calciner vessel, of 1.0 ft/sec is generally used and a freeboard of about six feet, in addition to a louvered baffle, is provided for de-entrainment of solids from the off-gas. The bed level is maintained by adjusting the rate of withdrawal of product. The calcination of the waste solution to granular alumina is accompanied by the release of large amounts of water vapor and gaseous products. These vapors and gases, along with air employed for fluidizing, feed atomizing, and purging, sweep a portion of the bed material, mainly the fine, irregularly-shaped particles, into the off-gas piping. The initial separation of these solids from the gas takes place in a cyclone which is followed by a wet scrubbing system, which includes a spray tower together with a venturi scrubber and its associated entrainment separator. In the scrubbing system, sufficient condensing is done to allow a scrubbing solution recycle rate of 10-20 gph back to the feed tanks. For a final treatment following the addition of superheat, the off-gas is passed successively through four silica gel beds in parallel and then through three AEC filters, also arranged in parallel. A schematic flowsheet of the WCF is shown in Figure 1.

Treatment to remove nearly 100 percent of the radioactivity from large volumes of off-gas is necessary in the WCF before the off-gas is released to the atmosphere. The calcination of Idaho Chemical Processing Plant (ICPP) aluminum nitrate wastes at 400°C results in two forms of radioactivity in the off-gas: vaporized ruthenium tetroxide, which is largely adsorbed in the silica gel beds, and fine solid material, which has essentially the same radioactive nuclide distribution as the bed material. In order to substantiate ruthenium decontamination factors that have been determined in previous pilot plant tests[6,7], the removal of ruthenium tetroxide by the off-gas system will be determined during initial radioactive operation of the facility. This report will discuss in detail only the removal of particulate matter from the off-gas as determined by using a radioactive tracer during operation of the WCF with simulated feed.

DATA COLLECTION

The off-gas was sampled for solids at various points in the system by passing a measured sidestream of the off-gas through a Millipore HA filter, a membrane-type filter with a dust removal efficiency of > 99 percent [8,9] for submicron particles. The sample probes were made from one-half-inch diameter stainless steel tubing with a one-inch taper to a sharp edge. The sample lines, which were from 10 to 35 feet in length, as well as the Millipore filter holders, were heated to preclude condensation. A typical sampling setup is shown schematically in Figure 2.

Four sampling stations were used to measure the rate of solids flow. They are located downstream from the venturi scrubber, downstream from the silica gel beds, and at two places downstream from the AEC filters. Equipment vent gas, which is mainly air used to sparge the contents of vessels not directly connected to the process system, enters the off-gas system between the last two sampling stations. The locations of these stations are shown schematically in Figure 3. The gas velocities at the face of the sample filters were approximately 10 cm/sec, except for one collection station downstream of the AEC filters which operated at a face velocity of 150 cm/sec. The off-gas sampling was nearly isokinetic, even though the particles were sufficiently small (< 0.3 micron) that it was not

FLUIDIZED BED WASTE CALCINING FACILITY

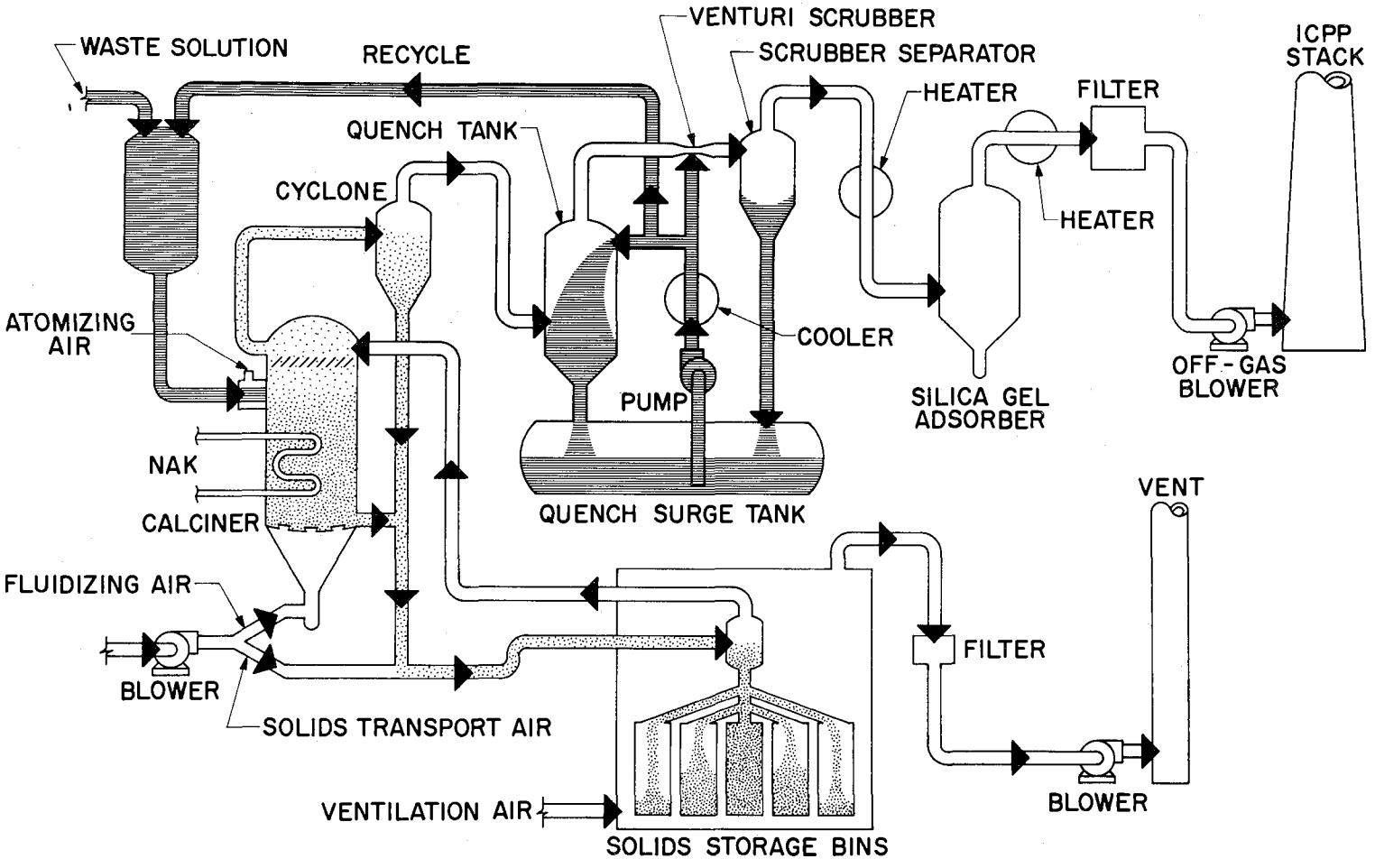


Figure 1. Fluidized Bed Waste Calcining Facility

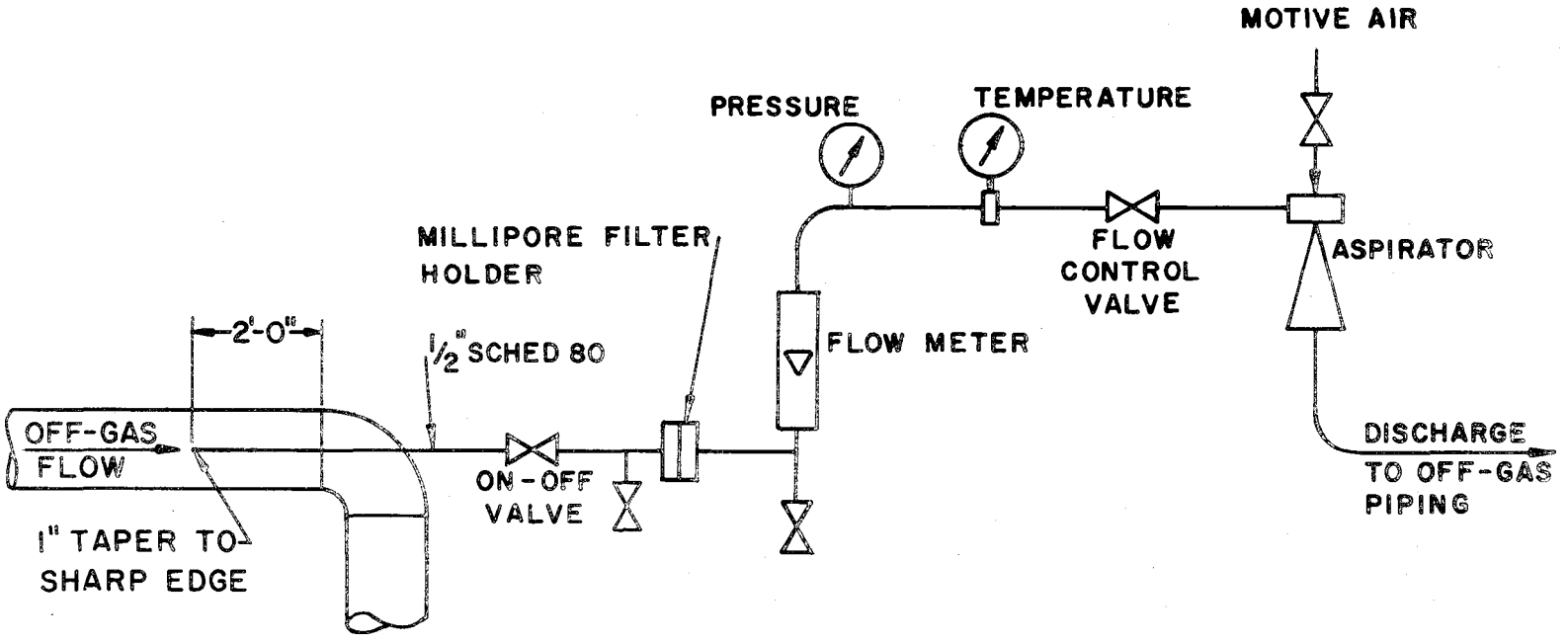


Figure 2. Typical Off-Gas Sampling Setup

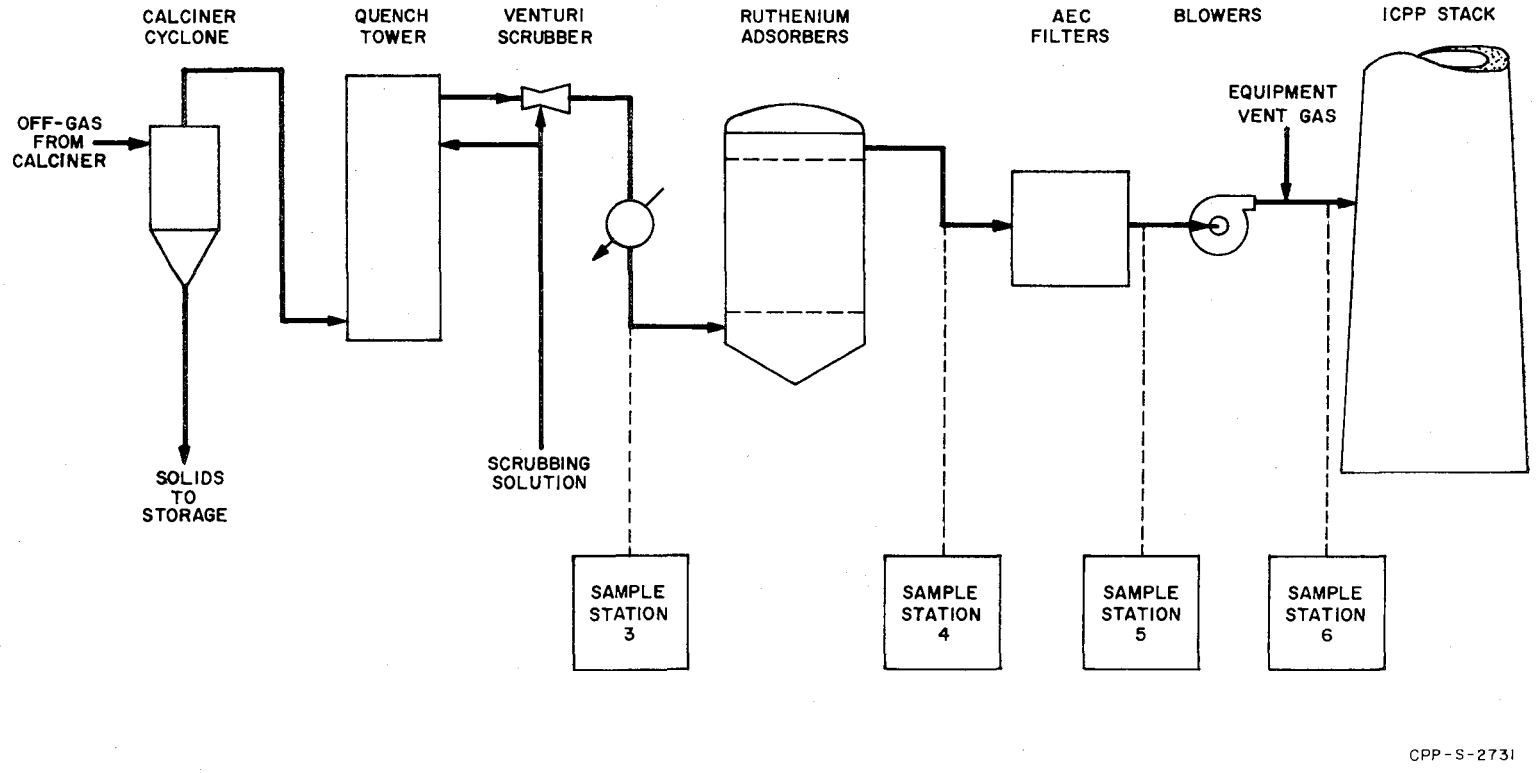


Figure 3. Location of Solids Sampling Stations

necessary[10]. In all cases the stream velocities were greater than the sampling velocities, so that larger particles, if there had been any, would have had a tendency to be carried into the probe in disproportionately high amounts.

After the solids were collected for a predetermined time, varying from 4 to 24 hours, depending on the solids concentration at the particular point, the filters were removed from the filter holders and the amounts of solids were determined by at least one of three different methods. One method, gravimetric, was to ash the filter plus the plastic bag used to transport the filter, and weigh the residue. This technique worked satisfactorily for samples collected only at sample station 3 which is downstream from the venturi scrubber, since the weight of solids collected at other sample stations was too low for such measurements to have practical significance. Another method, tracer activity, was used to correlate the activity of solids collected downstream from station 3 with the solids weight-to-activity ratio at station 3, where both gravimetric and tracer activity measurements were made. Because the sodium-24 tracer activity decayed beyond the detection limits within four days at the downstream sample stations, a third method, activation, was used in which the sodium normally in the solids was activated by irradiating the filters together with a standard alumina sample in the MTR, a nuclear reactor. The decay disintegrations of the solids on the filters were then counted, as in the tracer activity method, and compared with the activated standard alumina sample to arrive at a sample weight.

Spot checks of the sizes of particles collected at the four sampling stations in the WCF off-gas system were made with an electron microscope. The particles were all submicron in size, ranging from 0.3 micron in diameter to less than 0.01 micron, and all appeared to be essentially spherical in shape. Preparation of the sample for viewing involved the transfer of a small amount of partially ashed filter to a pollodion-covered electron microscope grid. Identification of the particle shape as well as estimation of the sizes of the particles was enhanced through the use of stereophotographs of the images. The size distributions of the particles found in the off-gas system are given in Table I.

PERFORMANCE

Removal of Dry Fines: Initial removal of the solids from the calciner effluent gas is performed in a Multiclone, a parallel arrangement of small cyclones with a single inlet and a common fines hopper. The system generally has been operated so as to give a cyclone decontamination factor (DF) of 4, which is equivalent to 75 percent efficiency and is the ratio of the inlet to the outlet flow of solids in the off-gas.

Although the original Multiclone unit had 16 elements, only 6 to 9 of these 6.5-inch diameter cyclone elements have normally been used and the rest have been blocked off because of a change in operating requirements. The original cyclone is shown in Figure 4. The off-gas inlet velocity to the individual elements has generally been 50 ft/sec when using six of the elements and the cyclone DF has ranged from 3.2 to 13.5, depending mainly on the solids loading in the inlet gas. At a nominal inlet flow rate of 29 lb/hr of solids, ranging in effective diameter from 2 weight percent larger than 700 microns to 10 weight percent smaller than 10 microns, the cyclone DF has been about four.

Fines collected in the calciner cyclone are currently sent to solids storage along with the bed product to give a combined product that is 97 weight percent larger than 100 microns in effective diameter. In early studies, the fines collected in the cyclone were returned to the bed, but this resulted in an undesirable four-fold increase in the rate of flow of solids to the cyclone and up to a two-fold increase in the rate of carryover of fines past the cyclone to the scrubbing system.

TABLE I

SIZE DISTRIBUTION OF PARTICULATE MATTER
COLLECTED DOWNSTREAM OF THE WCF VENTURI SCRUBBER
ON MEMBRANE-TYPE FILTERS

Location	Sampling Station Number	Number of Particles Measured	Average Particle Diameter (Microns)	Range of Particle Diameters Observed (Microns)
Downstream of Scrubbing System	3	47	0.10	0.01 to 0.26
Downstream of Ruthenium Adsorbers	4	27	0.04	0.02 to 0.20
Downstream of AEC Filters	5	49	0.04	0.006 to 0.13
Downstream of Equipment Vent System Inlet to The Process Off-Gas System	6	22	0.045	0.01 to 0.11

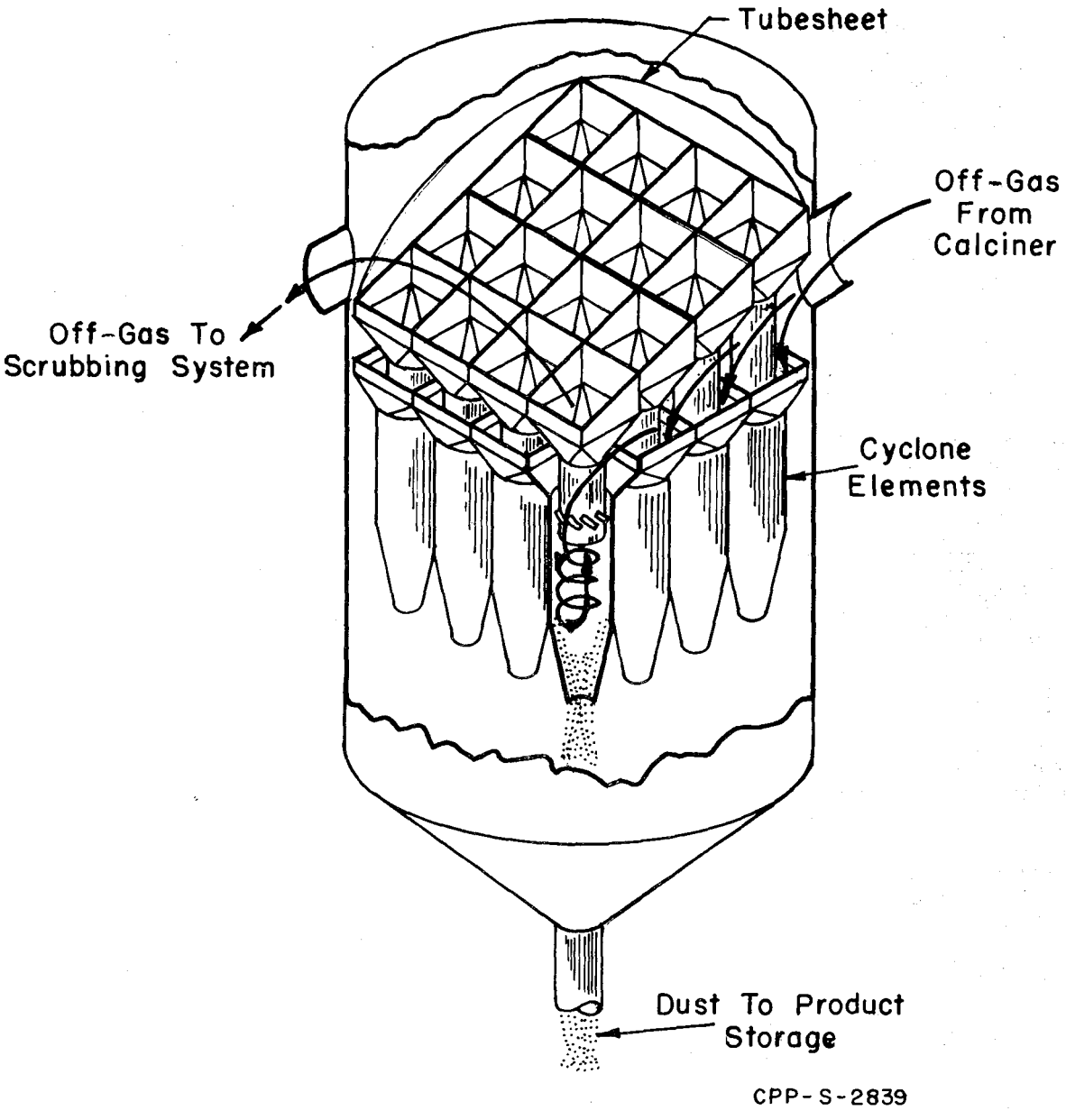


Figure 4. Calciner Cyclone Prior to Modifications

Removal of Wet Fines: Secondary removal of solids from the calciner effluent gas occurs in the scrubbing system where an average DF of 900 was attained during the latest extended test run of about one month duration. The scrubbing system consists of a spray tower, a venturi scrubber with its associated separator, and a heat exchanger. The complete system is generally operated at a pressure drop of approximately 70 inches of water. Virtually all of the 7.2 lb/hr of the incoming solids, 90 weight percent of which are smaller than 75 microns in effective diameter, are removed by the scrubbing system; the flow of solids downstream is reduced to only 0.008 lb/hr of particles, all of which are smaller than 0.3 micron in diameter.

The scrubbing solution, which at equilibrium conditions is about 5M nitric acid, 0.8M with respect to aluminum, and contains a small amount of undissolved alpha alumina, is pumped to both the spray tower and the venturi scrubber. About 63 gpm of cooled solution is sprayed into the spray tower to reduce the temperature of the off-gas before it enters the venturi scrubber. The 15 gpm (13 gal/1000 acf of off-gas) of cooled scrubbing solution injected into the venturi scrubber through four 0.25-inch diameter holes intimately contacts the suspended particles in the off-gas which has a velocity of about 300 ft/sec and causes some of the nitric oxides and water vapor to be condensed. Separation of the particle-laden scrubbing solution from the off-gas occurs in the entrainment separator which is followed by a heater to prevent further condensation. The condensed scrubbing solution is recycled to the feed at a rate necessary to prevent an excessive buildup of either dissolved or undissolved solids in the solution. The venturi scrubber and the entrainment separator are shown in Figure 5.

After passing through the cyclone and venturi scrubber with its associated separator, the effluent gas has been freed from the bulk of the solid material it contained when it left the calciner. Solids removed up to this point have been present in sufficient quantities to require continuous disposal or recycle. However, the quantity of solids remaining in the off-gas downstream from the venturi scrubber-separator is very small and the problem from this point on is primarily one of cleanup of the off-gas stream for disposal.

Final Off-Gas Cleanup: The concentration of particulate matter in the off-gas leaving the venturi scrubber-separator is reduced a total of 100-fold in passing through the silica gel beds and the AEC filters. The superficial off-gas velocity through the silica gel beds, across which a particulate DF of about 5 was obtained, was approximately 0.2 ft/sec, based on the area of three of the four units operated in parallel. The AEC filters operated at a superficial face velocity of about 2 ft/sec (a velocity of about 0.04 ft/sec through the filter fibers) with an average inlet particle diameter of about 0.04 micron. Initial indications were that the AEC filter DF was greater than 1000 just after introduction of the radioactive tracer; however, at equilibrium the DF had decreased to about 20.

The silica gel beds were installed primarily for the adsorption of ruthenium tetroxide which is volatilized initially from the calciner[6]; even so, they had a DF of 5 for particles with an average diameter of 0.1 micron. At least two-thirds of the ruthenium vaporized from the calciner is expected to be removed from the off-gas with the fines collected in the cyclone and with the scrubbing solution[7]. Ruthenium tetroxide vapor passing downstream from the scrubbing system will be largely adsorbed, with an expected DF of at least 1000, in the silica gel beds[6,7,11] which are seven-foot diameter by three-foot deep beds of 6- to 12-mesh particles. Ruthenium tetroxide vapor that condenses to particulates is expected to be filtered out either by the silica gel or the AEC filters.

The DF of the AEC filters was about 20 even though the particulate matter had an average diameter of only about 0.04 micron. Each of the three parallel units consists of a prefilter, specified to have a DF of 1.5 (35 percent efficiency)

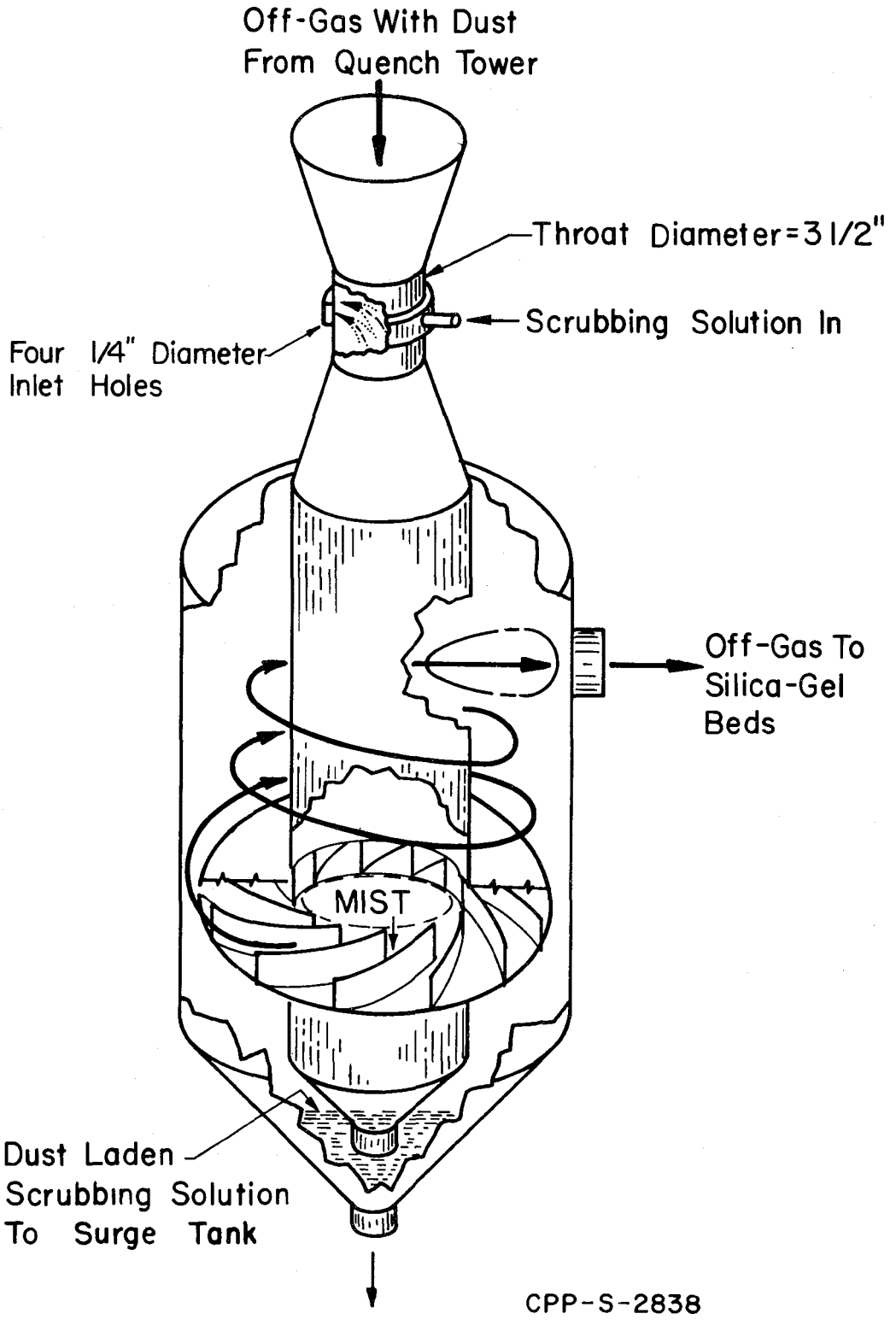


Figure 5. Venturi Scrubber and Entrainment Separator

by the NBS discoloration test, and a final filter, specified to have a DF of 3333 (99.97 percent efficiency) by the DOP mist test[12]. Just prior to the 30-day test run, the AEC filter installation was tested with 0.9-micron DOP mist particles and was found to have a DF of 10,000 for this material.

Shortly after the addition of the tracer to the system, a DF of over 1000 was indicated from measurements of solids in the off-gas taken upstream and downstream from the filters. Over a period of about 10 days, as shown in Figure 6, the indicated DF decreased before stabilizing near a value of 20. It would appear that these filters block the passage of a large number of the particles in the entering gas stream, but serve only as an impedance to the passage of other particles. The filters were in use for 14 days immediately prior to the time that the data were collected, so an equilibrium holdup of very small particulate matter that did not contain any radioactive tracer had probably already been established in the filters. The data from the two sample stations upstream of the filters did not exhibit the delayed penetration characterized by the data from the downstream sample stations; rates of solids carryover past both the scrubber and the silica gel beds rose almost instantaneously to the equilibrium level as exemplified in Figure 7 for carryover past the silica gel beds.

Additional evidence of the delayed penetration of the filters was obtained from post-run samples; the calciner was shut down and the off-gas piping was cut to allow fresh air to be pulled through only the silica gel beds and the AEC filters while sampling at stations 3, 4, and 5. During this week-long test, the solids loading downstream of the filters remained fairly constant at the indicated steady-state value (see Figure 6). During the same period, however, the solids loading of the air entering the filters dropped rapidly (see Figure 7); thus the re-entrainment of particles from the silica gel beds was negligible.

CONCLUSIONS

Removal of particulate solids from the WCF off-gas was very good, with a DF of 3.6×10^5 measured from the outlet of the calciner to the stack. This DF, in addition to a conservative atmospheric diffusion factor[14] of 10^{-4} sec/meter^3, is expected to keep the concentration of strontium-90 to about 1/13 of the Maximum Permissible Concentration as set forth in NBS Handbook 69[13]. The performance of the venturi scrubbing system, which alone had a DF of 900, was excellent. Individual DF's are shown schematically along with the particulate flow rates in Figure 8.

A delayed penetration of the filters was indicated from tracer activity data collected during a 30-day operating period. This finding indicates the necessity for observations of filter performance in a test of this type over an extended period of time before drawing conclusions regarding the efficiency of such filters.

The particle size of solids escaping collection by the venturi scrubber system averaged 0.1 micron in diameter as determined by viewing the particulate matter collected on membrane-type filters with an electron microscope. After passage through the silica gel beds and AEC filters, the average particle size was reduced to about 0.04 micron.

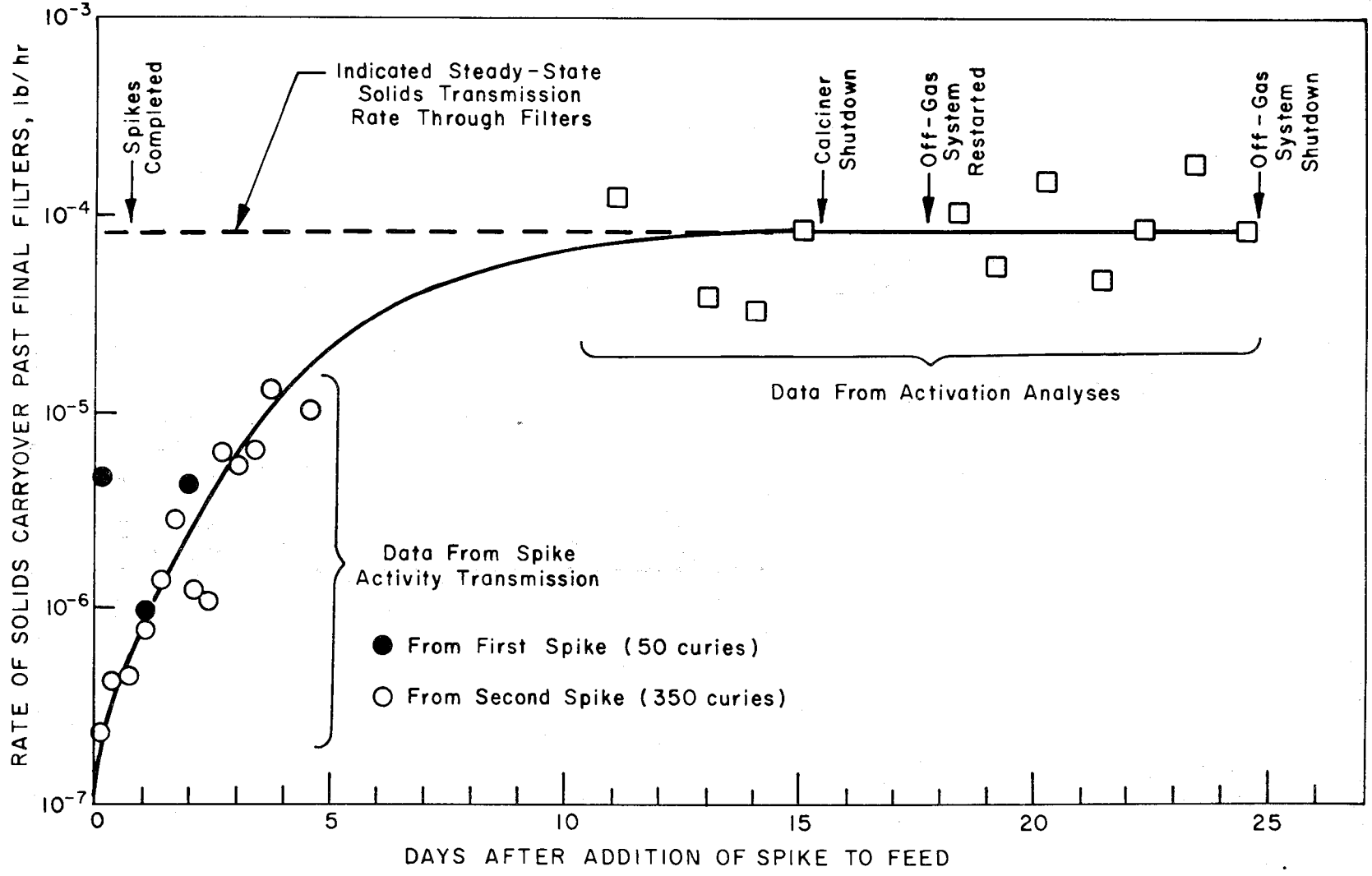


Figure 6. Solids Flow Rate Past the AEC Filters

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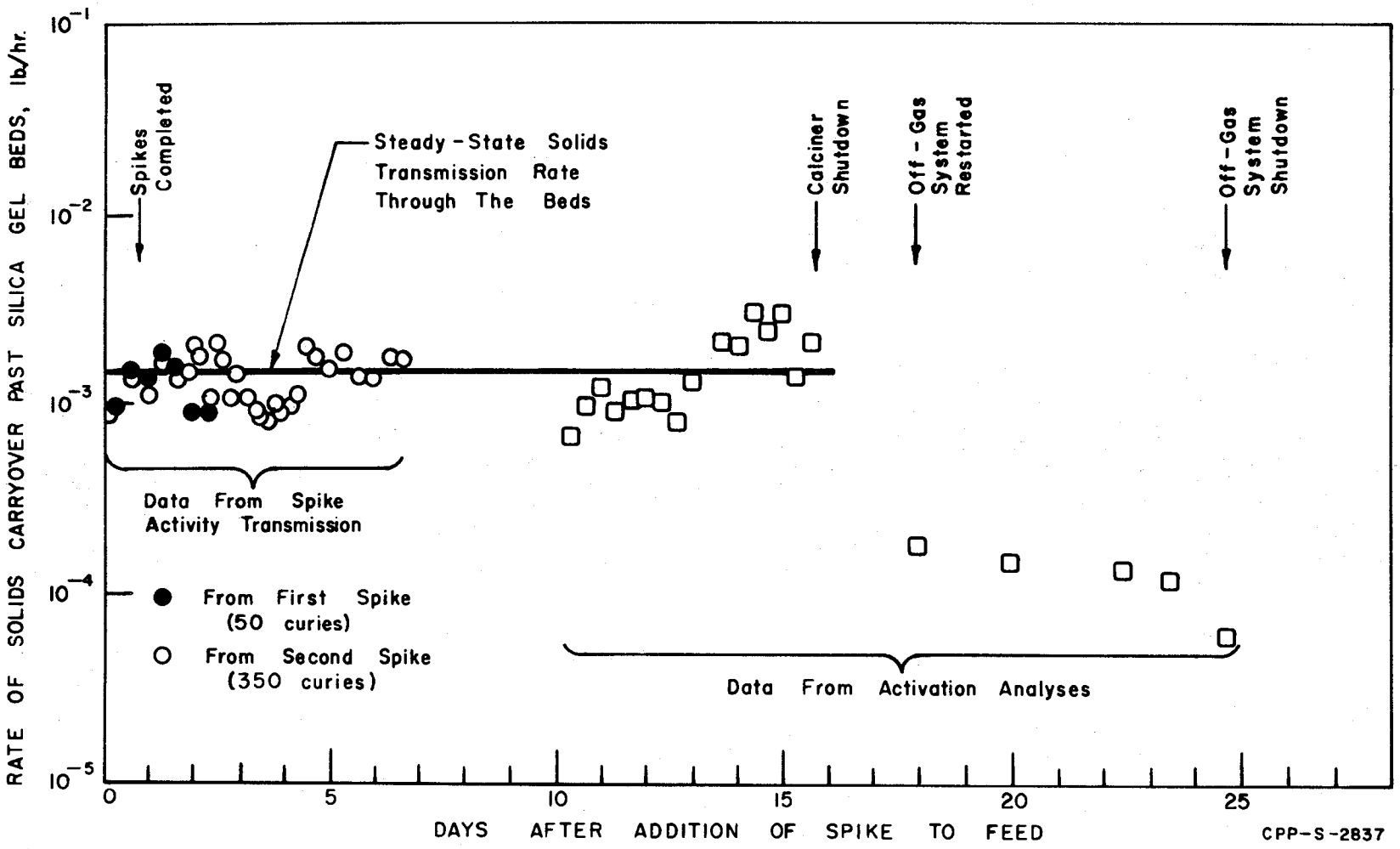


Figure 7. Solids Flow Rate Past the Silica Gel Beds

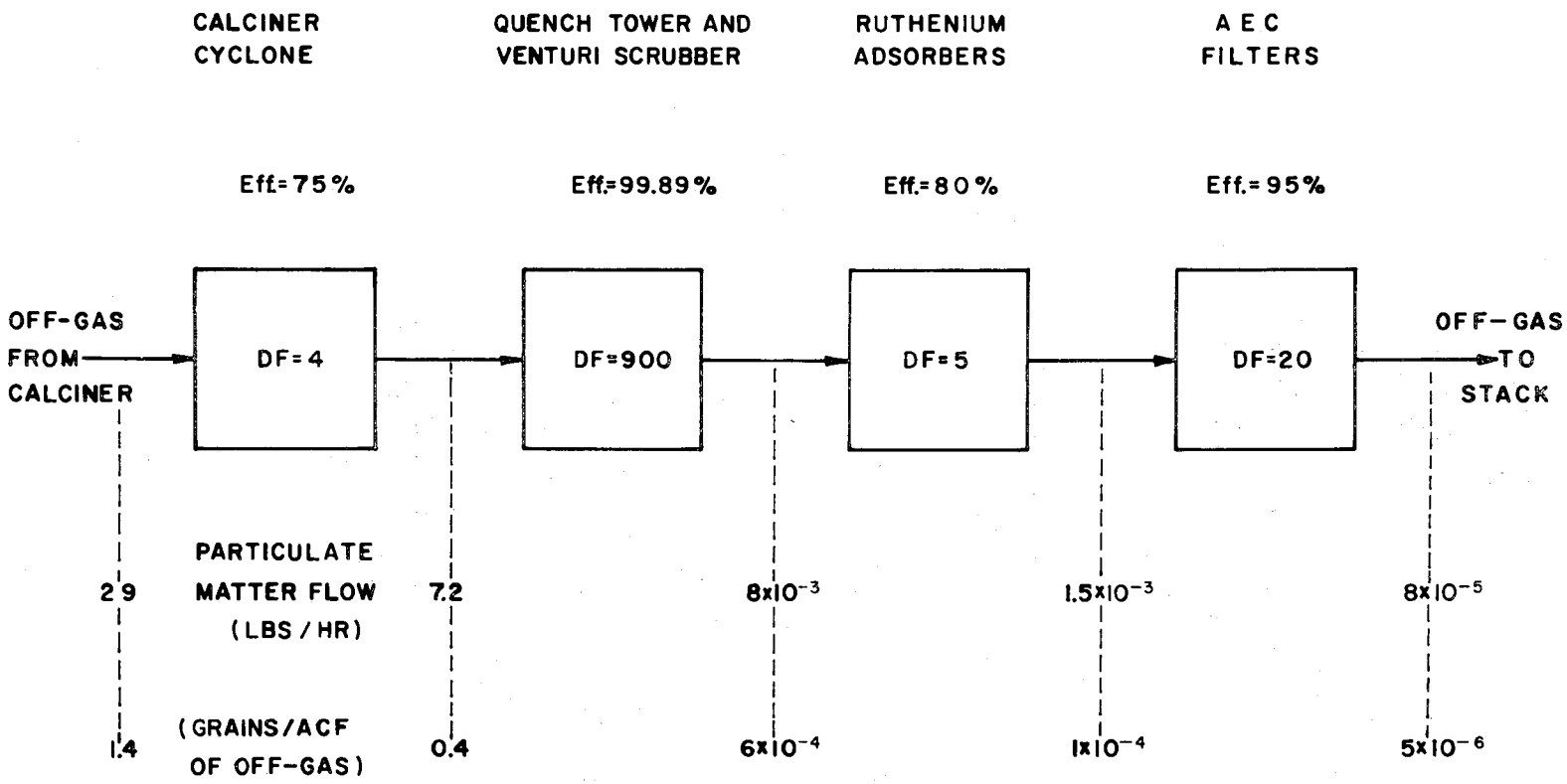


Figure 8. Decontamination Factors (DF) and Particulate Flow Rates for the Off-Gas System

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LITERATURE CITED

1. Grimmett, E. S., Calcination of Aluminum-Type Reactor Fuel Wastes In a Fluidized Bed, IDO-14416, August, 1957.

2. MacQueen, D. K., and J. I. Stevens, Design Bases for ICPP Waste Calcination Facility, IDO-14462, April, 1959.

3. Brown, B. P., E. S. Grimmett, and J. A. Buckham, Development of a Fluidized Bed Calcination Process for Aluminum Nitrate Wastes in a Two-Foot-Square Pilot Plant Calciner: Part I. Equipment Development and Initial Process Studies, IDO-14586, June, 1962.

4. Wheeler, B. R., E. S. Grimmett, and J. A. Buckham, Development of a Fluidized Bed Calcination Process for Aluminum Nitrate Wastes in a Two-Foot-Square Pilot Plant Calciner: Part II. Factors Affecting the Intra-Particle Porosity of Alumina, IDO-14587, July, 1962.

5. Bower, J. R., Editor, Chemical Processing Technology Quarterly Progress Report, April-June, 1960, IDO-14534, December, 1960.

6. Loeding, J. W., E. L. Carls, L. J. Anastasia, and A. A. Jonke, The Fluid-Bed Calcination of Radioactive Waste, ANL-6322, May, 1961.

7. Evans, D. R., Pilot Plant Studies With a Six-Inch-Diameter Fluidized Bed Calciner, IDO-14539, April, 1961.

8. Schadt, C., and R. D. Cadle, "Critical Comparison of Collection Efficiencies of Commonly Used Aerosol Sampling Devices", Analytical Chemistry, 29, 6, pp 864-868, 1957.

9. Megaw, W. J., and R. D. Wiffen, The Efficiency of Membrane Filters, AERE-R 4211, January, 1963.

10. Green, H. L., and W. R. Lane, Particulate Clouds: Dusts, Smokes and Mists, D. Van Nostrand Co., Inc., London, 1957.

11. Rhodes, D. W., and D. R. Anderson, Capacity Test Data for the Adsorption of Volatile Ruthenium on Silica Gel, IDO-14510, June, 1960.

12. Military Standard 282, Method 102.9.1, "DOP-Smoke Penetration and Air Resistance of Filters", May, 1956.

13. National Bureau of Standards Handbook 69, Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure, June, 1959.

14. Fuquay, J. J., Meteorology as Related to Waste Disposal and Weapons Tests, HW-47721A, January, 1957.

DISCUSSION AND COMMENT

HACL Comment: I am a little perplexed by the results on the absolute filters, because I think all the data we have indicate that as they load up, their performance gets better, and I think Mr. Modrow's supervisor wrote me about this, a question of whether or not this phenomena could be attributed to anything else. One possibility is mechanical vibration and migration of the particulates. But at the loadings that are loaded in the particle sizes, I think are less than the DOP sizes. What we would be concerned with is whether or not the adhesive forces in this system are some way reduced, and therefore particles do migrate. But I still am perplexed as to why, with continued use, the loading and deposition which we have always seen happen in every filter in the business. In fact, all AEC filters that have been on-stream and have been tested after they have been plugged a little seem to produce DF's that are almost of the order of one magnitude better because of the deposition. So this, I think, may be in the realm of speculation, but I would like to hear more about it.

Comment by the Speaker: I don't have any direct answer to that. The only thing that comes to my mind is that we are working here with a real dry particulate matter, rather than atmospheric dust, which most of the tests have been made with, or with a mist such as DOP. This could have something to do with it.

The filtering velocity, of course, is fairly low. The filtering velocity is about .04 of a foot per second and a face velocity of 2 feet per second, which is lower than normal. This could have something to do with it, too.

I was wondering, myself, if anyone else has seen this type of phenomena with the filters. I would be interested, too, in finding out exactly what the phenomena is, here, in this delayed penetration.

These filters were in use for two weeks prior to the addition of the radioactive tracer to the feed. The pressure drop over the total filtering system, which includes a box which holds both the prefilter and the absolute filter, registered about one inch of water, and some of this, I am sure, was due to the inlet and outlet valves in the system, and no pressure drop increase could be noted across the filters during this 30-day operating period.

HACL Comment: I have two points, I think, on which an answer can be postulated. One is that the lowered velocity here for the size range you are using ought to favor removal efficiency, rather than hinder it, because you are in the diffusion range.

Secondly, the other thing that occurred to me, and I think I wrote Dr. Hoffman about it, is the question of pulsation; possible pulsation flow induced in the system by the fan; if you have a little bit of vibration into the system, you might in fact get some agitation of the bed. These filters aren't as rigid as you might think, and could cause the migration. At any rate, I still would like to know if in your test setup you are going to follow this for more than the ten days? I think that the curve will start down again.

Comment by the Speaker: Could I answer the last question first? We are going to try to determine if there is any pressure fluctuation in the system in the forthcoming tests. We have centrifugal blowers just ahead of the stack, as you probably saw in the flow sheet. We don't see how this could affect the filters which are fairly close to the centrifugal blowers.

Do you think that a centrifugal blower would cause enough pulsation?

HACL Comment: As far as I know, we have some pretty good evidence in certain bag filters with centrifugal blowers, that if you get the blower and distance just right to the bag collector that the bags are vibrating all the time, the dust keeps coming off of them, and they tend to self-clean. So, I would believe that you could get air-column vibrations that would appear certainly at the surface, the back surface of the filter. This is really not steady flow, if you analyze it. It has got the cycle chopping of the centrifugal vane.

Comment by the Speaker: The filters were tested in place, just prior to this 30-day run with the DOP mist test. The DOP test size in this case was about 0.9 microns; and the efficiency of the filters with this test showed about 99.99+. A DF of about .020.

Session Chairman: I should like to thank Messrs. Anderson, Arnett, Green, List and Modrow for a very stimulating number of papers, as evidenced by the questions and discussions.

SESSION VI - SPECIAL PROBLEMS: RARE GASES AND INCINERATORS

Morning - 23 October 1963

A. J. Breslin, HASL, Chairman

Session Chairman: This is Session VI - Special Problems: Rare Gases and Incinerators. The ground rules are as before. I will ask you to hold your questions and discussion period until after the three papers have been presented.

The first paper is entitled, "Use of Foam for Containment and Cleanup of Radioactive Aerosol and Gases," by R. E. Yoder and L. Silverman, HACL, and will be presented by Dr. Silverman.

FOAM SUPPRESSION OF RADIOACTIVE IODINE AND PARTICULATES

Robert E. Yoder

and

Leslie Silverman

Harvard University School of Public Health

INTRODUCTION

The methods for the control of radioactive materials which may escape from nuclear reactors during normal operations or in an accident situation may be grouped into two broad areas. These are: a) containment in which the entire reactor is surrounded by an unfired pressure vessel designed to retain all the materials released from the reactor and, b) confinement in which the enclosed air surrounding the reactor is cleaned by filtration and/or scrubbing to remove any released materials before discharging the air to the environment.

Recent investigations by Silverman et al. (1, 2) have shown that iodine can be rapidly removed from contaminated air spaces by filling the volume with a high expansion foam similar to that used in fire fighting. (High expansion foams have expansion ratios $\sim$1000:1 whereas fire fighting foams have expansion ratios of $\sim$30:1. The expansion ratio is defined as the volume occupied by the foam to the volume of liquid used to produce the foam.) The foams which he used were water solutions of an ether lauryl sulfate surfactant containing a foam stabilizer. By means of standard chemical detection methods it was shown that the time required to reduce the air concentration of normal iodine to 5% of its initial value was one-tenth of that required when no foam was used. He also demonstrated that an aerosol particle concentration was significantly reduced with the addition of foam to the aerosol chamber.

These results prompted Silverman to suggest that a foam generator would make a useful stand-by decontamination system for reactors depending on containment for gaseous radioactivity control. There are several questions which must be answered before foam containment systems can be used in practice. One important question involved the radiation stability of such foams. No data were available as regards the levels of ionizing radiation which might destroy the foam. A second question involves the stability of the foam with live steam which might be present after a water reactor accident. The foam selected must withstand the high temperature and condensing action of the steam and must retain the captured fission gases. Another important aspect is the release of captured gases upon foam collapse by water spray. Not only must the foam remove iodine, but it must also fix the iodine in such a manner that it is not released. The use of sodium thiosulfate in stoichiometric excess as a primary foam additive

was to be investigated to determine the completeness of the sodium thiosulfate-iodine reaction.

After the foam collapse by water sprays, residual foaming agents in the water may cause frothing and foam production at the inlet of liquid storage facilities. Suitable anti-foam agents need to be selected to minimize subsequent foam production.

OBJECTIVES

Arrangements were made late in 1962 to perform a series of radioactive experiments in a 6000 cubic foot hot cell at the Oak Ridge National Laboratory. The chief purpose of these tests was to evaluate the effects of high activity levels, steam, water and general scale up of previous laboratory studies on the efficiency of foam supression systems.

Aside from the problems concerning the fate of radioactive gases in foam environments, problems involving particulate removal and particulate-iodine interactions must be considered. In addition to the iodine tests which were performed, two experiments were performed in which irradiated uranium foils were burned to produce a radioactive aerosol in conjunction with the released iodine. The fume produced by burning the uranium foils was combined with the iodine release.

METHODS

A. Apparatus. Figure 1 is a schematic drawing of a typical foam generator used in this study. A 2.5% solution of foam concentrate in water is sprayed from a nozzle onto a loosely woven nylon mesh fabric. The latter retains a large fraction of the foam solution. The blower, generally an axial flow fan in large units > 10,000 cfm and a centrifugal blower in smaller units, is adjusted to supply sufficient air to create bubbles from the liquid film on the cloth. This foam solution may be gravity fed or pumped to the nozzle. Proportioning pumps may be employed also to blend the water and concentrate. In our experiments, the solution was pre-mixed in 55 gallon drums and pumped to the spray nozzles.

Three foam generators were built for the hot cell experiments - two 1,000 cfm units and one 2,000 cfm unit. Figure 2 shows the placement of the generators in the hot cell. Each device was separately controlled to permit flexibility and to effect a comparison of the units. Placement of air inlets to the fans at the top of the cell maximized air recirculation. Foam generation and air encapsulation took place at the bottom of the cell.

A single furnace was used to volatilize the elemental iodine or to burn the uranium foil as required. The furnace shown in Figure 3 consisted of a stainless steel cavity with a funnel shaped entrance guide at the top. The cavity was surrounded by Cal-rod heaters cast in aluminum, the whole assembly was contained in a stainless steel can. The heater which operated at power levels up to 1500 watts was controlled by a powerstat on the control panel.

Elemental iodine-131 and iodine-127 carrier in a quartz ampoule was placed in a stainless steel container as shown in Figure 4, which could fit into the cavity of the furnace. The ampoule was broken by means of a breaker tool inserted through the top of the hot cell. The uranium foil was placed in a similar unit, the only difference being that several holes were drilled in the bottom to the container to allow oxygen to be blown over the burning foil.

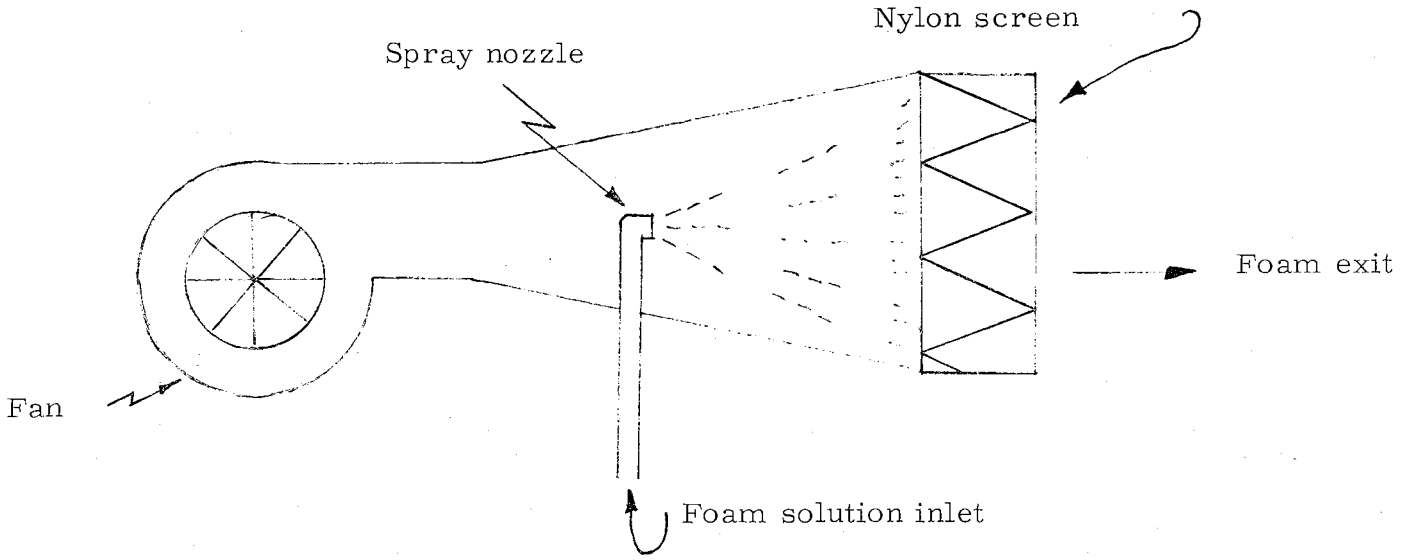


Figure 1 - Schematic Diagram of a Foam Generator

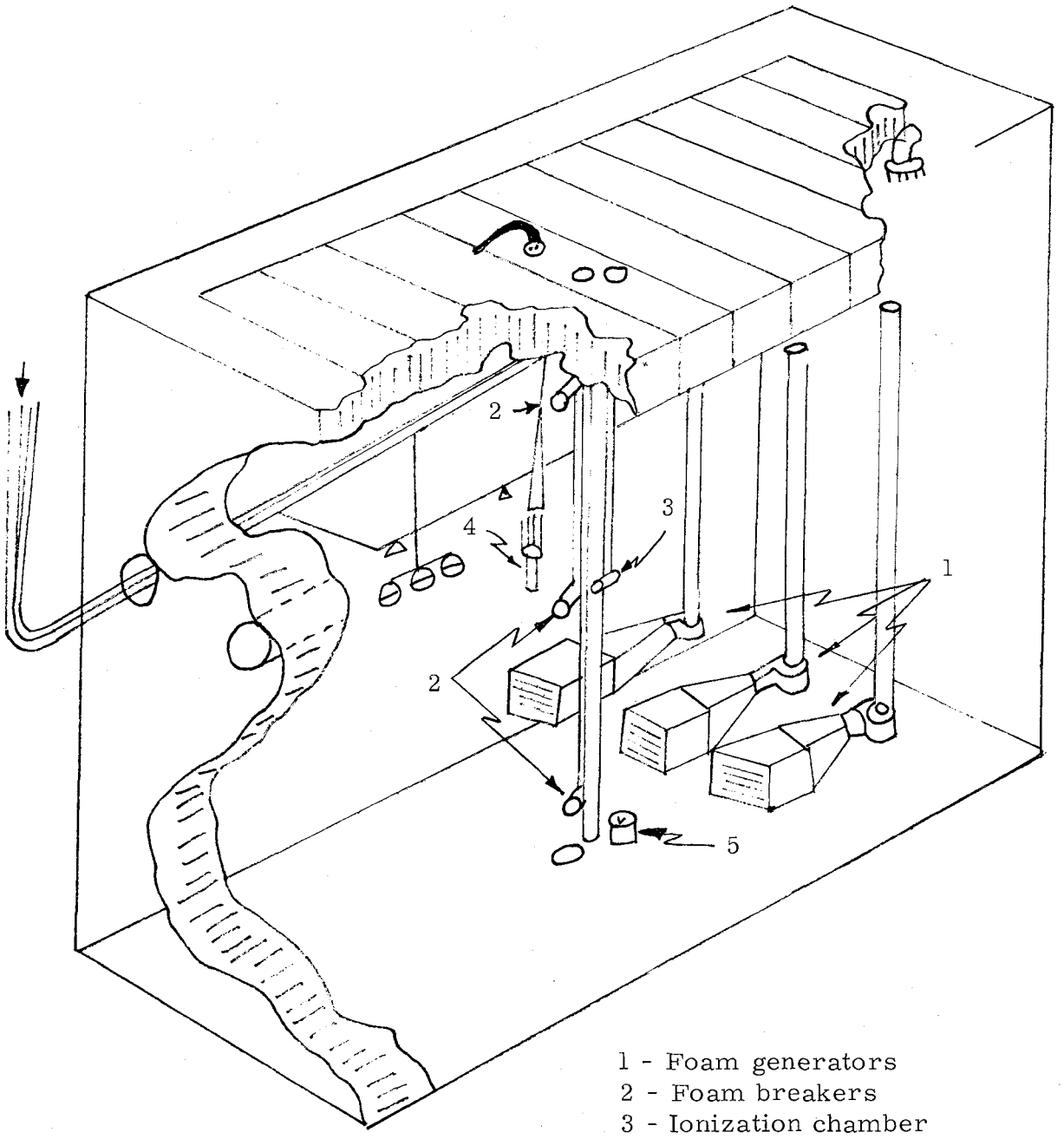


Figure 2 - Schematic Diagram of the ORNL Hot Cell

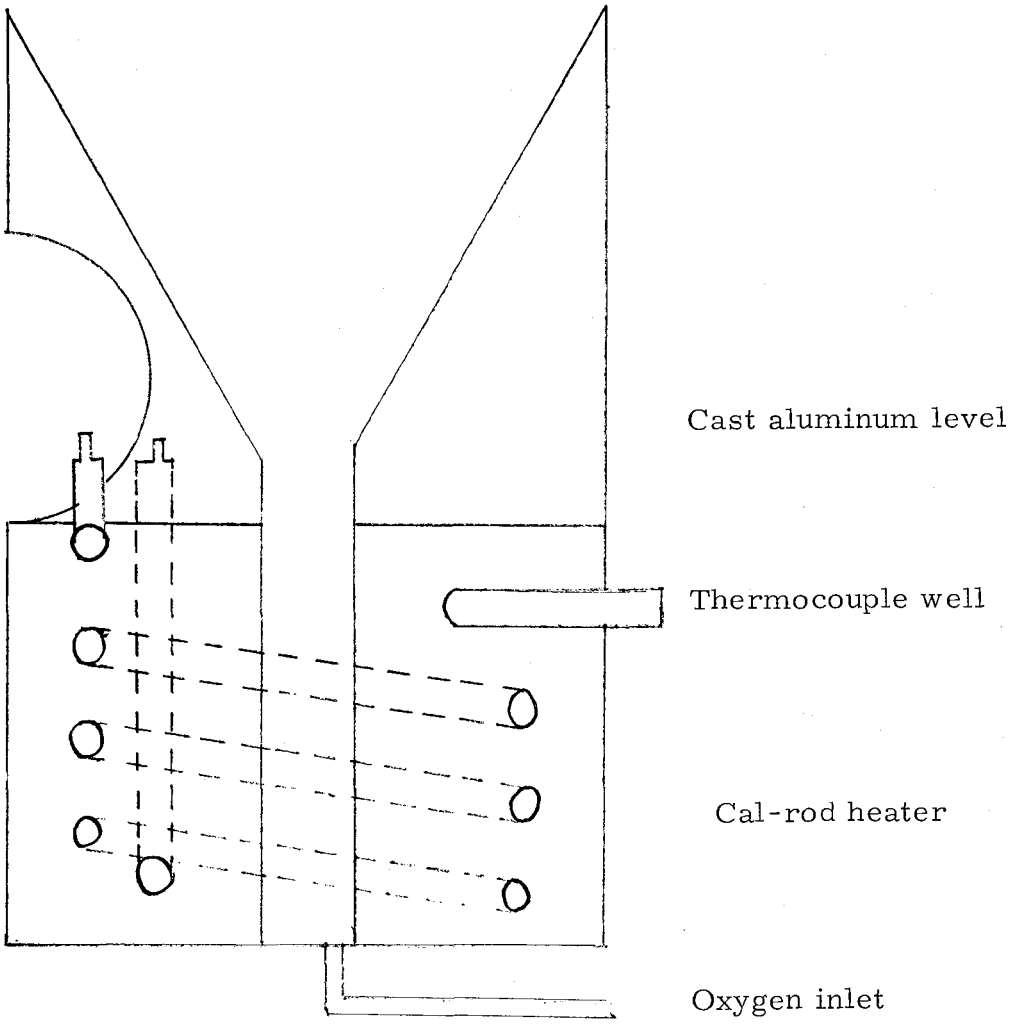


Figure 3 - Schematic Diagram of the Furnace

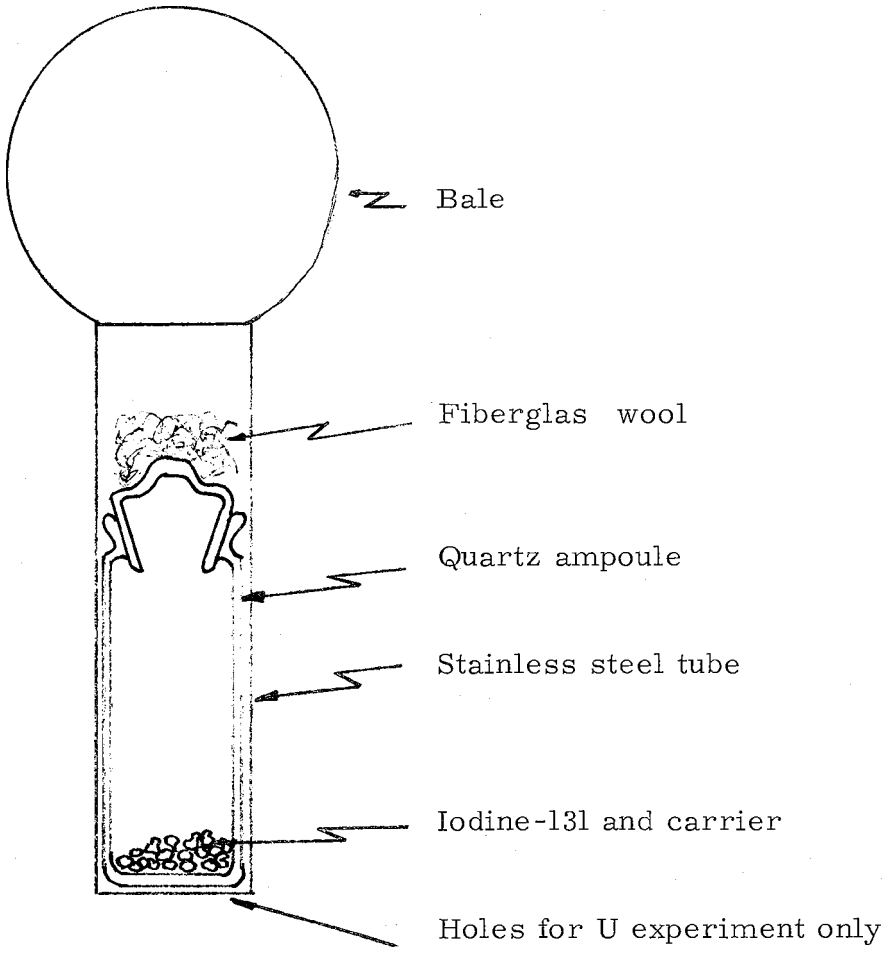


Figure 4 - Iodine Ampoule in the Carrier

The cell atmosphere was sampled at three locations through separate sampling lines as shown in Figure 2. A foam breaker was located at the inlet of the sample lines to prevent any introduction of foam into the lines. The foam breakers were $1\frac{1}{2}$ inch pipe nipples containing an electrically heated helical nichrome wire stretched across the inner diameter. The heat generated by the wire broke the foam, thus releasing the contained gas to the sampling line. The three sampling points were located at different distances from the sample collectors on top of the cell, so each sample line was made to the same length, 50 feet, to minimize variations in wall adsorption. The excess length of tubing was placed in a coil outside the cell face.

Each sampling line was connected to a manifold which held 9 charcoal adsorbent sample collectors. Each sampler was isolated from the manifold by a check valve to prevent accidental contamination of the charcoal by iodine diffusion from the manifold. The sampling lines and manifold were continually purged with air from the cell.

The charcoal samplers were polyethylene drying tubes, 5/8 inch in diameter and 8 inches long, fitted with a hose connection at each end. A small pad of 0.5 micron spun Fiberglas was placed in each end of the tube to support the charcoal, about 17 grams per tube. Figure 5 is a schematic diagram of the sampling manifold and a sampler tube.

In addition to the above sampling system a special sampler was developed which could be inserted directly into the cell. A schematic diagram of one of these devices is shown in Figure 6. Two of these units were fabricated, each holding four charcoal sampler tubes. A single tube with a check valve was lowered into the cell to determine the iodine concentration before the foam introduction. To prevent external contamination, each tube was sealed in a removable cellophane bag which was removed when the samples were withdrawn from the cell.

An ionization chamber was located as near to the center of the cell as possible. This was used to check the initial iodine inventory when the ampoule was inserted into the cell and also to monitor the cell activity during an experiment.

B. Procedures. After each carbon sampler was removed from its sample position it was checked for radioactivity with a Geiger counter and heat sealed to prevent iodine loss. The samples were analyzed for radioactivity either in a high pressure ionization chamber or in a scintillation spectrometer (the data being recorded as microcuries of iodine-131 in each sample). Suitable standards were prepared by the counting laboratory personnel by placing a known quantity of iodine-131 on a series of charcoal samplers. Several samples were observed to determine isotope purity, and there was no evidence of contamination in the iodine tests.

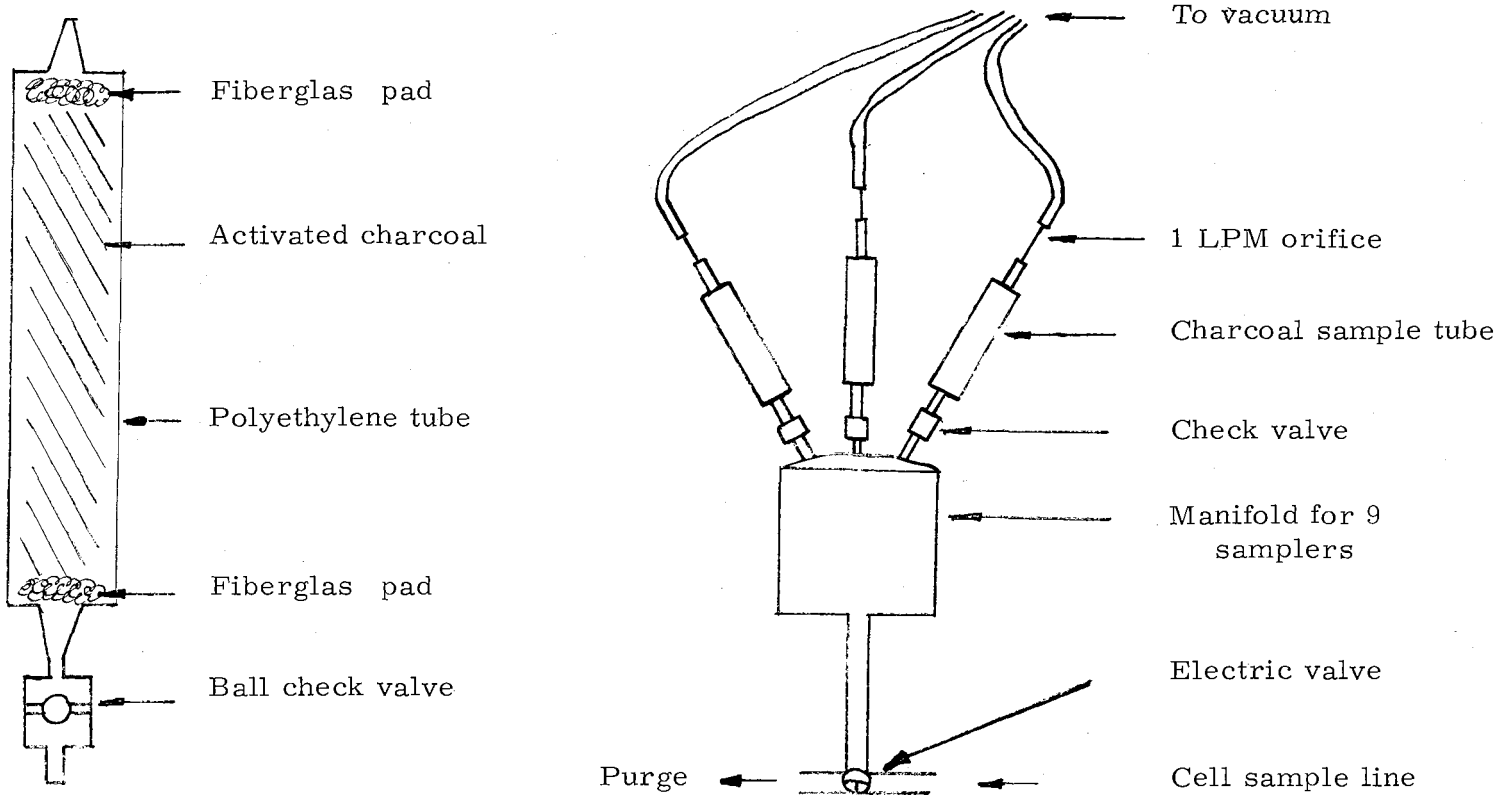
The uranium samples were analyzed in a similar manner. In addition, the samples were examined in a multichannel spectrometer to determine the various radioactive species present.

Water samples of the collapsed foam and spray water were taken after each test and analyzed for activity.

C. Sequence of Experiments. Before sealing the cell, the steam tests were performed, as well as the foam fill time tests. After sealing the cell, a series of tests were performed to measure the air leak rate into the cell.

The five scheduled iodine tests were conducted as follows:

Figure 5 - Schematic Diagram of a Charcoal Sampler and Sampling Manifold



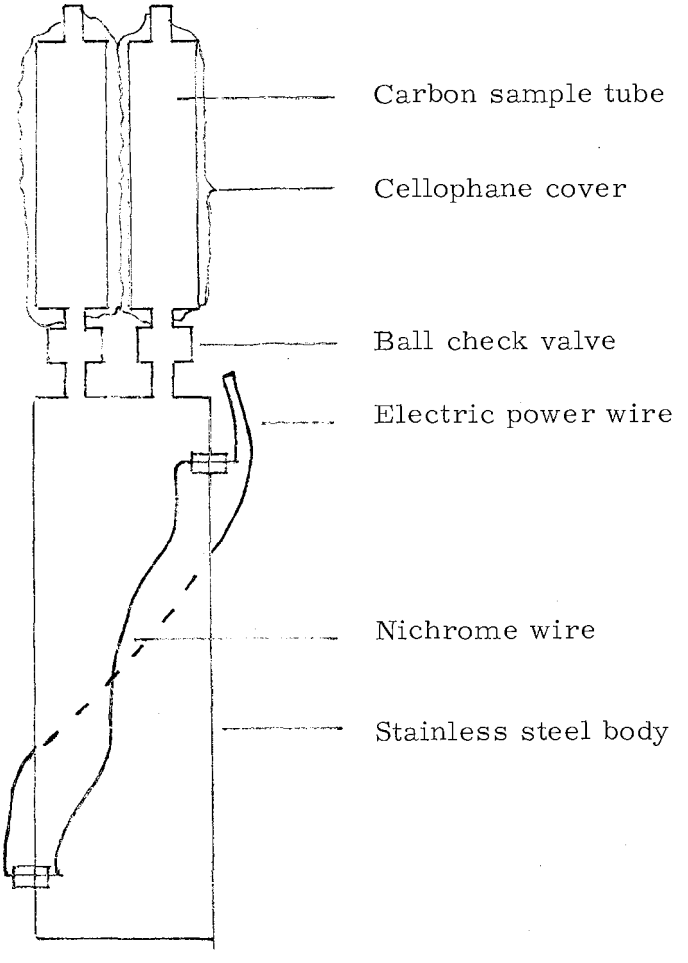


Figure 6 - Schematic Diagram of In-Cell Sampler

1. Iodine was released and its decay measured by cell leakage and diffusion to the walls with the recirculation fans turned on. This test was to provide a baseline for subsequent tests.

2. Iodine was released and then the cell was filled with foam, the foam generators and recirculating fans were then turned off. Two tests were performed in this manner to increase the reliability of the data.

3. Iodine was released and the cell was filled with foam, the foam generator was turned off and the recirculating fan remained on. Two tests were performed using this procedure. Initial data using normal iodine showed that recirculation of the contaminated air tended to improve the iodine capture by foam.

There were two uranium tests in which an irradiated uranium foil was burned and the cell filled with foam. The recirculating fans were operated in the manner showing the best results from the iodine tests.

RESULTS

A. Foam Generator Performance. Table 1 shows the expansion ratios obtained at Harvard and those obtained at Oak Ridge. Part of the poor performance at Oak Ridge was produced by the blower dampers vibrating out of position. This caused an improper air-liquid ratio. The addition of sodium thiosulfate also contributed to a lower expansion ratio. The units were used in various combinations during the several tests because visual observations indicated poor performance. By the end of the series of tests only a single 1,000 cfm unit was operating; the others had developed electrical or adjustment malfunctions. The time required to fill the cell was 10-15 minutes at 2000 cfm.

B. Steam Tests. Steam at 400 pounds per hour was injected into the open cell filled with foam. There seemed to be no deterioration of the foam present. The three foam generators easily replaced any foam collapsed by the injection of the steam and the height of the foam in the cell was raised during the test to a level exceeding that before the injection of the steam.

C. Foam Collapse Test. Water was sprayed into the foam filled cell from 6 spray nozzles located around the periphery of the cell. The total water flow rate was ~27 gallons/minute. The 6,000 cubic foot cell required approximately 250 gallons of foam solution per test (130 to fill and 120 to maintain the foam level over a 2 hour test period). Approximately 1800 gallons of water were required to collapse the foam. Dow Anti-foam A was added to the water according to the manufacturers directions with the result that no subsequent foaming occurred in the disposal of the liquid wastes.

D. Iodine Tests. A reactor operating for 10^8 seconds (approximately 3 years) at a flux of 10^{13} neutrons/cm^2-sec. has an I^{131}/I_{total} ratio of 1/44, with a total iodine inventory of 1250 grams. To stay within these limits of mass concentration and to provide adequate activity for sampling, one gram of I^{127} was added to the 10 curies of I^{131} which contained 100 milligrams of carrier. This provides a ratio much less than 1/44, but was the best compromise available. The surface area of the hot cell was 1.94×10^6 square centimeters and a monomolecular layer of iodine on this surface would require 0.27 grams of iodine. One gram of iodine-127 added to the iodine-131 thus was believed sufficient to preclude the possibility of plate-out of the total activity. The above value of the surface area does not include the area of the fan ducts, nylon screens of the generators or the surface of other equipment.

TABLE 1

FOAM CONCENTRATE EVALUATION AND GENERATOR PERFORMANCE

Generator	Foam Concentrate Designation[1]	Detergent Concentration	Expansion Ratio[2]
18" screen 250 cfm	Blue	1.5%	500:1*HACL[3]
Same as above	Pink	2.5%	1700:1*HACL
Same as above	AY	1.5%	940:1*HACL
Same as above	AX	1.5%	1800:1*HACL
Three generators 4,000 cfm	AY	2.5%	350:1 ORNL[4]
Same as above	AX	2.5%	350:1 ORNL
Two generators 2,000 cfm	AX	2.5%	320:1 ORNL
One generator 2,000 cfm	AX	2.5%	400:1 ORNL

1. Arbitrary manufacturers description. Exact composition not revealed but known to contain ammonium ether lauryl sulfate and lauryl alcohol.

2. Expansion ratio = volume of foam/volume of liquid used.

3. Harvard Air Cleaning Laboratory.

4. Oak Ridge National Laboratory.

* No sodium thiosulfate added.

The only method available to estimate the amount of iodine placed in the furnace was to hold the capsule at the ion chamber level inside the hot cell and read the ionization current. (The capsule at this point was suspended by a string and invariably swinging.) These data are presented in Table 2. The first experiment, 12-19-62, contained 7 curies of I^{131} and the last iodine experiment, 1-7-63, contained 11 curies of I^{131}.*

The release of the iodine from the furnace gas was determined visually by observing the purple vapor evolved and also by noting the reading of the electrometer. After the release the ionization chamber readings increased by a factor of ~10. At the point of maximum reading the samplers were started.

Nine air samples were taken inside the cell and twenty-seven were taken via the heated sample lines - nine through each line. Due to excessive iodine loss in the sample lines useful data could not be obtained from these systems, therefore our data analysis was restricted to the in-cell samples which were considered reliable. All flow rates for sampling with the outside samplers were controlled by critical orifices designed to maintain a flow rate of 1 liter per minute. The in-cell sample flow rates were metered with a Fisher-Porter rotameter.

Since the cell pressure varied as much as ± 1" w.g. from the desired pressure of -2" w.g. during the experiments, cell leakage rates also varied by an unknown amount. From orifice theory, based on a coefficient of 0.65, the leakage rate was estimated to be approximately 20 cfm.

The curves presented in Figure 7 show the composite results obtained in the five iodine experiments. "Fan On" means that the air was constantly recirculated in the cell with the foam liquid supply turned off following initial filling with foam. Foam was added as necessary to keep the cell filled. "Fan Off" means that the air was not recirculated (after initial filling with foam) and that the fan was turned on only to generate the required foam volume necessary to keep the cell full. These data show that the foam reduces the iodine concentration above the wall losses by a factor of three, but a comparison with Silverman, et al data (1) indicates that the iodine reduction is not as good as anticipated using chemical detection procedures. The advantage of using foam is clearly demonstrated however. The absolute value of the iodine-131 concentration at the start of the experiments is shown in Table 3 which also shows the final air concentrations, the absolute iodine inventory and the quantity of iodine collected by the foam.

The iodine activity material balance cannot be reconciled completely, as the material was stated to be a nominal 10 curies which was found to vary from 10 to 30 per cent. The iodine concentration was measured at the end of the experiment before and after foam collapse and no significant change in the air concentration was detected. This fact shows that no iodine is released from the collapsed foam.

It is assumed that the unaccounted for activity in the material balance leaked out of the cell or plated out on the inner surfaces of the cell and its contents. The latter assumption is supported by the ionization chamber readings which decrease very slowly after each experiment and which showed increasing initial activity levels for successive experiments. Desorption from the inner surfaces took place because the air leakage into the cell between experiments was sufficient to allow several air volume changes. Figure 8 shows the ionization chamber readings for two comparable experiments. Time zero is the time

* These specific values were supplied by the Isotopes Division, ORNL.

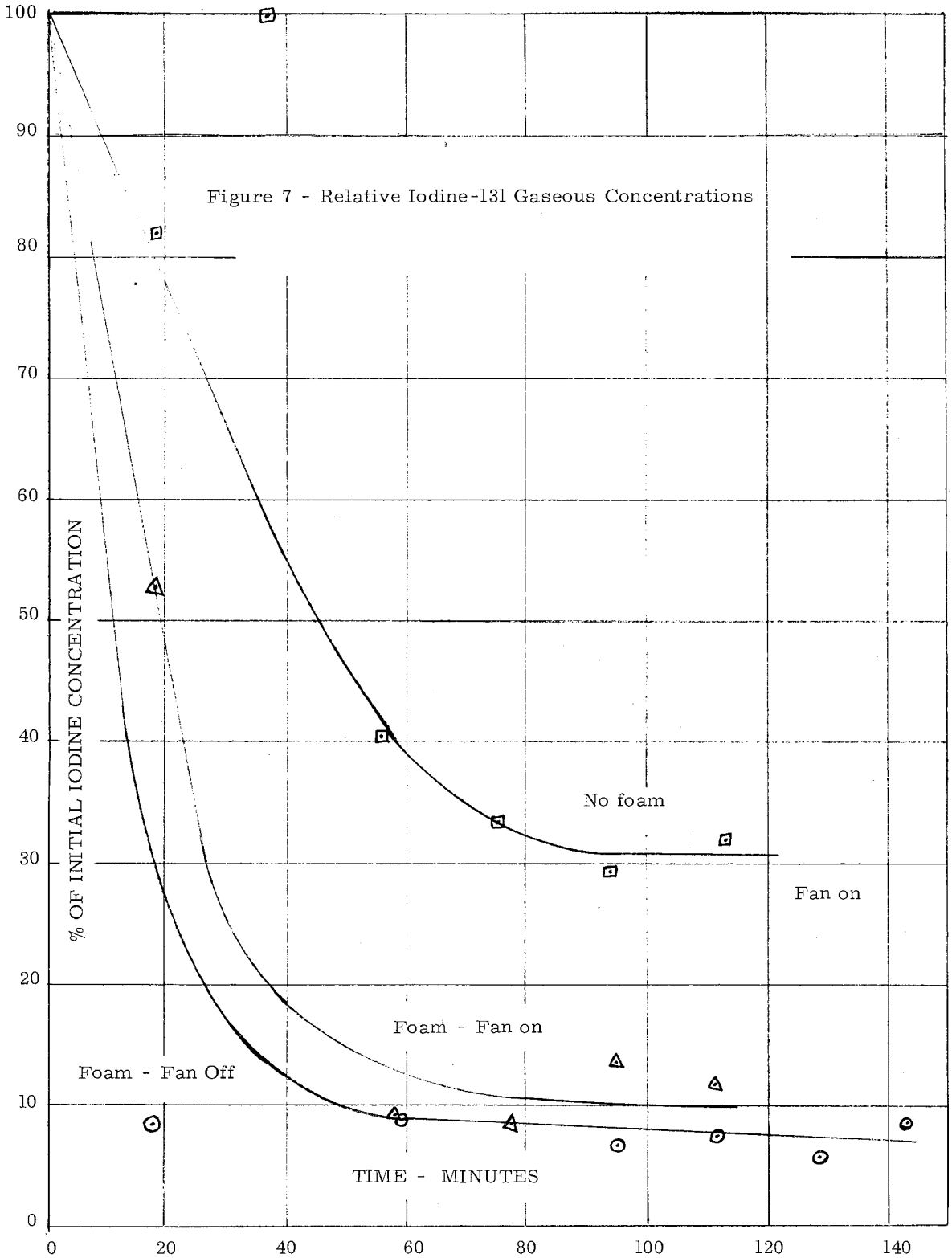


Figure 7 - Relative Iodine-131 Gaseous Concentrations

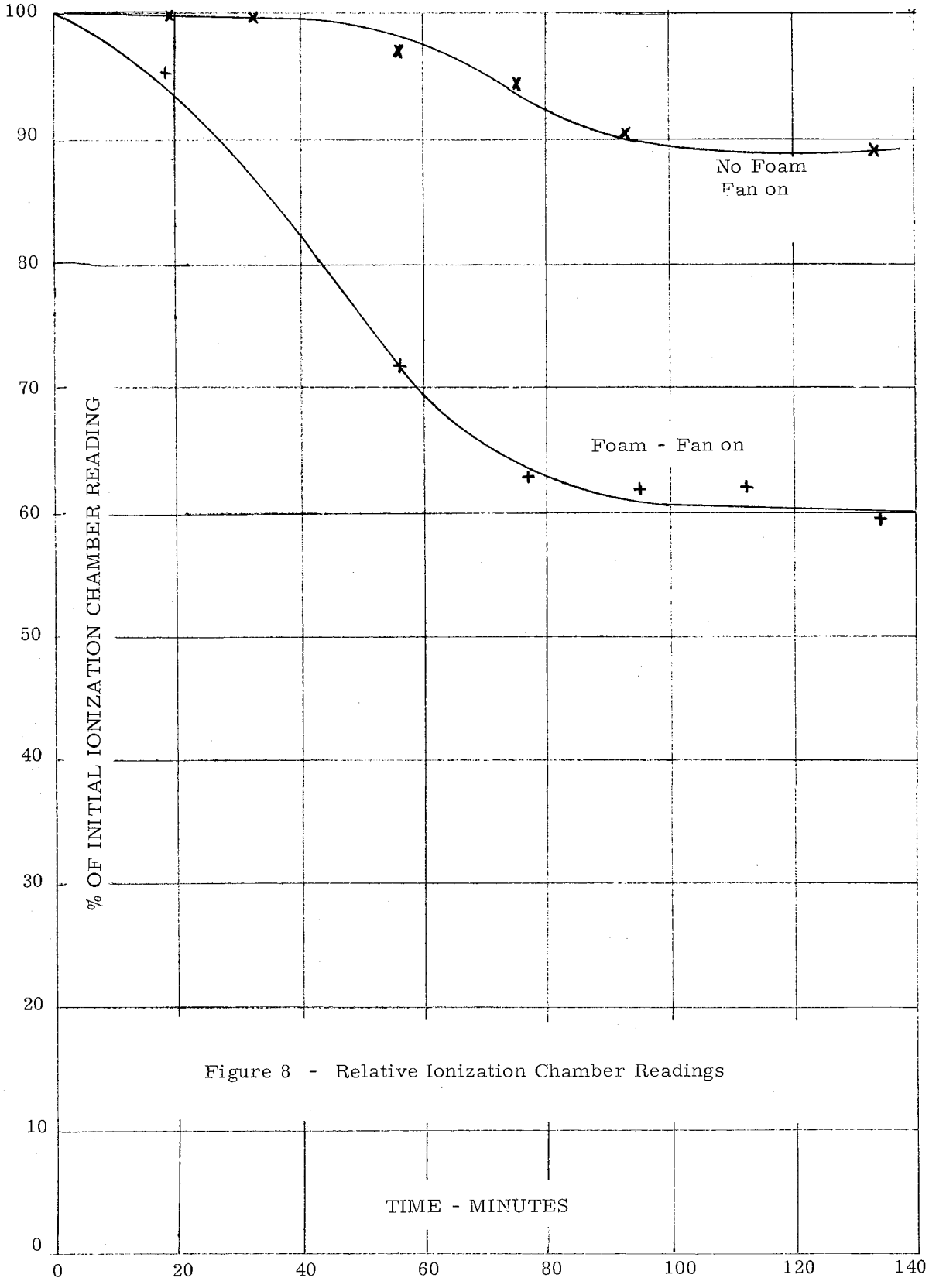


Figure 8 - Relative Ionization Chamber Readings

TABLE 2

IONIZATION CHAMBER READINGS DURING INSERTION OF THE IODINE-131 INTO THE HOT CELL

Test Date	Background Ionization Current (amperes)	Peak Ionization Current (amperes) (ampoule closest to the chamber)	Ionization Current with Sample in the Furnace (amperes)
12-19-62	2.5×10^{-12}	0.8×10^{-10}	8.0×10^{-12}
1-4-63	1.8×10^{-12}	1.1×10^{-10}	3.8×10^{-12}
1-5-63	8.6×10^{-12}	1.8×10^{-10}	1.0×10^{-11}
1-7-63	8.5×10^{-12}	2.6×10^{-10}	1.3×10^{-11}
1-8-63*	1.03×10^{-11}	9.6×10^{-10}	3.4×10^{-11}
1-9-63*	4×10^{-11}	7.4×10^{-10}	5.8×10^{-11}

* Uranium foil burning.

TABLE 3

IODINE AIR CONCENTRATIONS AND MATERIAL BALANCE

Test Date	Test Conditions	Initial Iodine Inventory curies	Iodine in Air Concentration at t = 0		Iodine in Air Concentration at end of Experiment		Iodine Concentration in collapsed foam and spray water total curies	% Iodine Retained in the Cell
			µc/ml	Total curies	µc/ml	Total curies		
1-4-63	No Foam-Fan On	9	8.9×10^{-3}	1.67	2.7×10^{-3}	0.52	0.95	16.3
1-5-63	Foam - Fan On	10	7.0×10^{-3}	1.31	0.7×10^{-3}	0.13	9.1	92.2
1-7-63	Foam - Fan Off	11	7.3×10^{-3}	1.37	0.55×10^{-3}	0.13	9.2	84.6

of the iodine-131 release. The shape of the curves in Figure 8 are similar to those presented in Figure 7 but do not reach the same low value because of the influence of the wall deposited iodine and also the iodine within the foam which has reacted with the sodium thiosulfate.

E. Uranium Tests. Two depleted (0.244% U^{235}) uranium foils were irradiated for 48 hours in the Oak Ridge Research Reactor in a neutron flux of 2.23×10^{14} n/cm^2 - sec. One foil was burned in each experiment. The first foil was allowed to decay for 69½ hours before burning, yielding a total fission product inventory (not counting 50% of the Xe and Kr) of 9.6 curies at the time of the experiment. The second foil was allowed to decay 96½ hours, yielding an activity of 7.9 curies. Approximately 0.34 curies of iodine-131 activity was in the foils.

The two uranium tests were identical, after burning the cell was filled with foam and the recirculating fans turned off since this mode of operation gave the best performance with the iodine-131. Each sample from these tests was observed on a gamma ray spectrometer and only iodine-131 was present, except in two samples in which 0.01% of the gamma activity was from iodine-133. The curves shown in Figure 9 are taken from the in-cell sample data and the activity is reported as iodine. The curve shapes in Figure 9 are dissimilar from those in Figure 7. Only postulations can be given at this time to explain the observed differences.

One explanation is that the iodine is attached to sub-micron uranium dioxide fume particles. Oxygen was blown over the foil during combustion and the oxides could have been ejected at that time. Preliminary tests using an unirradiated foil showed that only UO_2 was formed as a combustion product. If the iodine became attached to the fume particles, then its removal from the air would be much less than with no aerosol present. The diffusion coefficient of a 0.05 micron aerosol particle is 6.9×10^{-6} cm^2 per sec., far less than that for an iodine gas molecule - 0.1 cm^2/sec. Since foam collection is controlled by diffusion, one would expect the aerosol-adsorbed iodine to be more difficult to capture.

In contrast to the iodine tests the ionization chamber readings during the uranium tests did not decrease. Sufficient activity remained within the combustion furnace to completely mask any air concentration changes. For this reason it was difficult to determine precisely the time of activity release. The ionization current remained essentially constant throughout the experiment, at the value shown in Table 2, column 5.

Since time did not permit a test using a uranium foil and no foam, no base line is available for an analysis of the effectiveness of foam removal in these two experiments.

F. Cell Decontamination. After completing the series of experiments the cell was opened and the equipment extracted. The sampling lines were cut into three foot lengths and a four inch section of each length taken for radioactivity analysis. Only iodine-131 was present and the quantities were such that several sections had to be used for a composite sample.

The nylon mesh screens from the foam generators were quite radioactive (5R/hr. at the screen surface 15 days after the last test). This accounts for a large portion of the activity loss from the cell air. No assessment was made as to the composition of this activity.

G. Comparison Between Theory and Experimental Data. Fuchs (3) reports that the reduction in aerosol concentration within a spherical container may

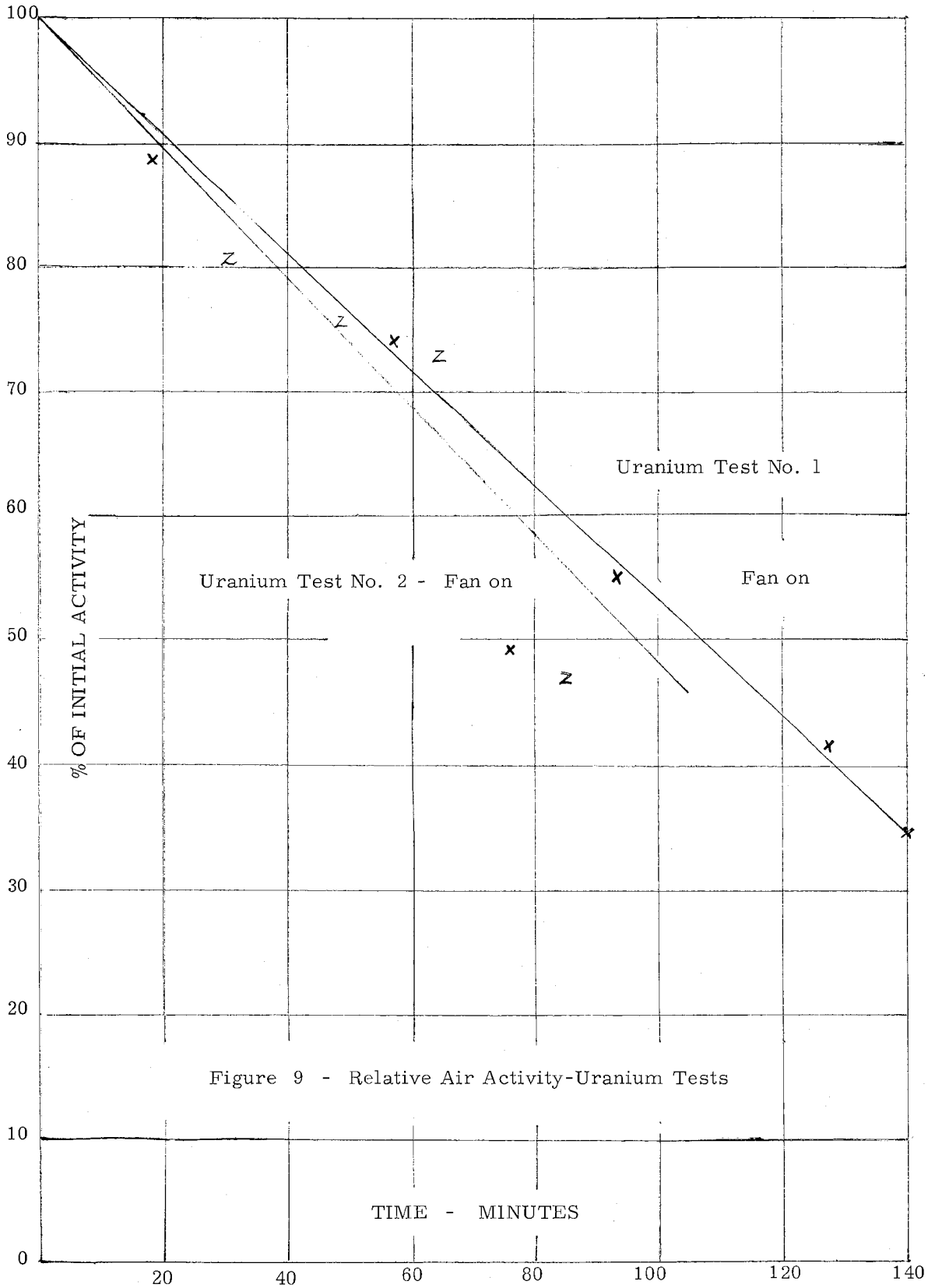


Figure 9 - Relative Air Activity-Uranium Tests

be calculated with the equation:

$$n = n_o \quad \frac{6}{\Pi^2} \sum_{v=1}^{\infty} \quad \frac{1}{v^2} \quad \exp\left(-D \Pi^2 v^2 t/R^2\right)$$

where:

n_o = the initial aerosol concentration in the container

n = the aerosol concentration at any time t

t = time in seconds

D = the diffusion coefficient of the aerosol $cm^2/sec.$

R = the radius of the sphere

v = a whole number

The above equation was developed for particles but for low concentrations of gas the formula should apply with appropriate changes in the diffusion coefficient assuming the gas molecules are readily transferred from the gas phase to the liquid phase and exert no back pressure once in the liquid phase. Sodium thiosulfate was added to the foam solution to meet this requirement as well as to convert the iodine to non-volatile sodium iodide.

Calculations using R = 2.5 cm (approximate size for a foam bubble) and t = 10 seconds predicts a removal of 87.5% of the iodine in this time. This removal rate is greater than that experienced in these experiments, see Figure 7. The size of the bubbles can be estimated only, because of rupture and compression within the foam mass.

At the present time experiments are in progress to measure the rate of iodine removal in single bubbles of controlled size and composition. Preliminary data from these experiments indicate that actual gas transfer rates to liquid absorbing films may be considerably lower than theory predicts. The mass transfer resistance (back pressure) produced by the iodine dissolved in the foam requires a modification of this equation before it can be applied to the data.

CONCLUSIONS

The experiments with radioactive iodine described in this paper confirm previous reports that ether lauryl sulfate foams with sodium thiosulfate reactant can be used to decrease the iodine concentration in a closed chamber. The iodine-131 concentration reduction attributable to leakage, dilution, and wall adsorption was 70% of the initial concentration, 100 minutes after the iodine release. When foam was added to the system, the iodine-131 concentration reduction was 90% with air recirculation and 92% with no air recirculation at 100 minutes respectively.

The rate of iodine concentration reduction was 1.15% of the initial concentration per minute without foam and 2% per minute with recirculation plus foam and 4% per minute with foam and no recirculation. The iodine concentration decreased to a constant value of 30% of the initial concentration in 100 minutes

in the no foam experiment, but required only 60 minutes to reach a constant value of 10% of the initial concentration with foam.

The data shows that the foam used decreased the iodine-131 concentration in a closed cell to a value one-third lower than that measured without foam and the rate of concentration reduction was nearly three times greater with foam than without.

Two uranium foil burning experiments using foam indicate that the presence of particulates alters the pattern of removal which is far less rapid than if no aerosol were present. One important fact observed in these experiments was that very little activity was released from the ignited uranium foils and the only material detected was iodine-131 and 133. The greater part of the activity remained in the furnace as evidenced by ionization chamber readings.

These data do not agree with the theory presented by Fuchs (3) which has been used to calculate the rate of aerosol concentration reduction in a spherical chamber. Further theoretical and experimental work is being carried out to explain the observed discrepancy.

BIBLIOGRAPHY

1. Silverman, L., Corn, M. and Stein, F., "Diffusion Board Containment Concepts and Foam Encapsulation Studies." Seventh AEC Air Cleaning Conference, Brookhaven National Laboratory, October 1961. p. 390.

2. Silverman, L., "Foam and Diffusion Board Approaches to Containment of Reactor Releases." Third Conference in Nuclear Reactor Chemistry, U. S. Atomic Energy Commission TID 7641. 1963. p. 169.

3. Fuchs, N. A.: The Mechanics of Aerosols. (1955) Technical Information Division, U. S. Army Chemical Warfare Laboratories, Army Chemical Center, Maryland. Translated in 1958.

LIMITS OF SENSITIVITY IN THE MONITORING OF RADIOACTIVE GASES, WITH PARTICULAR REFERENCE TO KRYPTON 85

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INTRODUCTION

The detection of radioactive gases is one of the important monitoring functions required around reactor installations. A stack gas monitor is needed to insure that levels of radioactive contaminants will not be released to the environment in quantities in excess of radiation protection guides. Radioactive gas or particle monitors are also often sensitive enough to give indications of possible malfunctions which release activities at levels well below the airborne activity concentrations which could result in excessive releases to the environment.

If we confine ourselves to the consideration of radioactivity in the gaseous phase, thus excluding the detection of radioactive particulate matter, we find that two main approaches are used in practical monitoring systems. One is to collect the gas in an ionization chamber and measure the current produced by its radioactivity. The second is to immerse a Geiger-Mueller or other counter into the gas and count the pulses produced in the detector by the rays emitted by the gas.

Both the ionization chamber and particle counter methods represent gross radioactivity measurements. Their advantage is that they use relatively simple and reliable instrumentation. They cannot be used to any appreciable degree to analyze the radiations and identify the radioactive contaminants, except perhaps by what can be learned from half-life or simple absorption measurements. Other methods, in particular, scintillation methods, must be used if more detailed data are needed.

In this paper we shall present calculations of the efficiencies of idealized ionization chambers and particle detectors. The results will give us an insight into the factors which effect the sensitivities of the detectors and indicate how the sensitivities might be best improved in particular instances. Calculations of the theoretical sensitivities of some common gas detectors will be made and compared with actual measurements.

All fission gases are both beta and gamma emitters. We shall confine outselves to detection of the beta radiation since in most instances, the beta radiation is the more sensitive indicator of radioactive gas contamination.

The calculations and measurements will deal with Krypton 85 as the radioactive gas. This gas is important as the most potentially serious atmospheric contaminant from the long-term use of nuclear power. Krypton 85 is also being used in medical research as a tracer in studies of the circulation, and must be monitored in connection with this work.

EFFICIENCY OF DETECTION OF SPHERICAL AND CYLINDRICAL IONIZATION CHAMBERS

Consider the current produced in a spherical ionization chamber which contains a radioactive gas. If we increase the size of the chamber, keeping the total amount of radioactive gas in the chamber constant, the fraction of energy emitted by the gas which is absorbed in the chamber will increase. The current produced by the gas will also increase with size and then will level off as the dimensions of the chamber significantly exceed the effective range of radiations within the chamber. The current contributed by the radiation background will increase steadily with increased chamber volume.

An approximation of the fraction of energy absorbed within a spherical ionization chamber may be obtained by considering the absorption of beta particles as exponential. Exponential absorption holds over most of the range of beta particles, with an absorption coefficient by

$$\frac{\mu}{\rho} = \frac{17}{E_m^{1.14}}$$

where μ / ρ is the absorption coefficient in cm^2/gm, and E_m is the maximum energy in Mev. (2)

Equations for the flux from a source uniformly distributed inside a spherical medium are given in Ref. (3). The equations for a sphere of radius R_o, and points P_1 at the center of the sphere, P_2 at the surface, and P_3 within the sphere and at a distance d from the center are:

at P_1

$$\phi = \frac{Sv}{\mu_s} (1-e^{-\mu_s R_o})$$

at P_2

$$\phi = \frac{Sv}{2\mu_s} \left\{ (1 - \frac{1}{2\mu_s R_o} + \frac{e^{-2\mu_s R_o})}{2\mu_s R_o} \right.$$

at P_3

$$\phi = \frac{Sv}{\mu_s} \left\{ (1 - \frac{e^{-b4}}{2} - \frac{e^{-b5}}{2} - \frac{1}{4\mu_s d} \left[e^{-b4}(1+b_4) - e^{-b5}(1+b_5) \right] \right.$$

$$\left. + \frac{b_4 b_5}{4\mu_s d} \left[E_i(b_4) - E_i(b_5) \right] \right.$$

where

$$b_4 = \mu_s (R_o - d) \text{ and } b_5 = \mu_s (R_o + d)$$

μ_s is the absorption coefficient for the radiation, S_v is the number of particles emitted per second per unit volume.

These equations enable evaluation of the ratio of the average dose rate in a sphere to the dose rate in an infinite medium. This ratio, increased by backscattering from the walls of the chamber, is equal to the efficiency of the spherical detector.

The fraction of the total energy emanating from the active volume of a cylindrical chamber which is absorbed within the active volume is given in reference (4) as:

$$F = \frac{E}{3R}\left[\frac{z}{2} + 2\left\{\frac{2a(r-\frac{a}{2})^2 + \frac{4}{3}r^3\left[\cos\phi\,(\sin^2\phi + 2)\right]_{\theta}^{0}}{\pi(r^2 - a^2)}\right\}\right]$$

F = fraction of energy emitted in active volume that is absorbed in that volume

E = total energy emitted by radionuclides within volume

R = range (inches of air) of β particles at one-third of maximum energy

z = axial length of the active volume of the chamber

r = outer radius of the active volume of the chamber

a = inner radius of the active volume of the chamber (outer radius of the central electrode)

θ = arc cos a/r

ION CHAMBERS FOR RADIOACTIVE GAS DETECTION

Laboratory instruments for measurement of radioactive gases have been described by Tolbert (5). The gas is collected in a specially designed vessel. Particular attention is paid to the insulators and electrodes to minimize leakage current and contact potential. The current is measured by a sensitive electrometer. For greatest sensitivities the vibrating reed electrometer is used. The most sensitive ranges on commercially available electrometers vary between one and three millivolts.

A commercially available spherical ion chamber which we have used in our laboratory has a volume of 2.8 liters. Large chambers, cylindrical in volume, have been used for field monitoring and are patterned after a design by Kanne. These chambers vary between 20 and 50 liters in size and have been discussed in several papers. (4,6)

Using the equations in the previous section, and Krypton 85 as the radioactive gas, we obtain efficiencies of 16 per cent neglecting backscatter and about 20 per cent including backscatter from the chamber walls for the 2.8 liter spherical chamber. For the 20 liter Kanne chamber, the efficiency is 25 per cent. (Krypton 85 data used in the calculations were E_{max} = 0.695 Mev., E_{avg} = 0.23 Mev, u/ρ = 25.8 cm^2/gm, u = .0332 cm^{-1} in air at STP).

The background current produced per unit volume in a field of 0.01 mr per hour would be approximately 10^{-18} amp/cc. This calculation neglects the

contribution of the alpha contamination. If we assume a contamination level of 3 alpha particles per hour per cm^2, use 5.9 Mev as the average energy per particle for radium series alpha particles, and assume that all the energy is dissipated in the chamber, we obtain a background current of 2.1×10^{-19} amperes per sq. cm. of surface. For the 2.8 liter ion chamber with a surface area of 9500 sq. cm. the alpha background is 2×10^{-15} amperes.

Actually, this result is an overestimate since it neglects absorption in the walls. In addition, the alpha contribution can be reduced by keeping the collection voltage low enough to give appreciable recombination in the alpha particle tracks, but high enough to maintain collection of all the ions from beta particles. It will also be shown later that the alpha pulses can be distinguished from the current produced by the beta particles and much of their effect can be excluded in a current reading.

Greatly increased sensitivites can be obtained by compressing the gas into an ionization chamber and taking a current measurement at a high pressure. Working at high pressures, say 50 atmospheres, we obtain not only an increased concentration of gas in the chamber, but a higher fraction of energy absorbed within the chamber. The current from the radiation background also goes up, but apparently not nearly as much as the current from the radioactive gas. Spiers (7) reported an increase of the background response of only a factor of four in raising the pressure of an ionization chamber to 78 atmospheres. The response to gamma radiation increased twenty times.

A modification of a portable ionization chamber discussed by Rising may be useful for monitoring in the field. (8) This ion chamber uses a 30V battery for the ion collection and the battery is mounted inside the chamber between the inner electrode and the connector. This arrangement appreciably reduces leakage current across the insulators and the low voltage results in reduced alpha particle background because of recombination along the alpha track.

SENSITIVITIES OBTAINABLE WITH IONIZATION CHAMBERS

The maximum sensitivity of a radiation detector is determined by many factors, including inherent noise in the system, background radiation, variations in radiation background, the time available to make a measurement, and the desired accuracy of the measurement. Criteria for practical limits of sensitivity for field use cannot be set to cover all applications and conditions and the limits are best established by studying the performance of the equipment under field conditions. As a means of comparing the sensitivities of detectors, it seems reasonable to set the lower limit of detection of the ionization chambers at that level of gas concentration which increases the background current by a factor of two.

If we apply this condition to the 2.8 liter ionization chamber at atmospheric pressure, we obtain a sensitivity of 2.5×10^{-7} μc/cc as the lower limit of detection for Kr^{85}. This is the level which will produce 2×10^{-18} amp/cc in the chamber, the same current produced by a background level of .02 mr/hr, if the chamber is considered to have an efficiency of 20 per cent for the radioactive gas. Lower concentrations may be detected using a 20 liter chamber at high pressure. A decrease of a factor of four is obtained from increased efficiency of detection, and the limit is even lower, dependent on how much the background decreases relative to the response to the source.

Further increases in sensitivity could be obtained by additional shielding around the counter to reduce the background contribution.

The direct measurement of current is limited by the stable resistance available and the maximum sensitivity of the voltmeter. These are 10^{12} ohm and 1 millivolt respectively, although 1 mv measurements require some care in providing proper shielding and minimizing noise signals. Although this indicates a sensitivity of detection of currents less than 10^{-15} amp, it may be preferable to use the rate of charge method for currents less than 10^{-13} amp. In this method, the charge collected by the electrometer over a period of time is measured rather than the "instantaneous" current.

The rate of charge method may, at low radioactivity levels, require several minutes to obtain a measurement. This does not appear to be an important consideration in monitoring at the extremely low levels possible with the method. The sensitivity of the rate of charge method appears limited only by the radiation background. We shall assume that we can monitor practically changes of the order of 50 per cent in the background level and that the lower limits of sensitivity given above can be reduced by a factor of 2 for the rate of charge method.

ANALYSIS OF DETECTION OF BETA RADIATION BY A PARTICLE DETECTOR

We shall now consider the general case of detection of radioactive gases by a particle detector which is immersed in the gas. Assume the detector has unit cross sectional area and the gas is sampled in a medium of dimensions much larger than the maximum range of the beta particles. There will be some attenuation in the detector wall. We shall assume that the attenuation of the beta particles in the medium is exponential over the range and can be quantitatively expressed by an absorption coefficient, μ.

To get the number of beta particles crossing unit area of a detector immersed in the radioactive gas, we have to integrate an expression of the form:

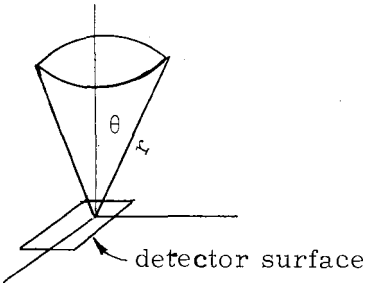
$$J = \frac{No \Delta V}{4 \pi r^2} \qquad e^{\frac{-\mu \rho r}{\rho}} \cos \theta \; A_w$$

No = the number of beta particles emitted per cc

θ = the angle between the normal to the surface of the detector and the radius vector between the detector and the element of volume ΔV

A_w = an average wall attenuation factor

ρ = the density



$$J = \frac{NoAw}{2} \iint \sin \theta \cos \theta \; e^{\frac{-\mu\rho}{\rho} r} \, d\theta dr$$

$$= \frac{NoAw}{4\mu} \left(1 - e^{-\mu r} \right)$$

It is seen that the effect of the radioactive gas at distances greater than a few times ($1/\mu$) becomes small.. The number of beta particles crossing unit area in the limit is given by

$$\frac{NoAw}{4\mu}$$

For Kr 85, $\mu = .0332$ cm^{-1} at atmospheric pressure, and $1/\mu = 30$ cm. A volume with dimensions of the order of 1 meter acts essentially as an infinite volume for detection of the beta particles.

A concentration of 10^{-7} μc/cc of Kr 85 gives 0.22 dpm/cc for N_o. Then $J = \frac{.22}{4(.033)} = 1.7$ beta particles/cm^2 -min.

COUNTERS FOR BETA PARTICLE DETECTION

Many types of counters are available for monitoring of radioactive gases - cylindrical, end-window and "pancake" G-M tubes, large-area proportional flow counters, scintillation detectors with thin beta-detecting crystals, and solid state detectors. The choice of one or another of these counters may be indicated by the requirements of a given application.

The Anton 112 cylindrical G-M tube is an inexpensive detector commonly used in radiation survey and prospecting instruments. It is 0.75" in diameter and 3" in length, with a surface area of approximately 45 cm^2. It has a steel wall, 30 mg/cm^2 thick. We shall assume an average wall thickness which is greater than the actual wall thickness by 20 per cent to account for angular variations in the path of the incident beta particles through the wall. The factor A_w for a wall thickness of 30 mg/cm^2 is calculated to be 0.4 for Kr 85. We may thus expect a counting rate for this tube of .4 x 45 x 1.7 or 30 counts per minute at 10^{-7} μc/cc Kr 85.

Mica end-window G-M tubes also make suitable gas detectors. They may be obtained with very thin windows of the order of 1 mg/cm^2, which will produce only a small attenuation of the incident radiation. The thinnest windows are necessary only for the low energy beta emitters such as C-14, but would not be of particular advantage for Kr-85.

The Anton 1008 tube is a double ended mica window halogen quenched pancake tube. The internal geometry is such that its volume and cathode surfaces are considerably smaller than that of a conventional tube having an equivalent mica window surface. Accordingly, its background is low for its detection area. This tube has a diameter of 1.75 in. and a thin window (available from 1.4-4 mg/cm^2). The tube is more efficient than the Anton 112, but is also much more expensive, and less readily available since the manufacturer has recently had production difficulties.

Thin walled proportional flow-counters are obtainable with large detection areas to give a relatively high counting rate for a given gas concentration.

Solid state detectors may be advantageous in gas detection because of the very low attenuation and the small response to background. If we neglect wall attenuation, we estimate about 1.7 cpm/cm^2 area of a solid state detector for a Kr 85 concentration of 10^{-7} μc/cm^3.

Scintillation detectors, employing thin scintillators, may also be used. The thinner the scintillator, the better the beta response relative to the background gamma radiation. Scintillation detectors for beta monitoring are

discussed in reference 9.

If the gas volume viewed by the detector is less than needed for maximum response, increased sensitivity can be obtained by pressurizing the gas. As long as the detector can see a source of Kr-85 beta radiation at least a meter in depth, there is no advantage to compressing the gas to obtain increased counts. However, by compressing the gas to, say, 10 atmospheres, one needs only a 10 cm depth for viewing. This smaller volume is much easier to shield, and facilitates the use of an anti-coincidence system for minimization of counts from cosmic rays. However, the types of detectors which can be used at elevated pressures are limited. The most suitable appears to be the solid state detector.

To complete our discussion of particle detectors, we may also mention internal gas counting methods, i.e. collecting the gas in a counting chamber and counting by some pulse counting method. Shielding plus anti-coincidence methods for reduction of cosmic-ray background can reduce the background to very low levels, and by inserting the gas into the counter, maximum efficiency is obtained.

The minimum size pulse which can be detected is governed by the noise level of the amplifier. Because of the small pulse produced in an ionization chamber by a beta particle, gas multiplication would be required to exceed the noise level sufficiently for detection.

Gas multiplication requires careful gas purification techniques, particularly with regard to the removal of electronegative impurities. For this reason, internal gas proportional counting is not considered an appropriate method for routine monitoring although it is widely used in research work. A high pressure proportional counter is described in reference 10.

SENSITIVITIES OBTAINABLE WITH PARTICLE DETECTORS

The number of beta particles incident per square centimeter per minute on the surface of a detector immersed in Kr-85 was calculated to be 1.7 for 10^{-7} μc/cc concentration. To evaluate the lower limit of detection for any given system, we shall stipulate that the lowest concentration the detector can monitor is that concentration which will increase the background by 50 per cent.

The Anton 112 cylindrical G-M tube has a background of approximately 30 cpm at 0.02 mr/hr. Its calculated response to Kr-85 is 3 cpm for 10^{-8} μc/cc. A level of 5×10^{-8} μc/cc would be required to increase the background by 50 per cent. To detect this activity at the 99 per cent confidence level would require an accumulated count given by $2.6 \frac{\sqrt{n}}{n} = 0.5$, or $n = 27$ counts. One minute counting time would be required for this level of detection.

The background of 30 cpm was measured in the basement of a masonry building and the detector was thus partly shielded. Additional lead shielding did little to reduce the background. Cosmic-ray guard counters in anti-coincidence with the detector would have to be added to give further significant decreases in background.

If the 30 mg/cm^2 wall of the Anton 112 provides excessive attenuation of the incident beta radiation, better performance will be obtained with thinner walled detectors previously mentioned. For Kr-85 beta rays, the very thin walled detectors should give a response about 2.5 times that of the 30 mg/cm^2 wall, per unit detector area. Additional data on the background response is necessary to evaluate the merits of a specific detector. The relative contribution of the background depends on the fraction of the total detector surface which is not used to admit the beta particles into the counter.

MEASUREMENTS WITH G-M COUNTERS AND IONIZATION CHAMBERS ON AIR CONTAINING KRYPTON 85

Measurements were made on air containing Krypton 85 with two commercially available G-M detectors and a 2.8 liter ionization chamber. A known amount of Krypton 85 was injected with a syringe into a 400 cubic foot tank. The krypton had been assayed in the syringe with a 2" by 2" NaI crystal and multichannel analyzer. An Anton 112 cylindrical G-M counter was mounted in the center of the tank and gave the response of the detector in what was essentially an infinite volume of air. The air from the tank was recycled through a 2.7 liter ionization chamber and a 55 gallon drum containing another Anton 112 tube in the center and an Amperex 200 HB end-window G-M tube with a 1.4 mg/cm^2 mica window. The end-window tube viewed the gas from the side of the drum. The arrangement of detectors is shown in Figure 1.

The responses of the cylindrical G-M counter and the ion chamber to a known dose rate from a cobalt-60 source were determined. The radiation background in the laboratory was also measured with the detectors.

The readings are given in Table 1. Column (1) gives the measurements on the Kr-85. Column (2) gives the background when no Krypton was present. This background was approximately 0.02 mr/hr. In Column (3) the background is subtracted from the total reading and the results extrapolated to 10^{-7} μc/cc. In Column (4), the ratio is given of the net reading at 10^{-7} μc/cc to the background.

TABLE 1

READINGS OF 2.8 LITER IONIZATION CHAMBER AND G-M DETECTORS IN AIR CONTAINING Kr-85

Detector	(1) Kr-85 conc.,* 2.18×10^{-6} μc/cc	(2) Background 0.02 mr/hr	(3) Net Reading at 10^{-7} μc/cc	(4) Ratio (3)/(2)
2.8 liter ion chamber	3.6×10^{-14} amp	5×10^{-15} amp	1.43×10^{-15} amp	0.29
Cylindrical G-M counter in large tank	359 c/m	30 c/m	15 c/m	0.50
Cylindrical G-M counter in 55 gallon drum	164 c/m	30 c/m	5.7 c/m	0.19
End window G-M counter in 55 gallon drum	198 c/m	36 c/m	7.4 c/m	0.21

* This value must be considered as tentative, pending calibration with an NBS Kr-85 standard.

The calculated response for the 2.8 liter ion chamber at 10^{-7} μc/cc (efficiency of 20 per cent) was 2.2×10^{-15} amperes, compared to a measured response of 1.43×10^{-15}. The calculated response for the cylindrical counter in the large tank was 30 counts per minute compared to the measured response of 29 counts per minute. The agreement between calculated and measured values is close enough to justify using the calculations to obtain general conclusions. Because in any given situation, a detector will be calibrated with known amounts of Krypton 85, rather than used with a calculated efficiency factor, no detailed investigation into the magnitudes of possible sources of error was made.

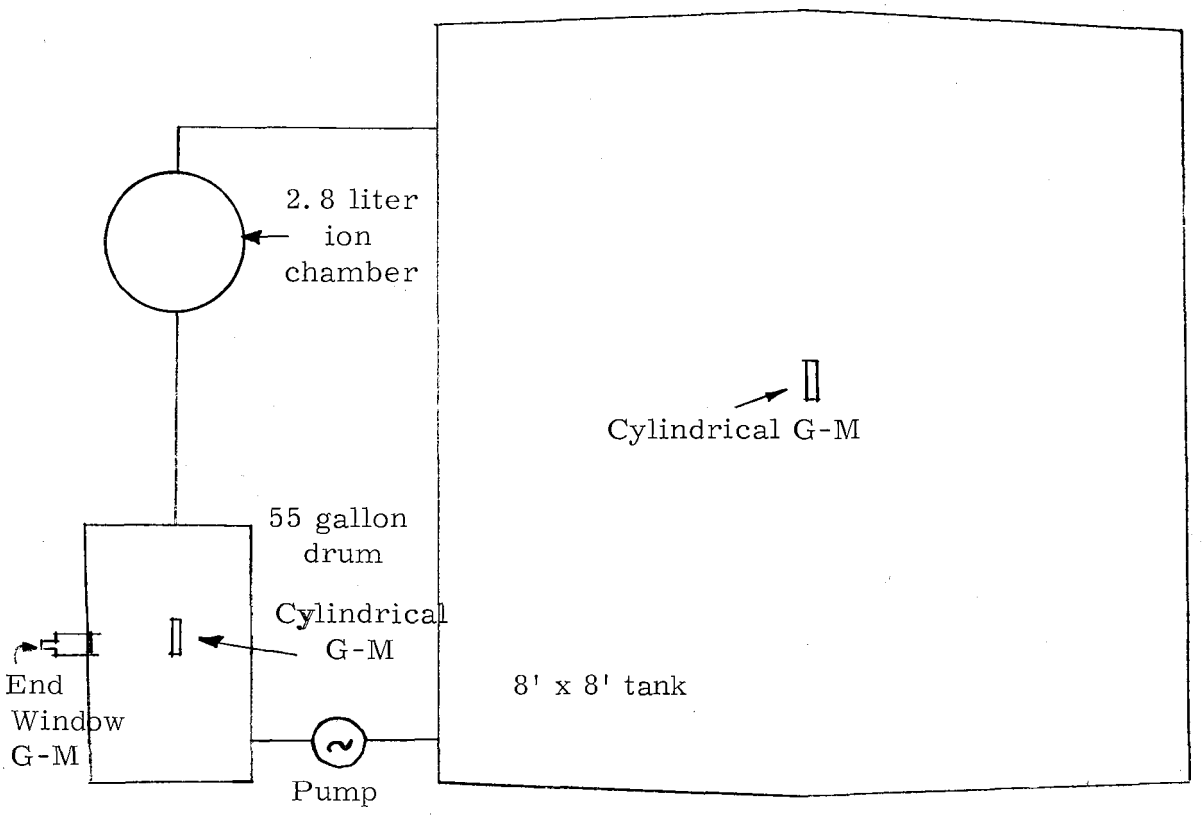


Figure 1 - Arrangement of detectors exposed to Drypton 85

The current in the 2.8 liter ion chamber was recorded on a Bristol recorder. A reproduction of a trace is given in Fig. 2. The trace shows the response of the measuring system when air containing Kr-85 was drawn through the chamber at a sampling rate of 0.2 cfm. It is seen that the recorder responded rapidly to a change in concentration from background levels to 2.2×10^{-6} μc/cc, reaching 90 per cent of its final level in a minute. This illustrates the advantage of a small collection volume for gas sampling. Much larger sampling rates would be needed to get as rapid a response for the detectors in the 55 gallon drum.

The fluctuations in the recorder trace around the mean value are due to the randomness of radioactive disintegrations. The reading of the meter at any time represents an integration of charge over a time interval of 2 RC preceding the instant of measurement, where RC is the time constant of the metering circuit. (11) The current reading will fluctuate according to the statistics of the counts accumulated during the 2 RC period.

The spikes superimposed on the average reading on the trace are produced by alpha particles. At the low current readings they may be neglected easily.

Sensitivities of particle detectors for radioactive gases have been reported in the literature. A G-M detector is used to measure the A-41 concentration of the effluent gas in the stack at the Washington State University Reactor (12). This method was selected after a review of all types of radioactive gas detection systems. The detector gave 10 counts per minute above a 67 cpm background at the maximum permissible concentration.

Ray (13) has used an Eberline Instrument Corporation Large Area flat plate gas proportional probe with a 0.85 mg/cm^2 aluminized mylar window to monitor argon-41 at General Atomics. He reported a net cpm sensitivity of 275 for a stack gas sample concentration of 10^{-7} μc/cc and a 1300 cpm background.

EXPERIENCE WITH IONIZATION CHAMBER MONITOR AT YANKEE ATOMIC ELECTRIC

A 500 ml spherical ionization chamber was installed in the stack gas sampling system at the Yankee Reactor at Rowe, Massachusetts for a period of approximately one month. The current from the chamber was read with a vibrating reed electrometer.

The ionization chamber was located in a 5 mr/hr radiation field which was reduced by shielding to a value which produced a 3×10^{-15} ampere ion current in the chamber. Radioactive gases (Xenons and Kryptons) were released daily to the stack for a short period (5-15 minutes) during sampling of the primary coolant water. The ion chamber - electrometer system responded to each gaseous release by showing an increased ion current at least twice background. The background ion current was $\sim 3 \times 10^{-15}$ amperes and during release the current rose to 10 to 12 $\times 10^{-15}$ amperes depending upon the quantity of material discharged. The 500 ml chamber gave about 0.4×10^{-15} amperes at 10^{-7} μc/cc so the maximum concentration released was 3×10^{-6} μc/cc.

Immediately following an activity release the ion current resumed its initial value prior to release. The lowest stack background recorded was 2×10^{-15} amperes and the highest value recorded was 6×10^{-15} amperes. A one hour room air background was taken each 8 hours. The room air reading was always about $\sim 0.4 \times 10^{-15}$ amperes less than the stack background. This lower value was constant regardless of the level of the stack activity. The reason for the difference has not been investigated. The baseline drift of the electrometer appeared to be sufficiently stable to allow its use as a field monitor.

FIGURE 2
RESPONSE OF IONIZATION CHAMBER
TO KRYPTON 85

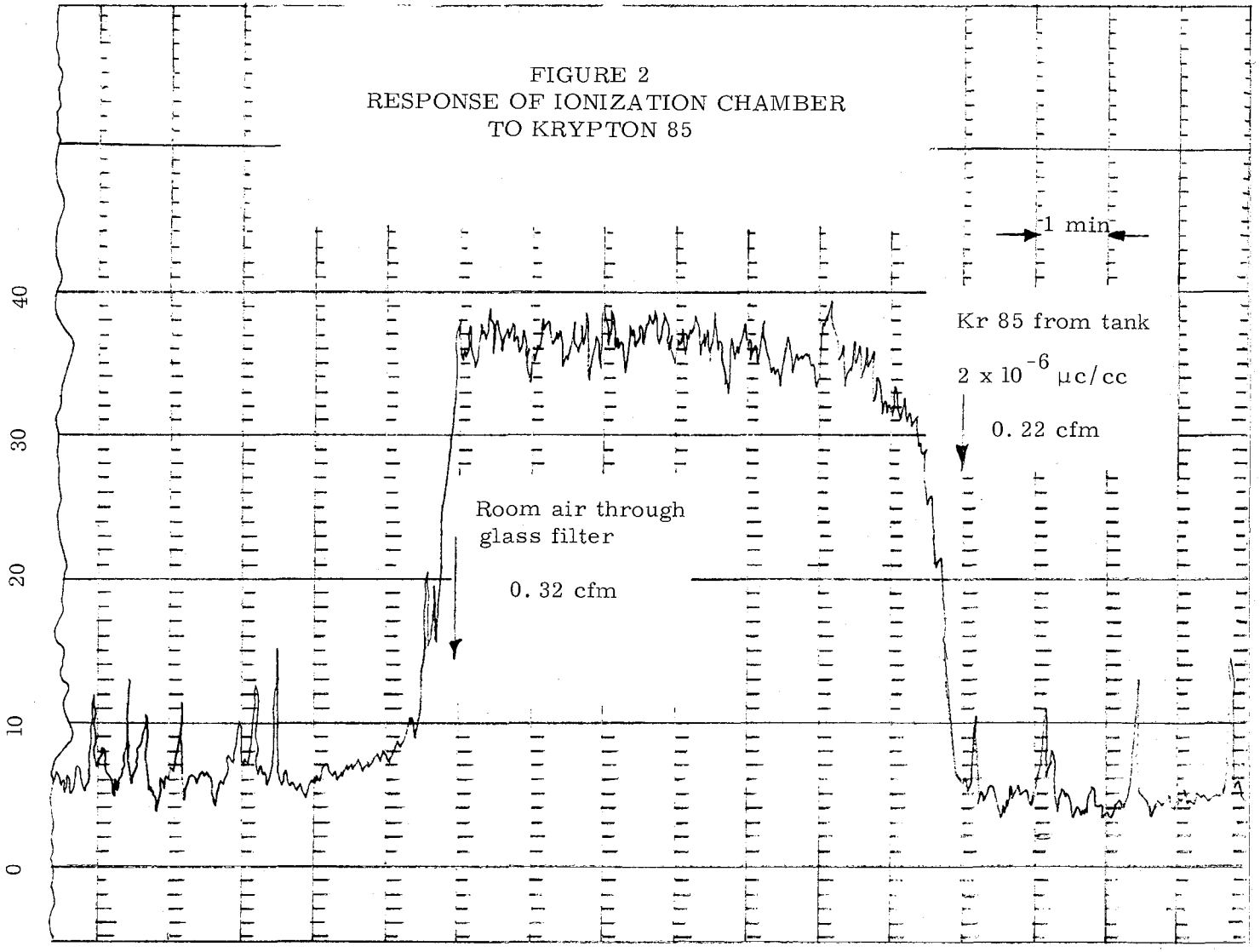


Table 2 summarizes the data obtained in these experiments.

TABLE 2

RADIOACTIVITY RELEASES AS MEASURED BY THE 500 ml IONIZATION CHAMBER AND ELECTROMETER

Date	Time of Release	Duration of Release (Minutes)	Peak Electrometer Reading Amperes x 10^{15}	Background Before Release (amperes x 10^{15})	Background After Release (amperes x 10^{15})
Aug. 2, 1963	8:20 A.M.	160	11.4	3.3	3.9
9, 1963	8:20 A.M.	15	11.1	6.0	6.3
9, 1963	1:20 P.M.	10	8.4	6.0	6.0
13, 1963	8:15 A.M.	15	9.0	4.5	4.5
15, 1963	8:25 A.M.	5	12.0	5.4	5.4
16, 1963	8:15 A.M.	20	11.1	4.2	4.2
22, 1963	7:55 A.M.	420	12.6	3.3	3.3
23, 1963	8:10 A.M.	5	10.8	3.3	3.3
24, 1963	8:05 A.M.	3	8.4	3.0	3.0
26, 1963	8:10 A.M.	5	8.4	3.6	3.6
27, 1963	8:10 A.M.	5	8.1	3.6	3.6
28, 1963	8:15 A.M.	15	12.0	3.3	3.3
29, 1963	8:10 A.M.	10	8.4	3.0	3.0

CONCLUSIONS AND RECOMMENDATIONS

The lowest gas concentration detectable is not the sole criterion for selection of a gas detection method. Simplicity, reliability, availability and cost are also factors which must be considered in the ultimate choice of a system. Information on reliability of equipment and of results is needed and must be obtained from laboratory studies and from information on field performance.

Additional operational data should be obtained for the different systems mentioned in this report - the cylindrical and pancake thin window counters; spherical ion chambers; large Kanne chambers; solid state detectors; and scintillation detectors. Commercial micromicroammeters should be tested to determine the lowest currents which can be measured reliably under field conditions.

In Table 3 the lowest levels of Krypton 85 which can be monitored under different operating conditions are shown. It is seen that for levels of the

order of 10^{-7} microcuries/cc, a simple cylindrical G-M counter is adequate if a large volume can be viewed, and it is the simplest detector available. If for reasons of shielding or space the sample volume must be small, an ionization chamber can be used. Alternately, the gas can be compressed into a small volume and viewed with a scintillation crystal or solid state detector. To achieve maximum sensitivity, the background must be reduced as much as possible. Scintillation or solid state detectors which view the gas under pressure and are shielded and covered with an umbrella of detectors in anticoincidence to minimize the response to cosmic radiation, should give the highest sensitivities. Although additional experimental data is needed to give the lowest levels detectable, these levels are probably of the order of 10^{-8} c/cc for a fifty per cent change in the background.

TABLE 3

LOWEST CONCENTRATIONS OF KRYPTON-85 WHICH CAN BE MONITORED BY VARIOUS DETECTORS

Detector	Level μc/cc
2.8 liter ion chamber, current reading	2.5×10^{-7}
2.8 liter ion chamber, rate of charge	1.3×10^{-7}
Kanne chamber, current reading	2.0×10^{-7}
Pressurized ion chamber, current reading	0.6×10^{-7}
Pressurized ion chamber, rate of charge	0.3×10^{-7}
Cylindrical G-M tube in infinite volume	0.5×10^{-7}
Solid state or thin scintillation detectors with cosmic-ray guard counters	0.1×10^{-7}

Calculations are based on an external radiation background of 0.02 mr/hr.

The MPC for occupational exposure to Kr-85, 40 hr week, is 10^{-5} μc/cc.

The MPC for continuous exposure of large populations is 3×10^{-7} μc/cc.

The sensitivity could also be increased, of course, by selectively concentrating Krypton before measurement, but this would involve much more complicated equipment and is outside the scope of this paper. (14)

REFERENCES

(1) A Stack Effluent Radioisotope Monitor. R. A. Harvey. IRE Trans. Nuclear Sci. NS6, 20-28 (1959) Dec.

(2) R. D. Evans. The Atomic Nucleus. McGraw-Hill, 1955.

(3) Reactor Shielding Design Manual. T. Rockwell III, Ed. USAEC Report TID-7004, March 1956. p. 371.

(4) Operational Experience with Kanne Ionization Chambers. J. E. Hoy. Health Physics 6, 203-210, 1961.

(5) Ionization Chamber Assay of Radioactive Gases. B. M. Tolbert. UCRL 3499, March 5, 1956.

(6) Determination of Efficiency of Kanne Chambers for the Detection of Radiogases. J. J. Fitzgerald & B. W. Borelli. KAPL-1231, 1954.

(7) The Construction and Performance of a High Pressure Condenser Ionization Chamber, F. W. Spiers. British Journal of Radiology, XXII, 169 (1949).

(8) A Portable Dose Rate Instrument for Measurement of Natural Background Radiation Levels. F. C. Rising. HW 67787. Dec. 19, 1960.

(9) A Study of Beta Scintillation Counting with Plastic Phosphorous. J. H. Havley, N. A. Hallden, and I. M. Fisenne Nucleonics 20, No. 1, (1962), p. 59.

(10) High Pressure Proportional Counter. T. E. Gilmer, R. Mase and E. D. Palmatier, Rev. Sci. Inst. 28, No. 8, Aug., 1957.

(11) Electrometers and Amplifiers. E. Fairstein in "Nuclear Instruments and Their Uses." A. H. Snell, ed. Wiley, 1962.

(12) Measurement of A-41 Concentration in Effluent Gas. R. C. Brown. Paper P. 23, in Abstracts, 7th Annual Meeting of Health Physics Society, June 10-14, 1962.

(13) Stack Gas Beta Monitor, W. H. Ray, AIHA Journal 23, 496, 1962.

(14) On the Activities in the Plant Off-Gas. S. Fujii, J. F. Manneschmidt, T. S. Mackay and E. W. Woodall. Oak Ridge National Laboratory Report CF-61-4-45, UC-70, 1961.

A RADIOACTIVE WASTE INCINERATOR

by

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Abstract:

A 50 lb/hr incinerator for the concentration of low-level radioactive combustible waste has been designed and fabricated under joint sponsorship of the U. S. Atomic Energy Commission and the U. S. Army. The experimental facility utilizes auxiliary gas firing to maintain high combustion gas temperatures of 2,000 to 2,500°F, and dry collection methods for gas cleaning. An evaluation program is presently being initiated at the U. S. Army Nuclear Defense Laboratory, Edgewood Arsenal, Maryland, where the facility is installed.

* * * * *

Introduction:

A 50 lb/hr incinerator for the concentration of low-level radioactive combustible waste has been designed and fabricated under joint sponsorship of the U. S. Atomic Energy Commission (AEC) and the U. S. Army. This experimental unit has been designed to investigate the effects of varying (1) the location, number, and orientation of overfire air inlets, (2) the inlet velocity and mass flow rate of primary and secondary combustion air, and (3) the use of auxiliary gas fuel to the primary and secondary combustion chambers. After optimum performance conditions are established, radioactive tracers will be utilized to evaluate the radiological limits of the unit, and actual radioactive waste will be incinerated. Upon satisfactory completion of the program, experimental equipment will be eliminated in a final prototype design. Gas cleaning equipment, which will be required to maintain control of the release of radioactivity within federal regulations, will consist of conventionally manufactured stock items.

Background:

The AEC has long been interested in combustion as a concentration and disposal technique for radioactive wastes. A review of incinerator designs and operational experiences was presented at the last Air Cleaning Conference[1] by R. Dennis and L. Silverman. Discontinued incineration projects at AEC installations resulted in an AEC-sponsored study of combustion by the U. S. Bureau of Mines. R. C. Corey, et al.,[2] concluded that (1) uniformity of combustion rate and maximum combustion efficiency for single-chambered incinerators designed for burning typical laboratory wastes (low bulk density, low ash, and relatively

high volatile content) was best achieved with an overfire air supply, and that (2) the mass flow rate and direction of overfire air could best be controlled by admitting air tangentially to a cylindrical combustion chamber.

At the completion of the Bureau of Mines study, the Harvard University Air Cleaning Laboratory (ACL), under AEC contract, studied the air cleaning problems associated with radioactive waste incineration. After conducting an extensive evaluation program on the Bureau of Mines unit, ACL proceeded to design and develop a complete incineration and air cleaning system. Experimental units, ACL I and ACL II, based on the Bureau of Mines design criteria for the combustion method, were built and evaluated. For the ACL II, a secondary combustion chamber and a new method of waste charging were added as improvements. This work was presented at the Sixth Air Cleaning Conference.[3]

The Department of the Army has assigned the responsibility for radioactive waste disposal to the U. S. Army Eastern Chemical Depot at Edgewood Arsenal, Maryland. One aspect of this responsibility is the disposal of large volumes of radioactive low-level combustible wastes including large animal carcasses. The U. S. Army Nuclear Defense Laboratory (USANDL), Edgewood Arsenal, Maryland, has been requested to study and recommend disposal methods for these wastes.

The common interest of the AEC and the Army has resulted in the present co-sponsored program under which the 50 lb/hr experimental incinerator has been designed and fabricated; this unit is about to be tested and evaluated. The design of this experimental facility was based on the evaluation of the ACL 25 lb/hr incinerator, and was developed by ACL with USANDL assistance.

A contract was awarded last year to Pyro Incinerator and Supply Corporation, Mineola, New York. The facility was to be installed at the U. S. Army Edgewood Arsenal by December 31, 1962, but because of many difficulties, installation is just now being completed. Initial studies, under the direction of USANDL and ACL, will include a detailed evaluation of the facilities performance. Since performance data are not presently available, we will devote this time to describing the facility and discussing our program.

Facility Requirements:

The following requirements have been established for the facility:

1. Burn dry combustible wastes, i.e. less than 10 percent moisture content, at a rate of not less than 60 lb/hr with auxiliary gas firing.
2. Burn wet combustible wastes, i.e. up to 60 percent moisture content, at not less than 40 lb/hr with auxiliary gas firing.
3. Safely burn combustible waste charges containing up to 200 μC/kg of radioactivity of any or all of the following materials; waste paper, towels, swab rags, surgical dressings, wood, animal carcasses, human or animal organs, rubber gloves, rubber or plastic tubing, and animal pen debris (sawdust, feces, vegetable matters).

Facility Description:

1. Incinerator: Figure 1 presents a flow diagram of the facility. The incinerator, on the left, consists of a cylindrical primary combustion chamber with a cylindrical secondary combustion chamber mounted directly above. Auxiliary gas firing will be provided in both chambers. Waste material will be introduced as packaged charges through the side charging box. The hot combustion gases exit tangentially from the top of the secondary combustion chamber to maintain the spiral gas flow pattern throughout the entire unit. The effluent gas is cooled by dilution with ambient air through the air dilution valve. The volume of cooling air required may vary from 1 to 4 times that of the total combustion air.

RADIOACTIVE WASTE INCINERATION FACILITY

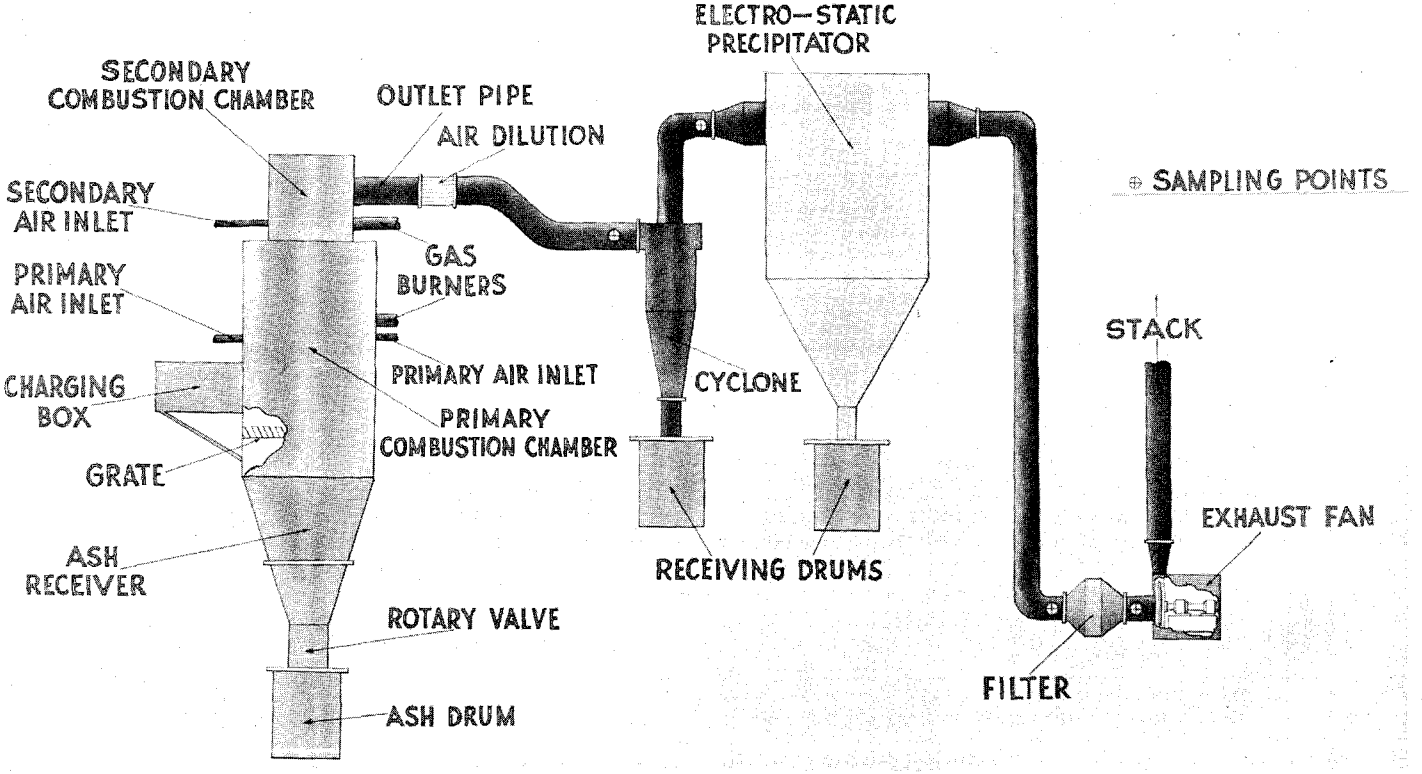


Figure 1

Since the incinerator is proposed for use in locations where liquid radioactive waste handling facilities are not available or are not desired, gas cleaning will be accomplished by dry collection methods; therefore, wet scrubbing techniques, which can cool as well as partially clean the gas, are excluded.

The system is composed of three basic units: (1) a medium velocity involute cyclone separator, which removes coarse particles entrained in the incinerator effluent and provides extended surface for gas temperature reduction, (2) a Cottrell-type electrostatic precipitator to collect fine solid particles, soot, mineral dust, and tar droplets formed by condensation of volatile organic vapors, and (3) a mineral fiber filtration unit, designed to capture any particulate blow-off from the electrostatic precipitator and to provide limited emergency protection in the event of electrical power failure or precipitator malfunction.

Figure 2 shows the facility lay-out as it is installed at the Edgewood Arsenal. Because of the space limitations, we have adapted a U-shaped configuration with the control panel placed in the center of the "U" so that the operator can observe most of the entire facility from the panel.

The incinerator shown in Figure 3 consists of a primary combustion chamber, 30 inches O.D. and 40 inches high, with a secondary combustion chamber, 20 inches O.D. and 32 3/8 inches high, mounted directly above the primary chamber. Both chambers are constructed from mild steel and lined with insulating refractory, 2 1/2 inches thick, to maintain a high combustion gas temperature of approximately 2,000 to 2,500°F.

Provision has been made to admit primary overfire air tangentially to the primary combustion chamber through two openings, approximately 24 inches above the top of the grate and 155° apart. The primary air inlets consist of 3-inch stainless steel pipes, into which specially shaped annular pipe sections, approximately 14 inches long, can be inserted to permit inlet velocity variation at constant flow rate. Two sets of air inlets, constructed as panel insert sections, are available. One pair is for tangential, horizontal air admission; the other for directing inlet air tangentially downward at a 30° angle relative to the horizontal. Total primary air, from either one or both inlets, is expected to range from 50 to 100 ft^3/min STP. Secondary combustion air, 20 to 40 ft^3/min STP, is admitted tangentially through a single 2-inch pipe, 6 1/2 inches above the base of the secondary chamber. Annular inserts are also provided to permit inlet velocity variation in the secondary air supply at constant flow rate.

Auxiliary gas firing will be provided by Eclipse Tunnel Mix Burners. Initially, it is planned to fire the secondary combustion chamber continuously to minimize discharge of unburned materials, and to fire the primary combustion chamber intermittently or continuously to maintain the desired operating temperature. Auxiliary gas firing will also be employed to preheat the combustion chamber to the desired operating temperature prior to charging waste. The primary burner is rated for 100,000 - 500,000 BTU/hr and the secondary, 50,000 - 250,000 BTU/hr. A platinum/platinum 10 percent rhodium thermocouple is located upstream of the dilution valve to measure the secondary chamber effluent gas temperature. The thermocouple is connected to a Bristol Free Vane Pyrometer Controller which regulates the Eclipse automatic control valve, thus providing automatic temperature control of the incinerator.

Waste material will be introduced as packaged charges, approximately 14 by 14 by 14 inches containing 6 to 10 pounds, through a side loading box, the bottom of which is located 9 inches above the grate. A three-pronged sliding fork inserted through the loading door permits temporary suspension of wet charges above the grate to facilitate rapid drying. A manually operated protec-

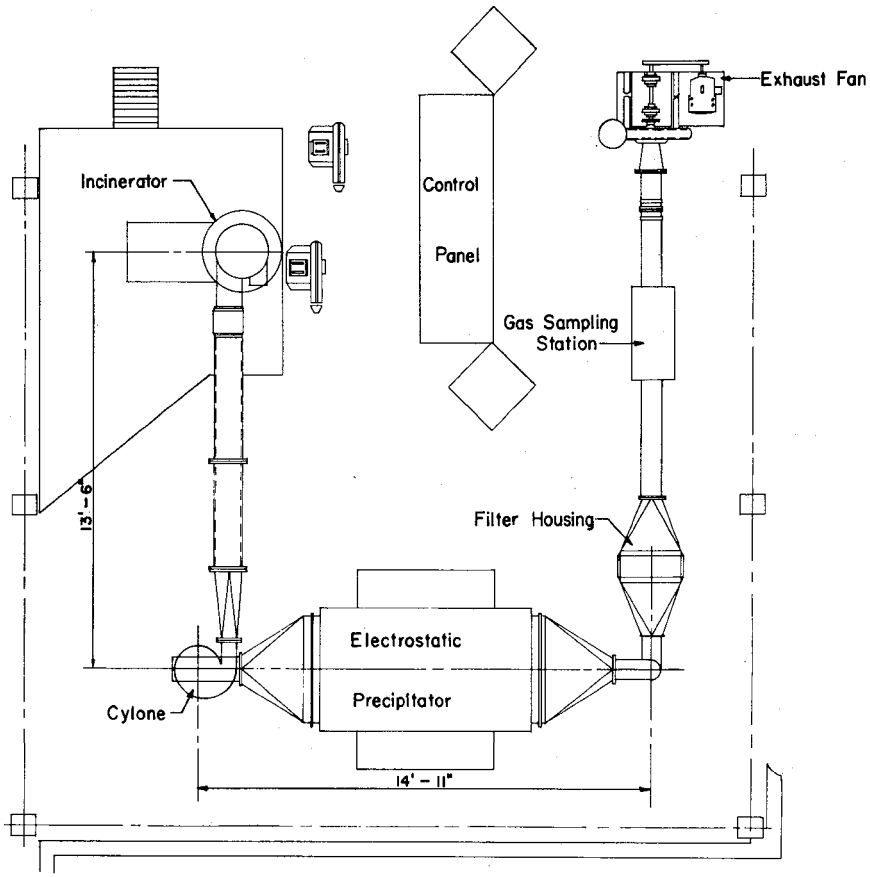


Figure 2

Incinerator Facility – Plan View

tive guillotine door, in conjunction with the totally enclosed charging box, is provided to minimize exposure of operating personnel to accidental release of dust or fumes during charging operations.

The incinerator grate, located 9 inches above the conical ash receiver, consists of four 40-pound cast-iron sections supported on a brick-work shoulder. The conical ash receiver flanged to the bottom of the combustion chamber discharges into a 55-gallon drum used for final collection of ash. A rotary valve with an air-tight shaft is attached to the bottom of the conical section to prevent ash spillage during change of ash drums. A hydraulic jack maintains a tight air seal between the drum rim and the incinerator hopper. Figure 4 shows a photograph of the incinerator during construction. The charge box and one air inlet panel have not been installed.

2. Gas Cleaning Equipment: The gas cleaning system, shown in Figure 5, is composed of a cyclone, electrostatic precipitator, and filter unit. The cyclone is capable of operating at gas flow rates to 760 ft^3/min STP and at temperatures to 750°F. Fractional collection efficiency at 70°F and 760 ft^3/min STP, shall be 95 percent for particles having a terminal settling velocity equivalent to those of 20-micron diameter spheres of specific gravity 2.0. The hopper discharge pipe is welded to a nonwarping steel cover plate and channel section. Gasketing, to be installed in the channel, will consist of 30 durometer Dow Silicon Rubber, 1/2-inch thick by 2 inches wide. A hydraulic jack will be used to maintain pressure contact between the 55-gallon steel drum and the gasket to prevent air leakage.

The cyclone effluent enters the 30 kV dc rod and plate electrostatic precipitator. It will furnish an average weight collection efficiency of 98 percent at gas flow rates to 1000 ft^3/min and at temperatures to 600°F. It is anticipated that submicron particles will be collected by operating the oversized unit at a decreased flow rate, and by not shaking the unit during operation. The precipitator will be cleaned by shaking methods when the incinerator is not in use and the material will be collected in the ash receiver located below.

The gas then enters the filter unit, which consists of two high-efficiency fiber filters in a parallel arrangement; MSA Dustfoe Space Filters rated for flow rates up to 1,000 ft^3/min STP will be used and will operate at air temperatures up to 500°F. The filter holder consists of two sixteen-gauge galvanized transition sections expanding from an 8-inch duct flange to a rectangular opening of approximately 2 by 4 ft. The filter holder is designed to handle commercial type filters of 24- by 24-inch face area and contains a clamping device so that units ranging in depths from 4 to 12 inches may be utilized. The filter holder is clamped between the transition sections with bolts and nuts around the exterior of the unit.

3. Control Instrumentation: Figure 6 shows the left end of the control panel. The facility is completely controlled from the control area and all blowers, electrostatic precipitator, etc., are connected by interlocks so that the auxiliary gas burners in the incinerator cannot fire unless the main exhaust fan is running. The interlock also prevents the shaker mechanisms on the electrostatic precipitator from operating while the main exhaust fan is operating. A key bypass is available for component testing. The timer system is utilized to control sampling times. The four sampling pumps can be started simultaneously and then turned off manually, or automatically by the timer. A continuous wind velocity and direction recorder is installed with the generator unit being placed at the same height as that of the top of the exhaust stack. The manometers indicate flow rates and pressure drops throughout the system. Figure 7 shows the remainder of the manometers and the second rack containing the Bristol

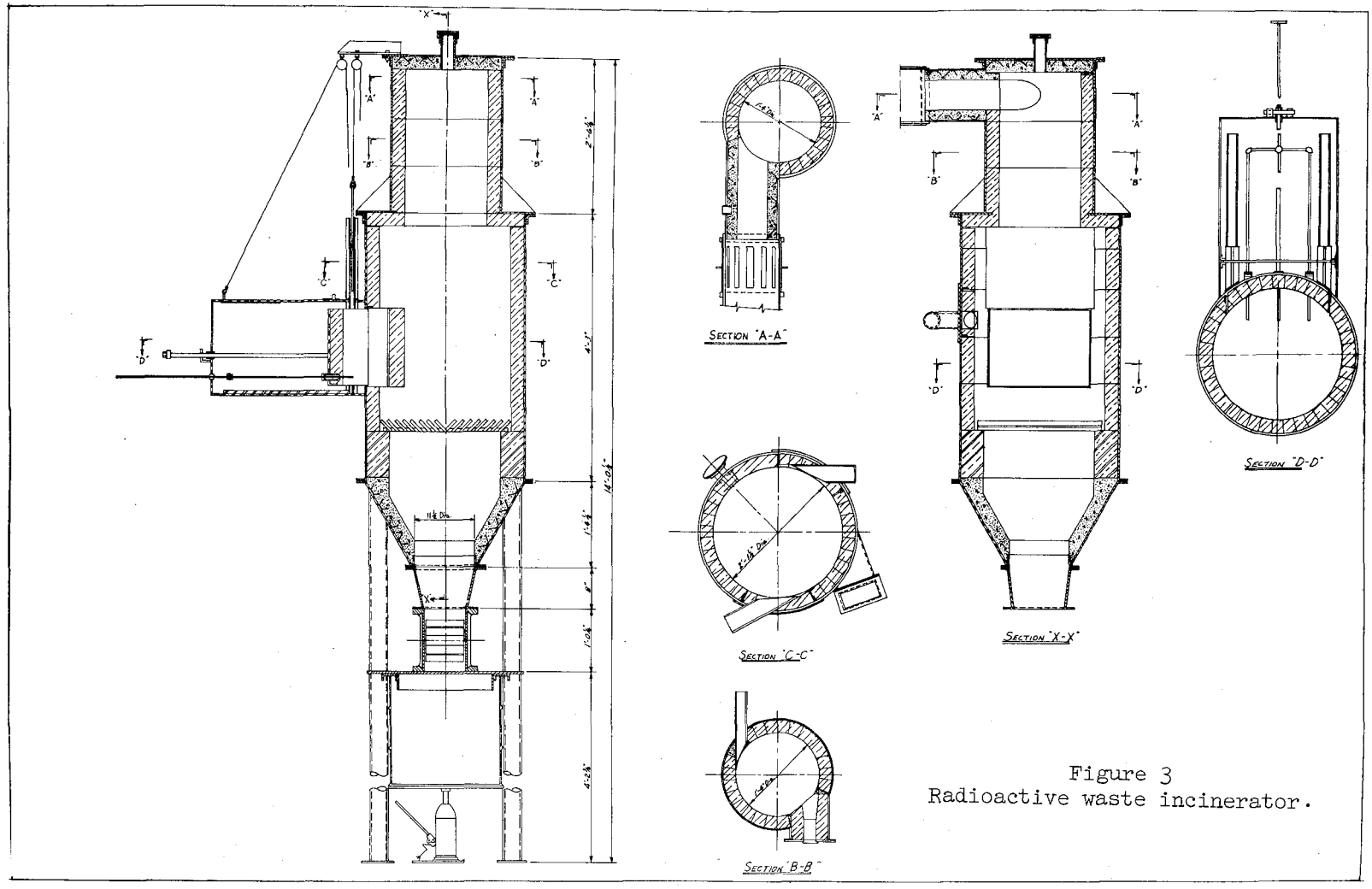


Figure 3
Radioactive waste incinerator.

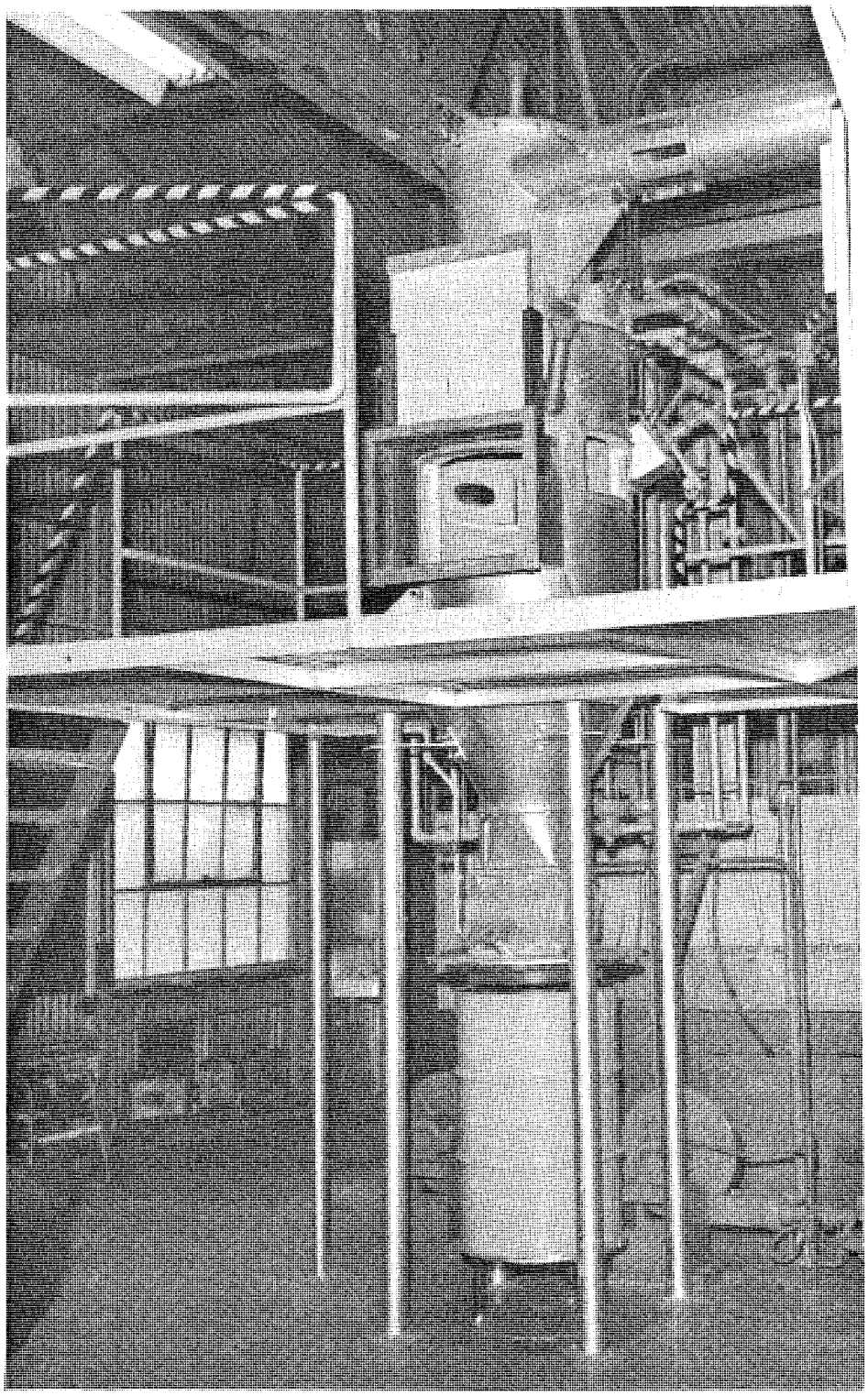


Figure 4
Radioactive waste incinerator.

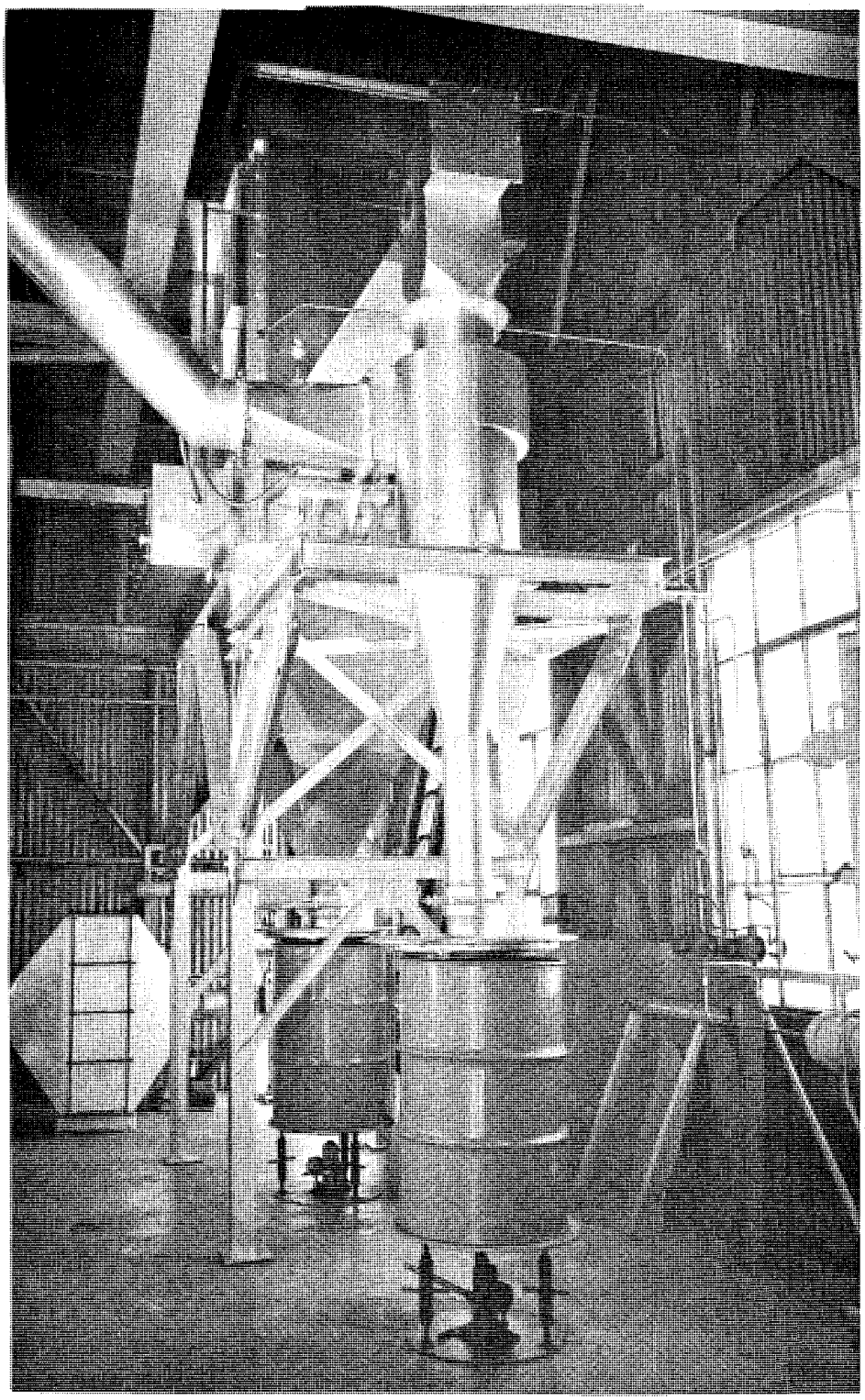


Figure 5
Gas cleaning system for radioactive waste incinerator.

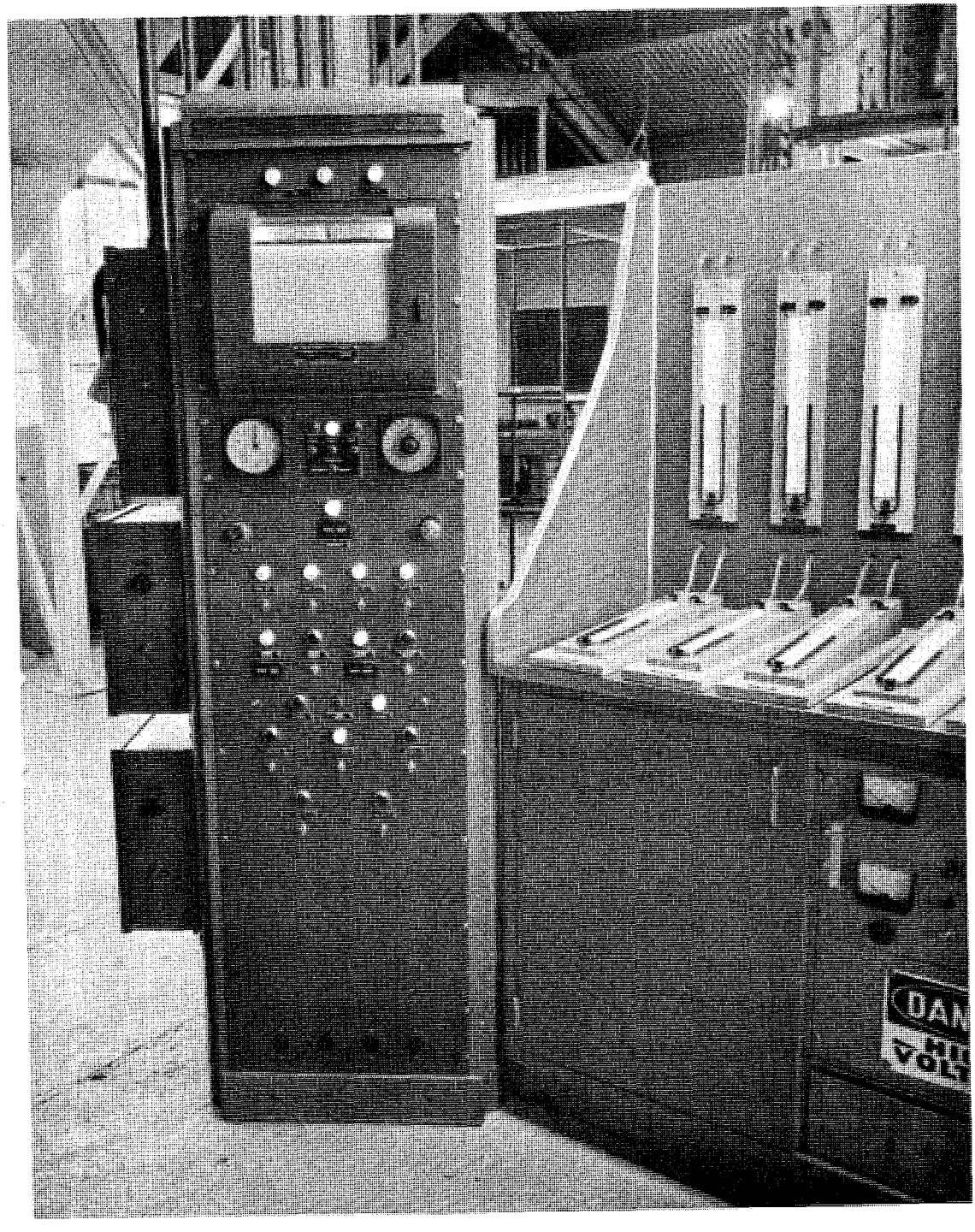


Figure 6
Left end of control panel for a radioactive waste incinerator.

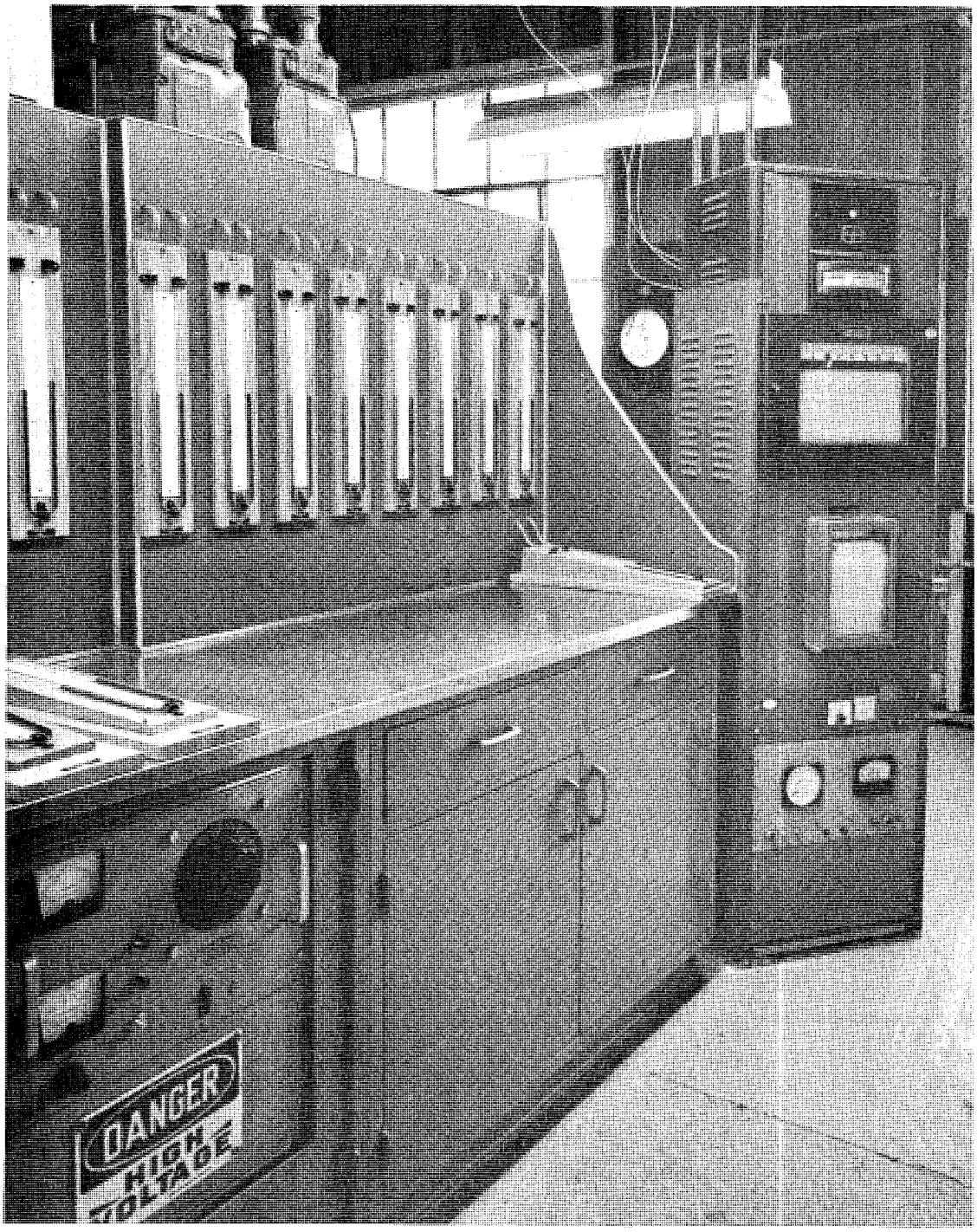


Figure 7
Right end of control panel for a radioactive waste incinerator.

indicator-controller for the incinerator. A multipoint recorder that records the temperatures at midbrick locations within the incinerator plus the temperature at each of the four sampling stations is located below the Bristol unit. Additional channels are available for experimental purposes. Finally, a continuous air monitor recorder is located at the bottom. The sampler for the air monitor is located near the charging box, which we feel to be the most hazardous position.

Figure 8 shows an isokinetic duct sampling station which includes a thermocouple, sampling probe and Pitot-static tube. The Pitot-static tube is located on the rear of the duct. In addition this is the gas sampling station. During sampling, a minimum of 100 bulb volumes is flushed through one of the gas sampling bulbs. When the sample has been taken, the valves are adjusted to switch the flow to the second bulb, allowing the first bulb to be removed from the system. Samples of the gas are then analyzed by a Fisher Gas Partitioner for carbon dioxide, oxygen, and nitrogen. The other three sampling stations consist only of the sample probe, thermocouple, and Pitot-static tube.

Program:

After the initial acceptance tests, which are presented in detail in NDL report[4] TM-8, the radiological treatment evaluation will involve a completely "cold" or nonradioactive engineering parameter study in which optimum conditions for efficient incineration and gas collection will be determined. This will be accomplished by studying such independent variables as: (1) air flow rate through the primary and secondary combustion chamber air inlets, (2) the air entry angle of the above mentioned inlets [0° or 30° relative to horizontal], (3) the rate of gas flow required for auxiliary burning, (4) time required to burn a given weight charge, (5) composition and temperature of combustion products, and (6) temperature distribution within the incinerator and about the grate.

Heat input, heat balance, and material balance will be evaluated under steady-state conditions by determining: (1) approximate analysis of the charge composition, to obtain a gross heating value; (2) temperature, humidity, and dew point, to obtain combustion air conditions; and (3) gas and proportional air rates, to obtain the total heating value of the auxiliary fuel.

In all tests of this phase, initial charges will not be radioactive and will consist of sawdust, typical waste, typical waste plus carcasses, and carcasses, in this order. Upon defining the experimental limits, radioactive materials will then be utilized to complete this phase of the evaluation.

Particulate samples will be collected before and after the cyclone, the electrostatic precipitator, and the filter units. These samples will be utilized to determine; (1) the dust loading of the gas stream, (2) the cleaning efficiency of each unit and, (3) the radiological decontamination factors.

To determine the operating efficiency and maximum permissible radioactive charge to the incinerator, specific nuclides will be employed. The isotopes, strontium 89, radium 226, and iodine 131, have been chosen because of their hazard and wide usage by the AEC and the Army. It is tentatively planned to introduce controlled amounts of these isotopes into carefully weighed and sealed packages of sawdust. Sampling of the effluent gas stream will permit evaluation of each air cleaning operation for each nuclide. Activity concentration will then be increased to determine the maximum amount of each isotope that can be handled safely with the facility. The system is designed for particulate removal and is not expected to effectively remove gases or vapors such as iodine, phosphorus, sulfur or carbon.

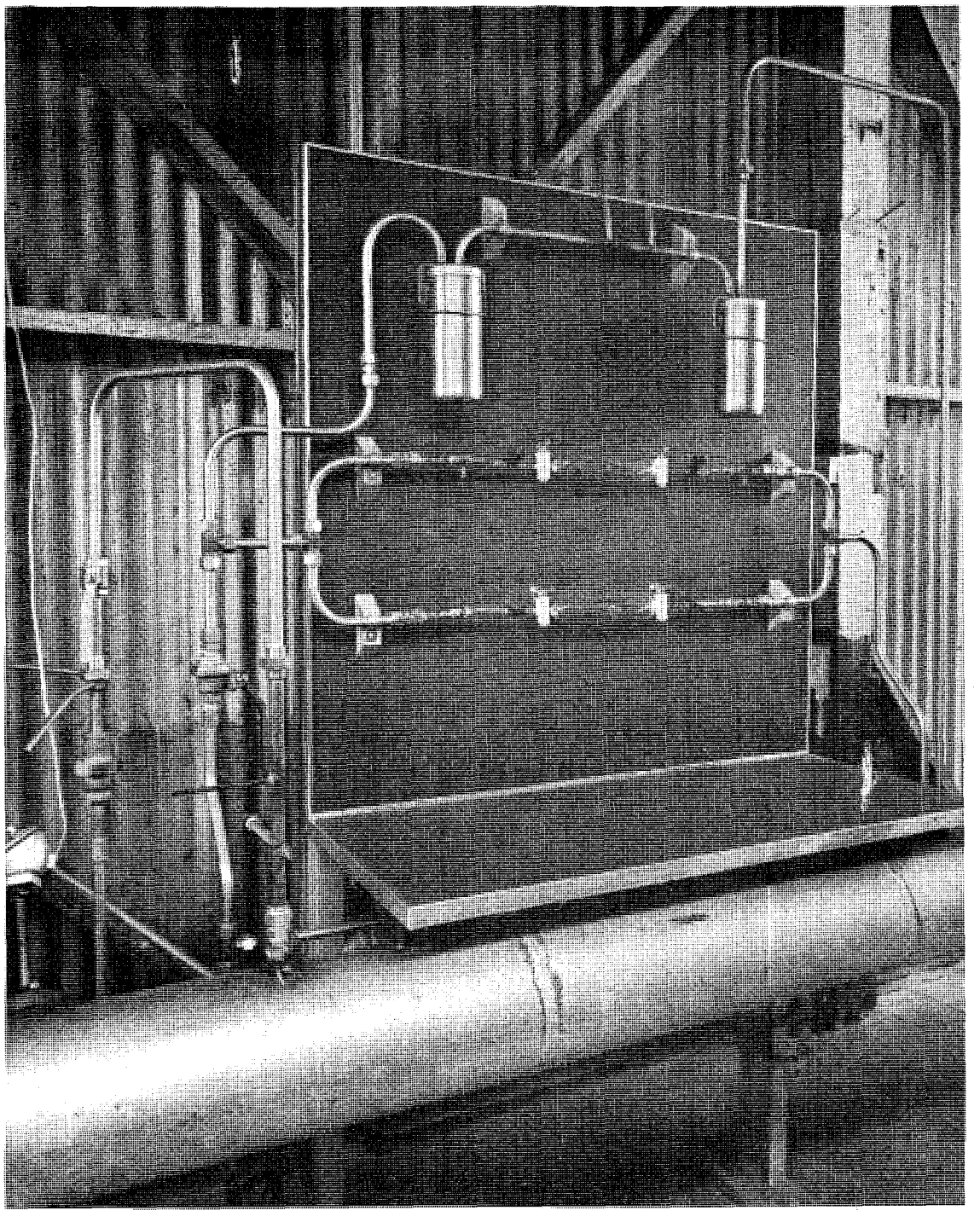


Figure 8
Isokinetic dust and gas sampling station for a radioactive waste incinerator.

LITERATURE CITED

1. Dennis, R. and Silverman, L.; Radioactive Waste Incinerator Design and Operational Experience - A Review. Proceedings of the 7th AEC Air Cleaning Conference, October 10-12, 1961, TID-7627.

2. Corey, R. C., Spano, L. A., Schwartz, C. H., and Perry, H.; Experimental Study of Effects of Tangential Overfire Air on the Incineration of Combustible Wastes. Air Repair 3, 1-8, 1953.

3. Dennis, R., Muller, F. L., Kristal, E., and Silverman, L.; Special Incineration Studies - Institutional Design. Proceedings of the 6th AEC Air Cleaning Conference, July 7-9, 1959, TID-7593.

4. Dennis, R., Kyritsis, W., and Bloore, E. W.; An Evaluation Program for Radioactive Waste Incineration. March 1963. NDL-TM-8.

DISCUSSION AND COMMENT

In the reactor containment following maximum credible accident, one will expect to have some rather intense, local heat forces which would tend to superheat the air-water vapor mixture locally. These sources might coincide also with the fission products. Now, comment on the stability of an aqueous foam in the vicinity of the heat source.

We would hope that one could use sequential treatment, but in trying to meet that objective we did release steam at the same time we released foam, and we also tried to use the heated source for this, but we could not get the equivalent heat conditions.

Actually, if you consider reactor accident of the loss of coolant type, you have steam first, followed by the fission products. So the question is when do you use the foam, immediately, or as soon as your steam has been released?

I don't think the heat source that is present in an accident would be the kind that would disturb me. The reactor vessel, and all the rest, are insulated for the operating temperature, and you are not going to get above operating temperatures. Maybe I am wrong on that thinking, but after all, your reactors, your coolant is at, say, five or six hundred degrees, and at 2,000 psi, and then in the accident you release all this steam at that pressure, and get the equivalent energy release. The stored energy is rather tremendous in a water reactor, as you know. But whether there would be any source hotter than the reactor vessel, I don't know. The shielding, of course, has to take care of that.

I don't visualize a very large, hot ball situation; I visualize steam as our fundamental problem, and we tried steam releases, and again as a condenser foam is able to compete with this, but only on the basis of the same equivalent heat sink value.

The foams we have investigated are effective as fire-fighting media. The foams differ only in the sense that we add a reactant to them, like sodium thiosulfate, but the original idea of this type of foam generator goes to the Sheffield Mine Research Establishment, in England, where this was tried for fighting mine fires. The intent was that you could use it more as a blockage mechanism to keep oxygen from getting to the fire, and you would generate foam of this type. They used simply a brattice cloth into which was sprayed a detergent solution, and there would be air flow through the mine drift to actually form the foam.

As far as actually fighting fires go, the unit which you may want to see later today is one that they have at Idaho at the NRTS for firefighting. There are several more of them around the country. And I would rather let some safety fire expert, talk about the fire-protection qualities of the foam.

The optimum generation of Hi-Ex foam for fire extinguishment presupposed some opening in the structure to permit the air to escape.

Our concept is that we treat the air within the containment in a recirculating fashion. We just run the air through the unit, and fill the chamber up, and as you might note, one of the things is a question of whether

or not you plug the supply line to the blower. By having this line near the top of the vessel, all that is left is a small mount, and in the tests that we have run, we do not get the foam to flow down the small intake pipe. There is too much resistance, it just draws air from above the foam column.

So, what we are really doing, in its simplest form, is treating a reservoir of air, changing it into a reservoir with millions of capsules inside of aqueous foams.

We thought of other foams than aqueous foams. We are working with porous concrete. But we don't think anybody will let us do this in their containment vessel.

Richland Operations Comment: My comment is a comment, and not a question, on the fire-fighting capabilities. Actually, high-expansion foam seems to have tremendous potential in specialized uses in fire-fighting problems, and facilities of handling and using radioactive material, not as a replacement for sprinkler systems, or some of the other conventional methods, but because of its unique application in areas where personnel are excluded and some unusual approaches are necessary.

One of the phenomena of this is the fact that high-expansion foam has a difficult time extinguishing a candle, for instance, In fact sometimes you can't extinguish a single candle burning, because you have just enough oxygen in each of those little bubbles to keep the flame going. If you have a raging gasoline fire of, say, 5,000 gallons of gasoline at one time, it will do a beautiful job in a matter of two or three minutes. We had a rather extensive series of demonstrations at Hanford in May, and I know that Idaho had some in January.

The foam can also be frozen and it will stand outside in a bank.

One characteristic of the foam is very desirable; you may have noticed someone walking through it. You could actually crawl through it, or walk through it if this room is filled to the top, and although you could get a bit disorientated on your balance, you have no problem breathing, and only very slight irritation to the eyes. There is no better protection for people who are caught in one of these kinds of an incident; fire, explosion, whatever it might be than to dive in the foam, stay in it, and work your way out.

We burned an old building at Hanford. We introduced the foam by an indirect method, and it had to make two 90-degree turns to get into the space, fill the space, and control the fire in the glove box. After the glove box gloves had burned out, the foam flowed through the opening and extinguished the fire.

I was in the room while this was going on, to give more of an eye-witness review of it.

I had to find my way through, and find out where the heat was. It is possible to get within six inches of metal that was probably at a temperature of 1500 degrees, and not feel the heat. So, foam has great thermal protection for people who are caught in situations.

Session Chairman: Gentlemen, thank all of you for participating in Session VI. We will now adjourn for lunch.

SESSION VII - METEOROLOGICAL ASPECTS OF AIR CLEANING

Afternoon - 23 October 1963

D. H. Slade, USWB, Chairman

Session Chairman: I am D. H. Slade from the United States Weather Bureau in Washington, and will be the chairman of Session VII which is primarily, but not entirely, meteorological. The first three papers deal with meteorology in one form or another, and there will be two papers after the mid-afternoon break which are essentially air cleaning papers. The procedure has been to leave the discussion until after a number of papers have been presented, so we will have the first three papers and then the discussion.

The role of a meteorologist in the nuclear energy industry is basically to predict the details of transport and diffusion of airborne materials from the source to what we might call the consumer. We are, therefore, intermediate in the chain between air cleaning personnel and the health physicist. You, we, and the health physicists have our own problems, which frequently seem rather far apart. We are a chain, however, and I think, as in a chain, we cannot consider our fields of interest as totally independent of each other.

I hope the papers presented in this session will give you some idea of the problems that meteorologists face.

It is my pleasure to present the first paper, the title of which is "Innovations and Developments in Air Pollution Studies." Much of the report was prepared by others in my group, if there are questions on some of this work which I am unable to answer, I will be happy to refer you to these people.

INNOVATIONS AND DEVELOPMENTS IN AIR POLLUTION STUDIES

David H. Slade
U. S. Weather Bureau

The Environmental Meteorological Research Project of the U. S. Weather Bureau, the group with which I am associated, has for the last fifteen years performed research and development in the fields of atmospheric pollution, diffusion and transport under the auspices of the AEC and the PHS. Our work has covered a wide range of studies from basic micrometeorological investigations through the development of practical techniques for immediate use. I would like to cover, in the few minutes allotted for this talk, some of the highlights of our current work.

THE "TETROON": CONSTANT LEVEL TETRAHEDRON BALLOON

A balloon ascends or descends according to whether its buoyancy force is greater or less than the weight of the balloon system. If the balloon is filled with a lighter-than-air gas and is constrained to keep a constant volume by a non-elastic envelope, for instance, then there is some given atmospheric density level at which the balloon will float in the absence of vertical motions. Slackness in the balloon and consequent loss of volume resulting from seepage of the gas or cooling of the balloon is overcome by super pressuring the balloon with respect to ambient flight pressure. Similarly, heating of this balloon system by the sun will not result in an increased volume. Such balloons, constructed of thin mylar plastic in the form of a tetrahedron, are called "tetroons" and have been used for the past five years in a number of atmospheric studies.

In the presence of atmospheric vertical motions, the tetroon will depart from its constant density surface and travel upward or downward at a rate that

is felt to be a good approximation to the motion of the local environment.

In practice, the tetroon is tracked by a transponder-radar system. The radar scans in the vertical and horizontal until the transmitted radar pulse impinges on the transponder receiver. This received signal triggers the transponder transmitter, a unit weighing about five ounces which emits a signal fed directly into the video circuit of the radar. Using the WSR-57 radar, the standard Weather Bureau weather surveillance radar, transponder equipped tetroons have been tracked to almost 90 miles. The tetroon-transponder-radar system furnishes one of the simplest yet comprehensive methods of determining three-dimensional air motions over meso-scale distances yet developed for assessing both transport (trajectory) and turbulence (diffusion) data.

Perhaps the best way to illustrate uses of tetroons is by reference to the tetroon-derived data themselves. Figure 1 shows the trajectories of five typical flights followed by skin tracking (the transponder had not yet been developed). Flights 1 (1000 ft.), 2 (4200 ft.) and 3 (1600 ft.) were made during a nine-hour period while flights 4 and 5 were separated by about six hours. The utility of the tetroon-radar system for assessing atmospheric trajectories at a variety of levels is obvious. Such data could not be obtained from surface measuring systems while the conventional rawinsonde measurements would be incapable of presenting the detailed structure of wind speed and direction shown by the tetroon.

Typical of the turbulence type of statistic that may be obtained from tetroon position data are the mean spectra shown in Figure 2. The greatest speed variance in the top part of Figure 2 is associated with the low frequency oscillations which are probably "synoptic" or inertial in character. These variance data along with the mean wind speed, all obtainable from tetroon trajectories, may be used to directly compute the useful quantity, turbulence intensity.

Lateral variance and turbulence intensity statistics, taken from tetroon surface radar reflection readings at the NASA Wallops Island Site are compared in Table I with a variety of similar values determined analytically from weather

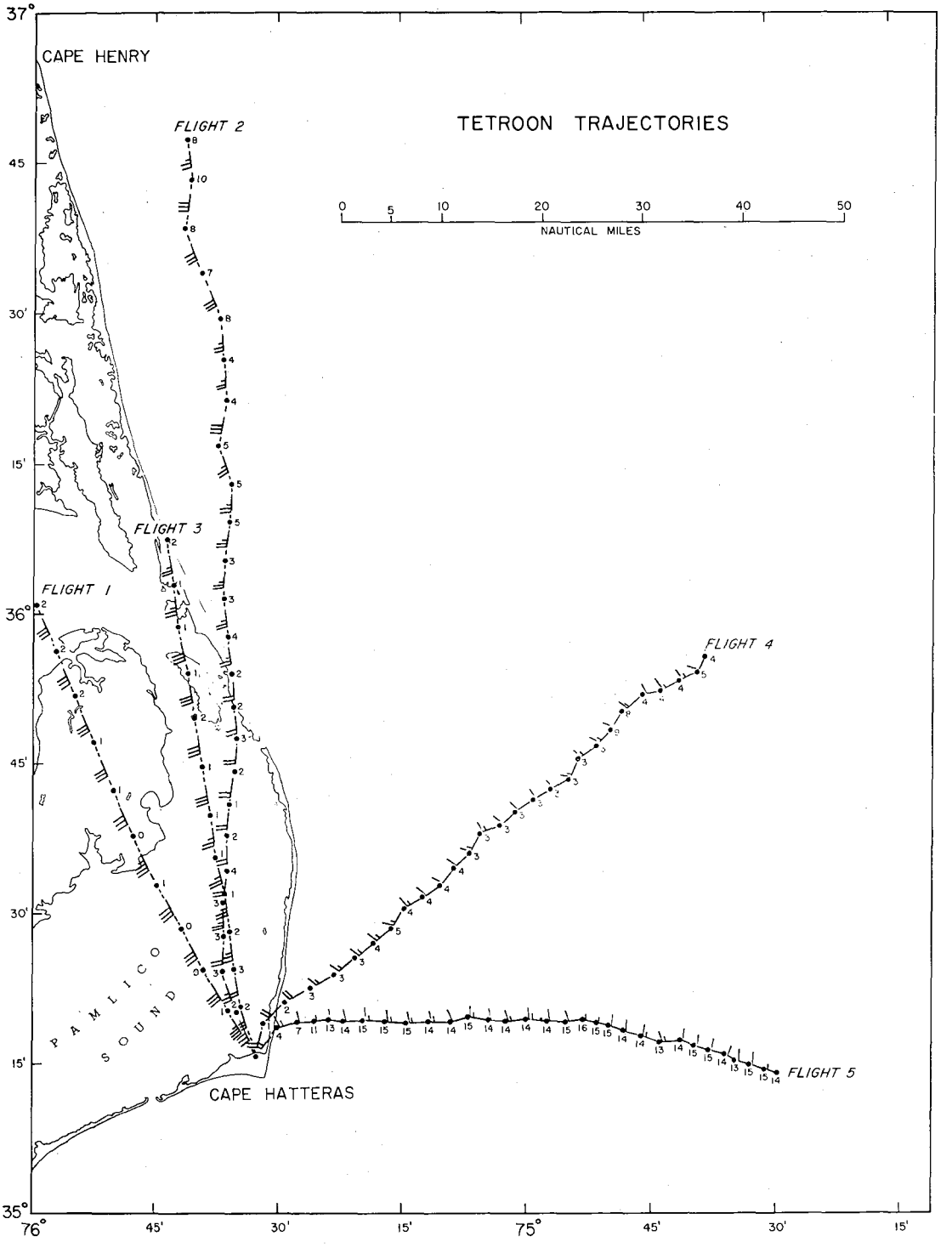

TETROON TRAJECTORIES
0 5 10 20 30 40 50
NAUTICAL MILES
CAPE HENRY
FLIGHT 1
FLIGHT 2
FLIGHT 3
FLIGHT 4
FLIGHT 5
CAPE HATTERAS
PAMLICO SOUND
37°
45'
30'
15'
36°
45'
30'
15'
35°
76°
45'
30'
15'
75°
45'
30'
15'

Figure 1

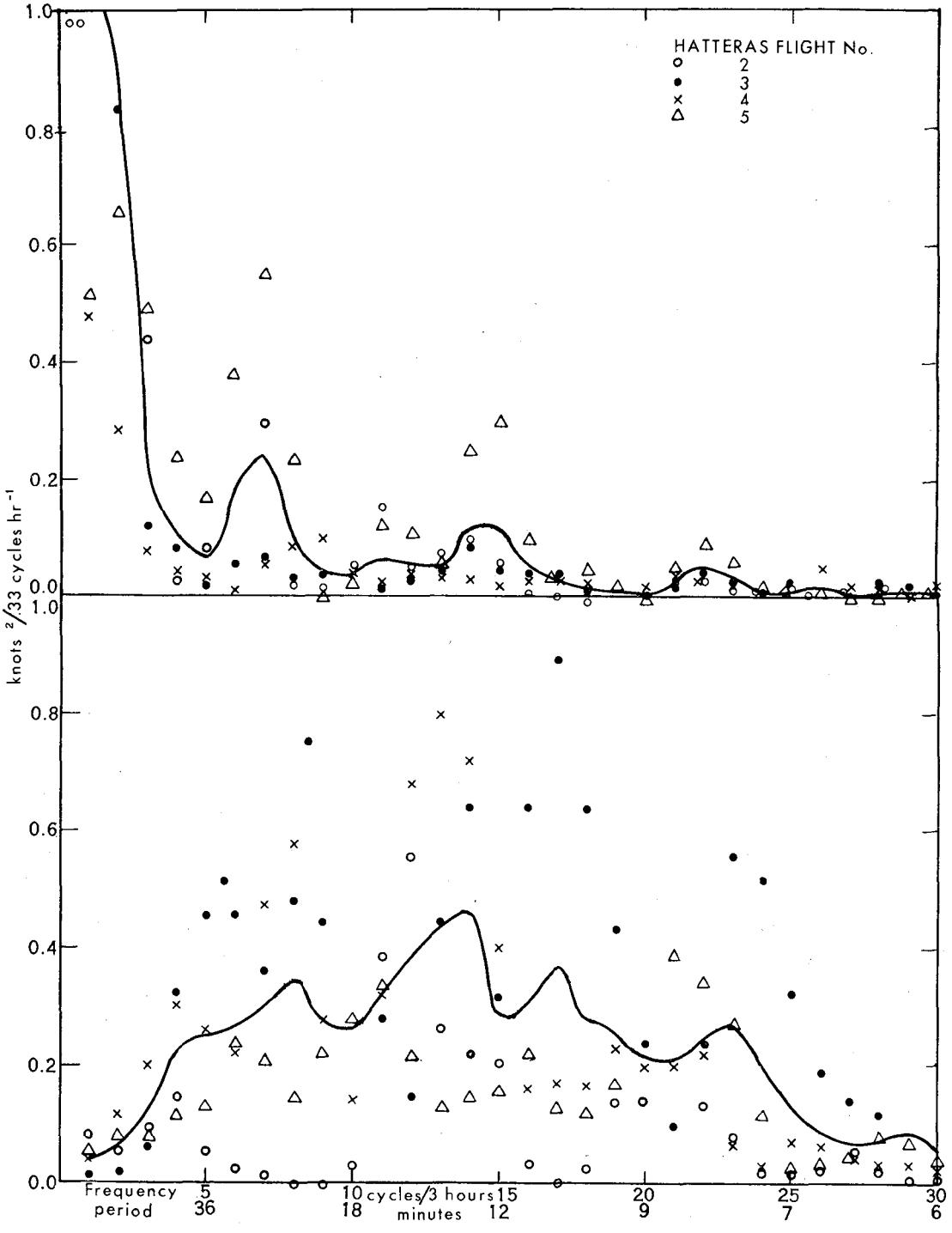

HATTERAS FLIGHT No.
2
3
4
5
knots ²/.33 cycles hr⁻¹
1.0
0.8
0.6
0.4
0.2
0.0
Frequency period
5
36
10
18
cycles/3 hours
minutes
15
12
20
9
25
7
30
6

Figure 2

charts or wind records.

TABLE I

Location	Height (Ft)	Variance $(Kt)^2$	Turbulence Intensity	Number of Evaluations
O'Neil, Neb	6	0.91	0.10	5
Idaho Falls	20	1.18	0.12	4
Brookhaven	75	4.56	0.15	2
Brookhaven	150	6.25	0.12	2
Idaho Falls	250	1.29	0.08	4
Brookhaven	300	5.87	0.11	2
England	1000-3000	0.18	0.03	8
Wallops (Flt. 7)	2500	0.15	0.03	4
Wallops (Flt. 3)	3000	0.31	0.03	3
Western Hemisph.	10,000	0.83	0.08	13
Western Hemisph.	18,000	1.72	0.07	4
Western Hemisph.	30,000	5.90	0.11	2

The order of magnitude difference in the variance may be real and ascribed to a real minimum in variance at this approximately 1 Km level (note the agreement with the "England" data due to Durst), may arise from the different definitions of length scale in Eulerian and Lagrangian wind measurements or may indicate the effect of low turbulence values for over-water trajectories.

Since the tetroon flights from Wallops Island and Cape Hatteras lay mostly over the water, it is not surprising that the paths showed comparatively little vertical turbulence. Because one of the chief uncertainties with respect to the analysis of tetroon data is the degree to which they respond to vertical air motions, a series of late summer tetroon flights were made in the desert near Las Vegas where daytime vertical turbulence would be expected to be quite intense. Figure 3 shows five early afternoon vertical trajectories. Oscillations of 5000 to 10,000 feet are common here compared to the few hundred to 1000 or 2000 feet vertical oscillations noted over the smoother ocean surface.

An interesting trajectory pattern may be noted if the tetroon circulation in the plane perpendicular to the mean path is plotted (Figure 4). The clockwise and counterclockwise circulation pattern, when superimposed on the mean wind, indicate the existence of helical flow patterns, a type of system noted

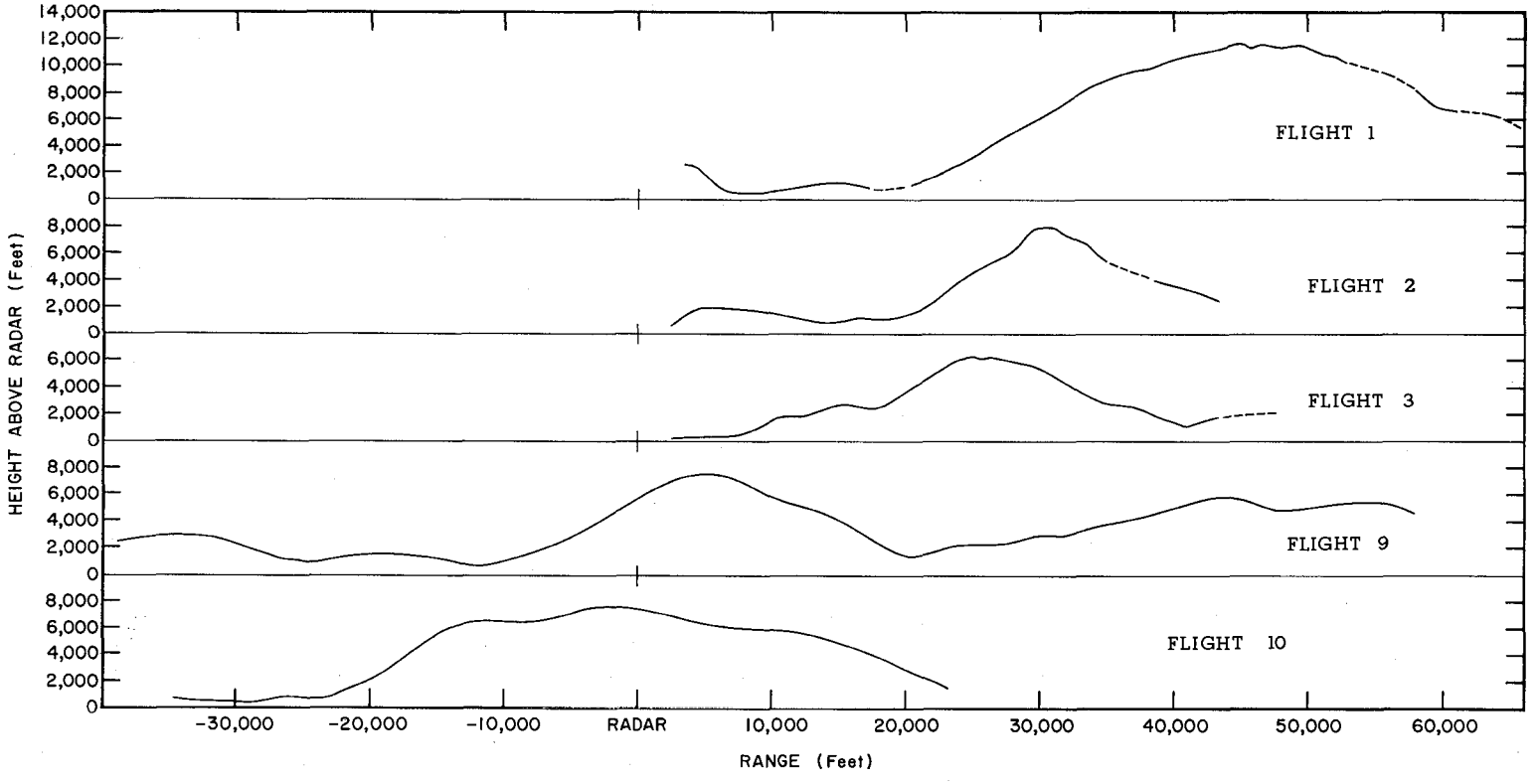

HEIGHT ABOVE RADAR (Feet)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
FLIGHT 1
FLIGHT 2
FLIGHT 3
FLIGHT 9
FLIGHT 10
-30,000
-20,000
-10,000
RADAR
10,000
20,000
30,000
40,000
50,000
60,000
RANGE (Feet)

Figure 3

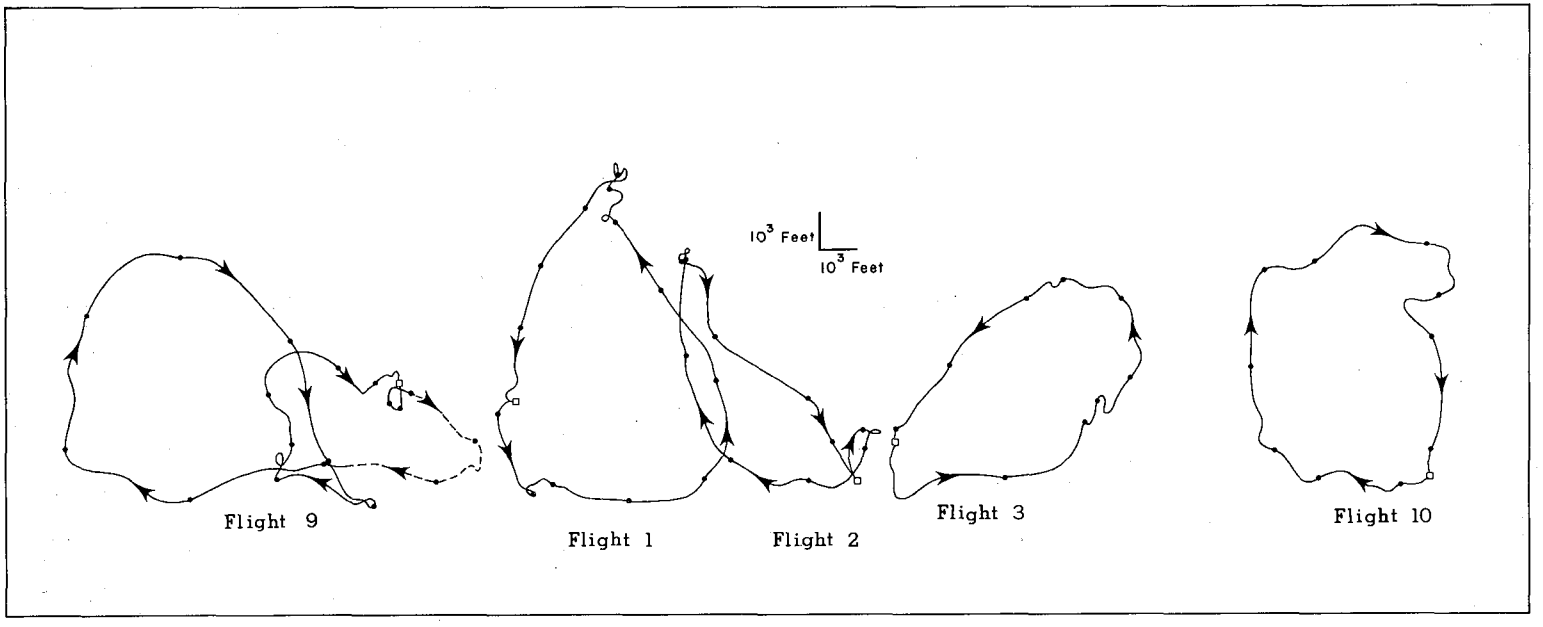

10^3 Feet
10^3 Feet
Flight 9
Flight 1
Flight 2
Flight 3
Flight 10

Figure 4

by other investigators. In general, this series of flights amply demonstrated that the heightened vertical motion activity over the daytime desert was quantitatively sensed by the tetroon flights.

The tetroon flights that have been described thus far utilized direct reflective or "skin" tracking. Many of the tetroons thus tracked were lost because of the impossibility of tracking by passive reflectors in the presence of ground clutter. The transponder described earlier was first used in an experiment near Cincinnati, Ohio in May of 1962. A maximum trajectory length of 54 miles and trajectories 10 to 20 miles long when the tetroon was floating very close to the ground amply demonstrated the superiority of this tracking method compared with tracking by passive reflection. While the number of flights was limited, the data were used to compute tetroon separation rates and mean square dispersion, shearing stress and eddy energy dissipation, all of which are quantities of great theoretical and practical interest and impossible, except by tetroon, to measure directly on this length scale and at typical tetroon altitudes.

The latest tetroon experiment was by far the largest by any system of reckoning. During a month interval, 88 tetroons were released from various points in the Los Angeles Basin and tracked by a radar mounted on Catalina Island. Totally, tetroons were tracked for over 400 hours with a longest track of 21 hours and a maximum distance of 88 miles. A detailed preliminary report on this project (Pack and Angell, 1963) is being published and will contain a bibliography of all previous papers on the subject.

One of the primary objectives of this experiment, beside the full scale test and demonstration of the technique, was to study the air flow in a region of considerable meteorological complexity, a region where the pollution problem is occasionally severe. The complexity is well illustrated by Figure 5 showing some of the tracks of tetroons released from Marineland, California during a two day period. This apparent chaos yields to standard statistical techniques such

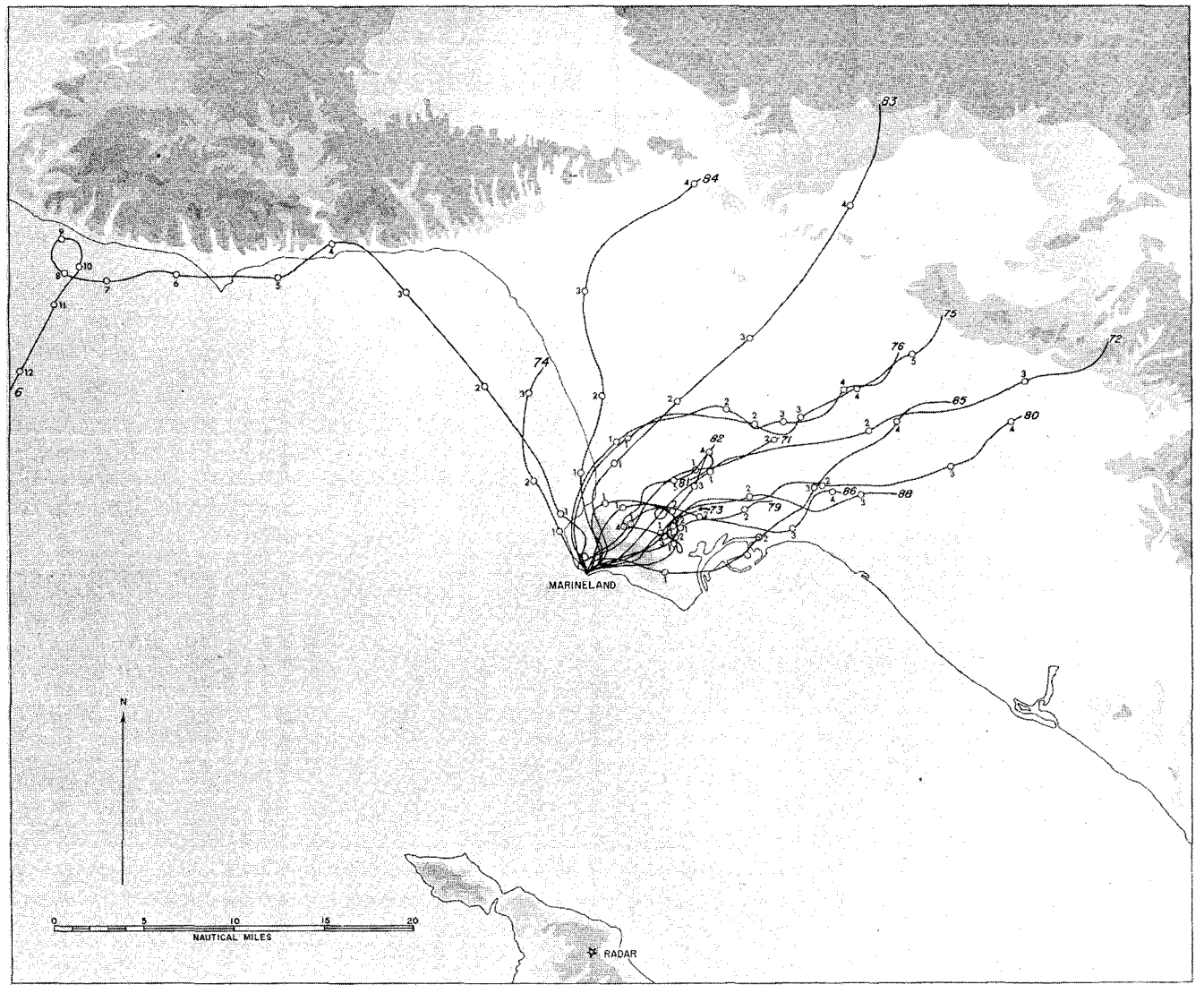


Figure 5

as those used in previous experiments to determine diffusion coefficients. Figure 6 shows the rate of continuous plume lateral spreading, a situation analogous to the lateral spreading of smoke from a chimney, derived from tetroon motion statistics. The power law relationship fits in almost perfectly with other data in the literature.

The response of tetroons to air motions in the vicinity of mountain barriers is shown in Figure 7. The paired flights 75 and 76 show, quite well, the difference in vertical motion over the water and land.

The future use of the tetroon system seems almost limitless. A program of routine daily release, similar to the routine sounding program of the upper atmosphere would furnish an as yet untapped reservoir of neverbefore observed data of direct use in a broad variety of meteorological sub-disciplines including air pollution, mesometeorology, numerical forecasting and aviation weather. The tetroon is an ideal vehicle for quantitatively observing a variety of aspects of the sea breeze. The tetroon may be "handed" from radar to radar with an increase of at least an order of magnitude in trajectory length. Investigations of severe weather furnish a fertile field for later generations of tetroon-transponder systems.

OTHER PROGRAMS

An interesting project currently being completed deals with the subject of wind persistence. It has been a common practice in hazards analyses for nuclear reactors, to assume that the wind direction will remain constant during the period of a release of radioactive products to the atmosphere. For postulated accidental releases, this period may be as long as a few days for the bulk of the activity to escape. Such an assumption is extremely conservative since it does not take account of the long period natural variability of the wind (the shorter period variability is essentially accounted for in the diffusion coefficients). A machine program has been developed which uses standard weather station wind observations, readily available for hundreds of locations within

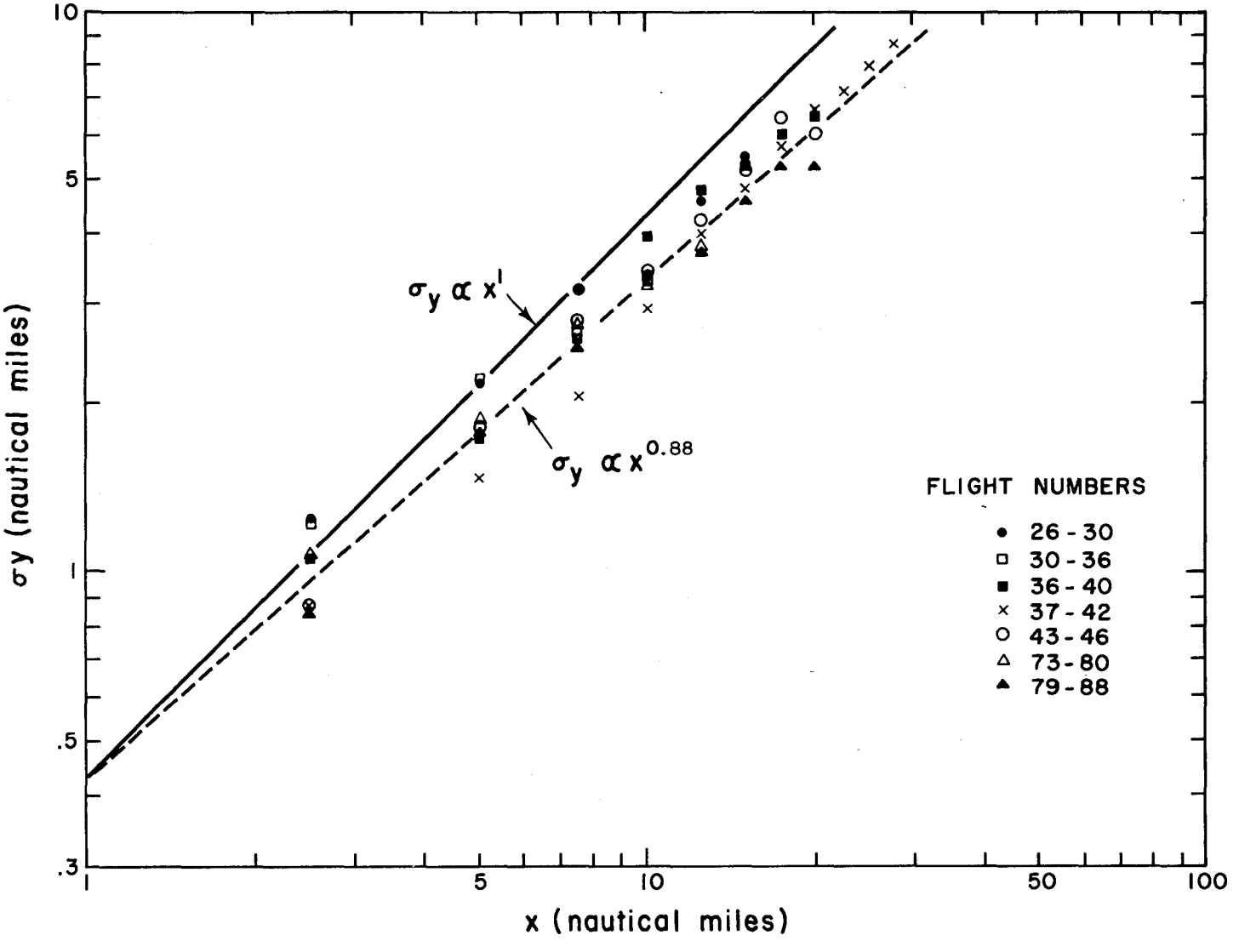

10
5
1
.5
.3
σy (nautical miles)
1
5
10
50
100
x (nautical miles)
σy ∝ x^1
σy ∝ x^0.88
FLIGHT NUMBERS
26 - 30
30 - 36
36 - 40
37 - 42
43 - 46
73 - 80
79 - 88

Figure 6

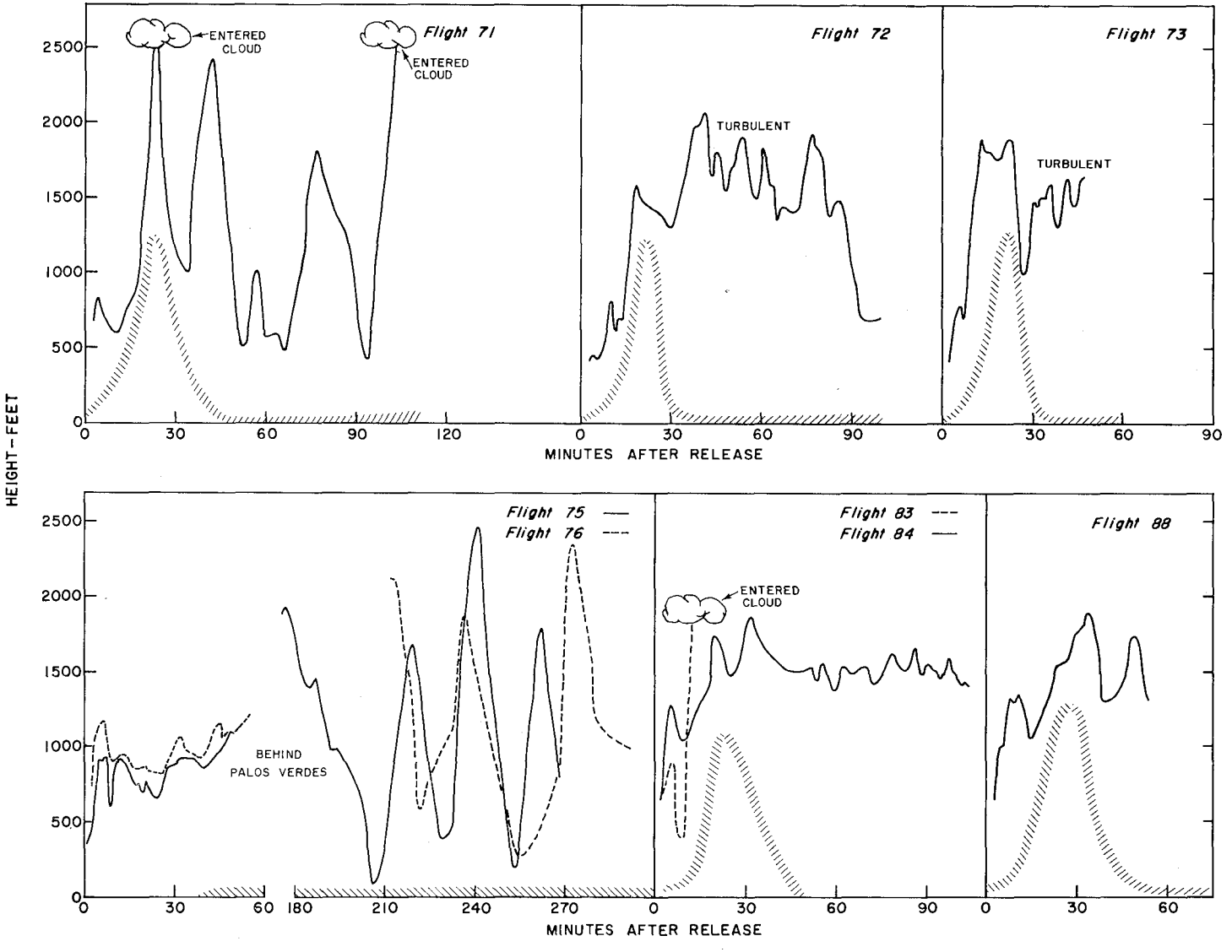

HEIGHT-FEET
2500
2000
1500
1000
500
0
ENTERED CLOUD
ENTERED CLOUD
Flight 71
Flight 72
TURBULENT
Flight 73
TURBULENT
0 30 60 90 120
0 30 60 90
0 30 60 90
MINUTES AFTER RELEASE
Flight 75
Flight 76
Flight 83
Flight 84
Flight 88
ENTERED CLOUD
BEHIND PALOS VERDES
0 30 60 180 210 240 270
0 30 60 90
0 30 60
MINUTES AFTER RELEASE

Figure 7

the United States, to estimate the tendency of the wind to remain within angular sectors of 22-1/2, 67-1/2 and 112-1/2 degrees (one, three and five compass points) for various lengths of time. Figure 8 shows a typical graph resulting from five summers of Corpus Christi wind data. This graph may be interpreted by recourse to a typical point, say on the 10% line, such as that enclosed within the small circle. This point indicates that 10% of the total number of times that the wind switched to the east it was observed to remain in that direction for at least f i v e h o u r s . Thus, the directions for which the 10%- as well as the 50%-line is high are the directions of greatest wind persistence. The upper row of points on the diagram represent the maximum number of hours for which the wind remained in the indicated direction. This program is being run for the four seasons at 64 locations in the United States for one, two and three direction sectors.

Another program developed for use with routinely obtained weather data was designed to translate this readily available information directly into a diffusion climatology. Originally developed by Turner (1961) and based on a series of diffusion coefficients recommended by Pasquill (1961), this FORTRAN program uses wind speed, cloud cover and sun elevation to furnish data that may be analyzed as in Figure 9 for Cape Canaveral in summer. The areas on the diagram are labelled in order of increasing stability with "A" representing very unstable conditions and "F" very stable. The total area represented by each letter is proportional to the total length of time that that stability condition occurred during the summer. By assigning numerical values of vertical and horizontal turbulence parameters to each stability category, a quantitative estimate of seasonal diffusion is obtained. The combination of the results of the two machine programs for a particular site with information on source strength and population distribution about the site results in a quantitative, objective first estimate appraisal of the hazard potential.

Our group has just completed construction of a quarter-meter path length

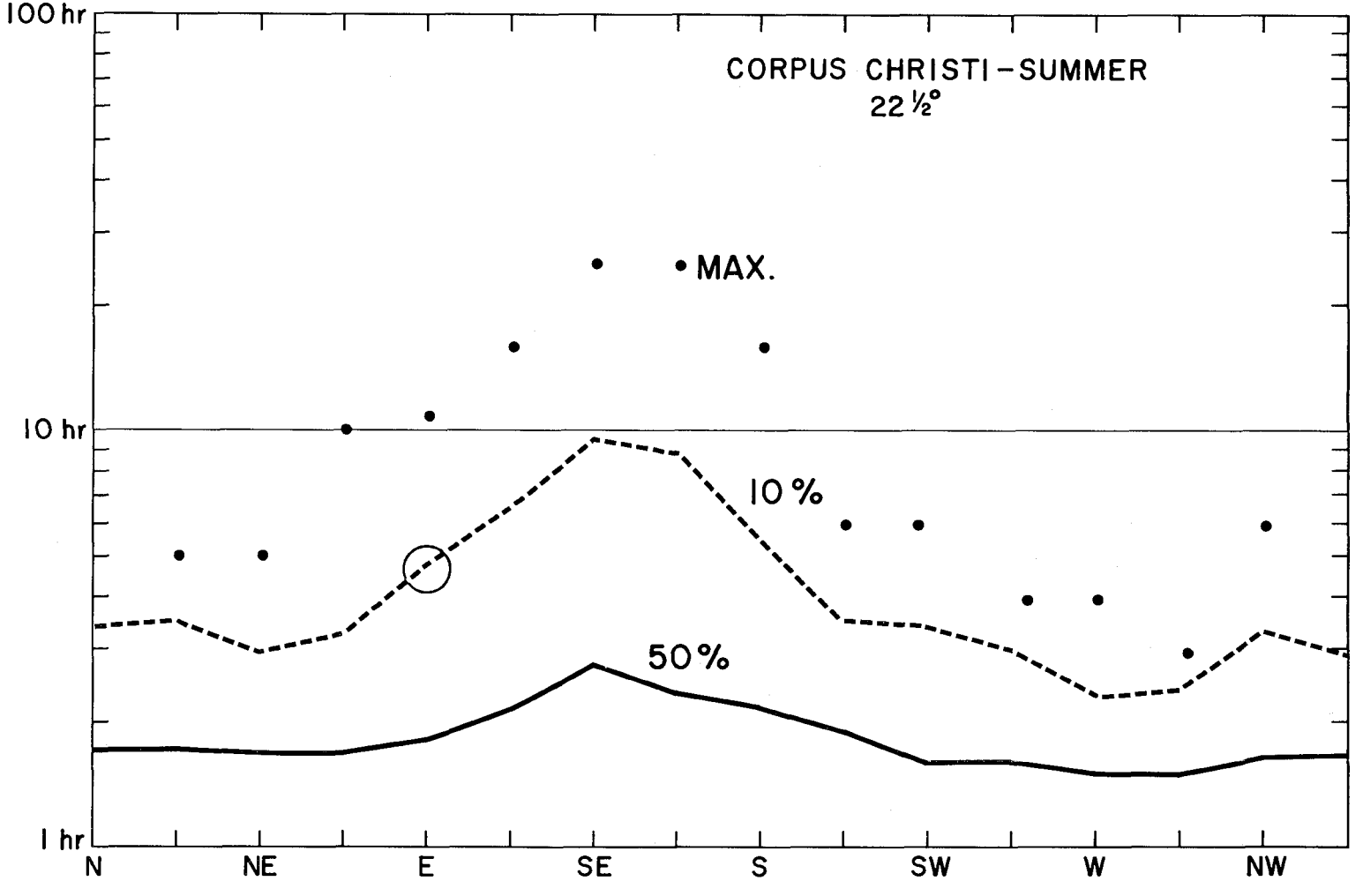

100 hr
10 hr
1 hr
CORPUS CHRISTI - SUMMER
22½°
MAX.
10 %
50 %
N
NE
E
SE
S
SW
W
NW

Figure 8

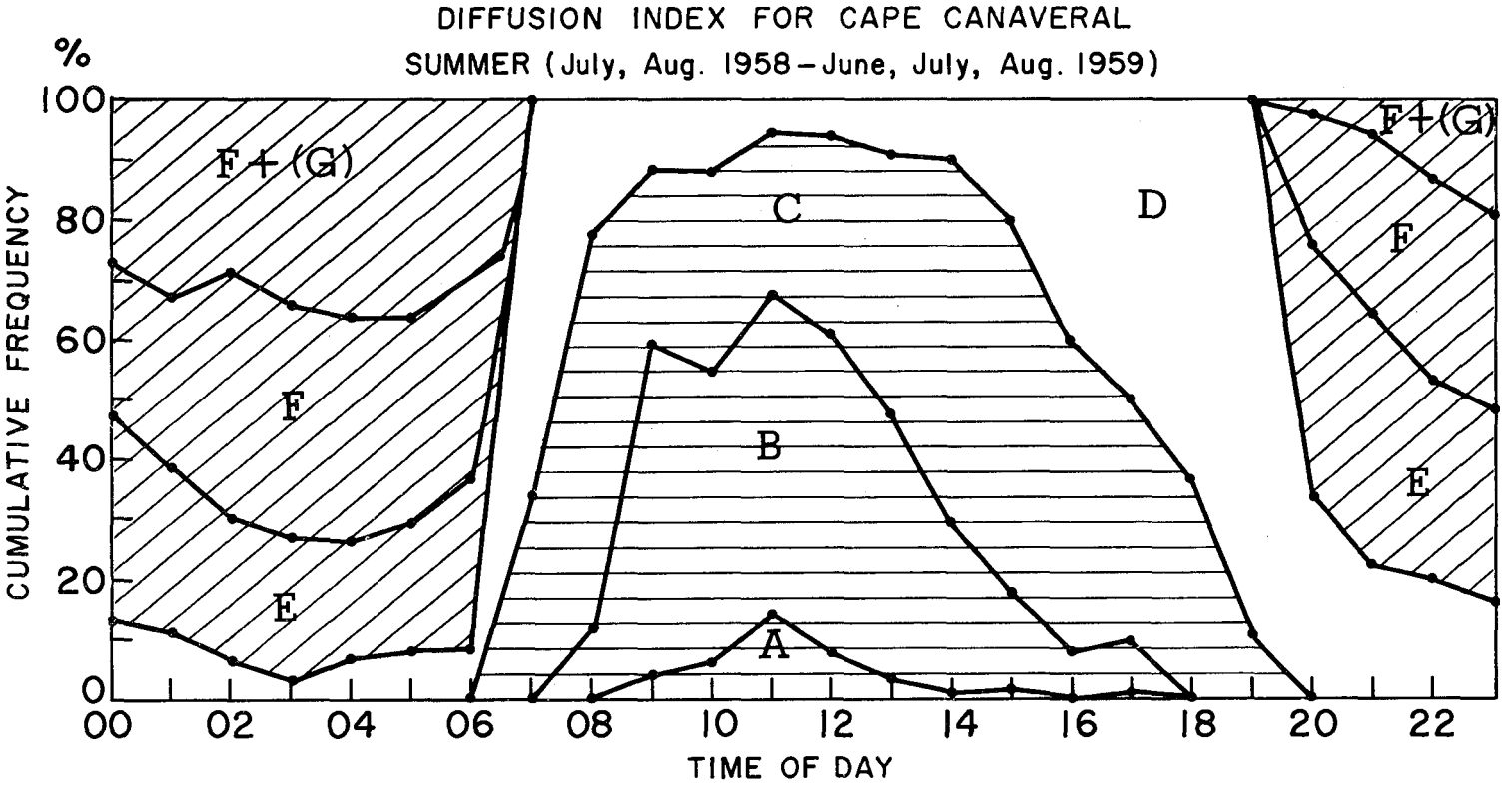

DIFFUSION INDEX FOR CAPE CANAVERAL
SUMMER (July, Aug. 1958 – June, July, Aug. 1959)
%
CUMULATIVE FREQUENCY
100
80
60
40
20
0
F+(G)
F
E
C
B
A
D
F+(G)
F
E
00
02
04
06
08
10
12
14
16
18
20
22
TIME OF DAY

Figure 9

ultrasonic anemometer. As the name indicates, this instrument measures wind speed, in this case vertical wind speed fluctuations, by utilizing high frequency sound waves. The speed of sound across an open atmospheric path is altered by the component of air motion directed along the path and the mean path air temperature. Fluctuations in both air motions and air temperature cause corresponding fluctuations in the observed speed of sound. The path directed air velocity can be measured accurately by detecting the difference in phase shift between the two received sonic signals at opposite ends of the open path using two oppositely directed continuously transmitting sonic transducers as sources. The sum of the phase shifts would yield a measure of the path mean temperature. Due to problems concerning accurate measurement of the mean path temperature and the precise orientation of the sonic array, the fluctuation of vertical motion rather than the absolute value is being measured. The ultrasonic anemometer is inherently superior to conventional mechanical vertical motion systems because of its freedom from mechanical resonance effects. This advantage coupled with high response time and excellent sensitivity properties allow a reading rate more than ample for any conceivable meteorological use. The instrument has been tested and will shortly be used in micrometeorological data acquisition by our group.

Studies of the effects of meteorological variables on the vertical diffusion of the natural radioactive gas, radon, are currently being pursued at our office. The study of the vertical gradient of radon near the ground provides an excellent quantitative insight into vertical diffusion processes in this region of the atmosphere. The techniques is rather inexpensive and may be applied over any land surface.

It was decided that the radon daughter products would be the subject of the study rather than the radon parent. The reasons for this decision were that the daughters may be easily and economically collected by drawing known volumes of air containing the particulate-attached daughter products through common partic-

ulate filters and that the β activity of the daughters is measurable to a degree of accuracy commensurate with the accuracy needed in diffusion studies. A considerable amount of time has been spent in developing a unique calibration procedure which has the advantages of economy and comparative simplicity and further permits samples to be collected over time periods as short as twenty minutes. A complete description of this technique will be published in the near future (Hosler, Lockhart and Dewitt). It will suffice to say here that the procedure involves obtaining an estimate of the radon concentration from the radon daughter activity, which is then corrected for radioactive equilibrium departure between it and its daughters. Calibration and checks on the accuracy of these corrections are obtained from analysis of radon grab samples made at the time of the filtration runs.

Figure 10 shows, at the bottom, the concentration data at two levels in the atmosphere for a nighttime period. The typically observed increase in concentration after sunset is evident at both heights. Numerous experiments have shown that the vertical profile of radon concentration is closely related to the atmospheric thermal stability. The highest radon activity is normally observed just prior to sunrise and radon concentrations exceeding 5×10^{-9} curies meter $^{-3}$ have frequently occurred at our test site. Concentrations of 10^{-11} to 5×10^{-10} curies meter $^{-3}$ are normally observed during afternoon hours. Future plans call for gradient measurements over a 300-foot vertical interval and study of vertical diffusion over this layer.

Our group is currently involved in revision the publication "Meteorology and Atomic Energy" (1955). A vast amount of information has been developed in this field in the eight years since the publication of the first edition. Many of the theoretical developments and experimental verifications that form the basis of our present systems of diffusion estimation were in an embryonic state at that time. A publication date of mid 1964 is indicated at this time.

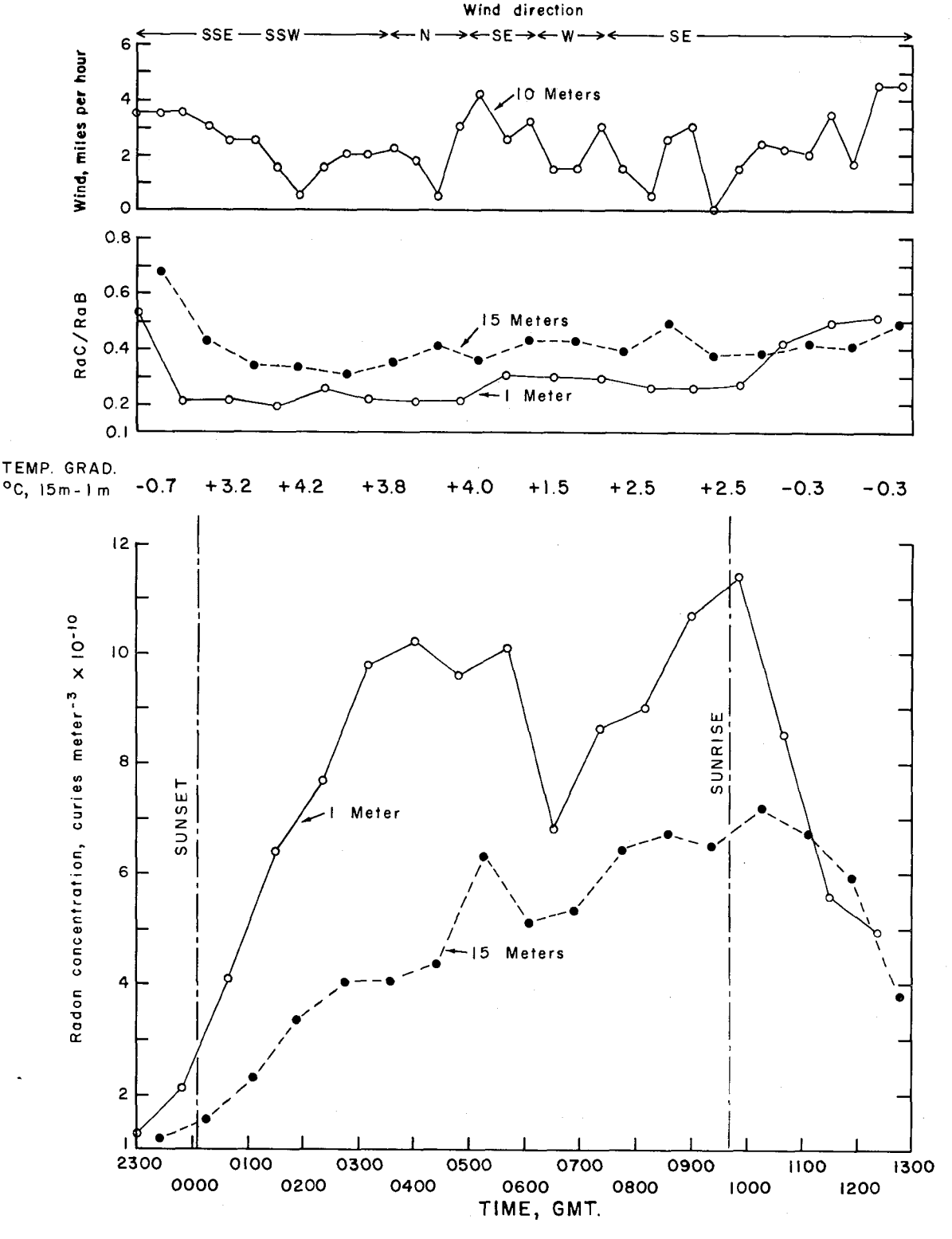

Wind direction
SSE
SSW
N
SE
W
SE
Wind, miles per hour
10 Meters
RaC/RaB
15 Meters
1 Meter
TEMP. GRAD.
°C, 15m-1m
-0.7
+3.2
+4.2
+3.8
+4.0
+1.5
+2.5
+2.5
-0.3
-0.3
Radon concentration, curies meter-3 X 10-10
SUNSET
SUNRISE
1 Meter
15 Meters
2300
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
TIME, GMT.

Figure 10

ILLUSTRATIONS

Figure 1. Trajectories of five tetroon flights from Cape Hatteras, N. C. Tetroon positions plotted at 10 minute intervals. Tetroon velocity (knots) indicated in the conventional meteorological form. Tetroon height in thousands of feet indicated beneath each position.

Figure 2. Speed variance (top) and vertical velocity variance (bottom) as functions of frequency of oscillation for individual tetroon flights and the mean of all flights (solid line) for Cape Hatteras experiments.

Figure 3. Tetroon height versus distance along trajectory for early afternoon flights at Yucca Flat near Las Vegas, Nevada.

Figure 4. Tetroon circulation in transverse plane (looking downstream) for early afternoon flights. Circulation patterns are ordered and spaced across the Flat in agreement with trajectory location.

Figure 5. Tetroon trajectories of two or more hours duration for releases from Marineland Harbor. Hours since tetroon release indicated next to small circles. Topography shading for heights exceeding 500, 1000 and 2000 feet.

Figure 6. Standard deviation of lateral tetroon displacement (σ_y) as a function of downstream distance (x) for sets of serial releases.

Figure 7. Tetroon height as a function of time after release as derived from aircraft tracking of Marienland, Palos Verdes releases. Height of the terrain (cross hatching) estimated from topographic maps and aircraft reports.

Figure 8. Wind persistence diagram for Corpus Christi, Texas, summer, one sector (22-1/2 degrees).

Figure 9. Climatological diffusion index for Cape Canaveral, Florida, summer. A: very unstable, B: moderately unstable, C: slightly unstable, D: neutral, E: slightly stable, F: moderately stable, G: very stable.

Figure 10. Vertical distribution of radon concentration and concurrent meteorological data for the night inversion case of June 18-19, 1962.

REFERENCES

Hosler, C. R., Lockhart, L. B. and DeWitt, W. P. Techniques of Determining Radon Concentration in Air Near the Ground. (To be published)

Pack, D. H. and Angell, J. K., 1963: A Preliminary Study of Air Trajectories in the Los Angeles Basin as Derived From Tetroon Flights. (To be published in the MONTHLY WEATHER REVIEW, vol 91, No. 10-12).

Pasquill, F., 1961: The Estimation of the Dispersion of Windborne Material. METEOROLOGICAL MAGAZINE, 90, 33-49.

Turner, D. B., 1961: Relationship Between 24-hour Mean Air Quality Measurements and Meteorological Factors. JOURNAL OF THE AIR POLLUTION CONTROL ASSOC., 11, 483-489.

DISCUSSION AND COMMENT

It is easy to characterize stability in the sense that I can answer it, but I don't think I can answer it simply. The typical region at the time of these experiments was one which was slightly unstable perhaps up to a few thousand feet, and above that was this very stable capping inversion. Therefore, one would say that probably in the lowest of the Theta-N it was probably below the inversion. It would be something in terms of whatever corresponds to slightly unstable by day and slightly stable by night.

However, I don't think those schemes were really designed to give information on these more complicated patterns that we seem to face so often in real life, but only for rough estimates. Also, the lines on the curves were based on many points, I believe, points derived during night-time flights and daytime flights. I don't think I would really want to assign a category, at least, you couldn't do it with a lot of confidence.

Session Chairman: The next paper in Session VII is by Mr. James Fuquay, of Hanford Atomic Products Operation. It is entitled, "Comparison of Results of Atmospheric Diffusion Experiments with Calculations from Prediction Models."

COMPARISON OF RESULTS OF ATMOSPHERIC DIFFUSION EXPERIMENTS WITH CALCULATIONS FROM PREDICTION MODELS

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ABSTRACT

Results of 340 diffusion experiments utilizing a ground source and encompassing a wide range of atmospheric stabilities are summarized. Peak exposures normalized for wind speed and source strength when plotted against the travel-time show stratification when stability and growth parameters are factored into the analysis. Differences in the results between sites are greatly reduced when diffusion is considered time dependent from those which result from the distance from source concept. In general, exposure limits for unstable, neutral, moderately stable and stable meteorological conditions are established, which are compared with the predictions from some of the diffusion models currently being applied. Whereas, the agreement between predicted and observed exposure values are good for diffusion in neutral and unstable atmospheres, there are significant differences noted in the stable case. These differences point to the need to investigate atmosphere mechanisms which have not been factored into the models. Results of the Hanford model, which attempts to account for depletion of the plume through deposition, are presented.

INTRODUCTION

In the last ten years, there has been a large amount of experimental data obtained from diffusion programs in the United States. The emphasis has been on studying the environmental contamination resulting from a continuous release of material near the ground. This appears to be as logical a starting point as any since the results of such experimentation serve to satisfy many of the demands of the atomic, chemical and space industries while at the same time present

much fewer difficulties in the experimental design, requiring less equipment and expense than studies with an elevated source.

Major experimental programs which have contributed to the understanding of diffusion resulting from releases near the ground include Prairie Grass (O'Neill, Nebraska, 1956), Green Glow (Hanford, Washington, 1959), 30 Series (Hanford, 1960-1963), Ocean Breeze (Cape Canaveral, Florida, 1961-1962), Dry Gulch (Vandenberg Air Force Base, California, 1961-1962), National Reactor Testing Station Series (Arco, Idaho, 1960-1962) and the FRT-2 Series (Dugway, Utah, 1960). The total number of experiments has reached 340, all of which either have been documented or are presently being prepared for publication. There is now the opportunity to examine these data as a whole and to gain insight into any differences that there might be between them. In addition, these results can be compared with those obtained from prediction models which are now popularly employed.

A priori, differences might be expected between results at the various sites primarily because of differences in the tracers used, the physical characteristics of the surfaces and the climatological regimes. The first two considerations bear directly on the depletion of the cloud through deposition of material on the surface which it contacts, causing lower air dosages than would be expected if deposition were not occurring. The complexities of these interactions are not fully understood, and, at the present time, the models which attempt to account for them have not been adequately subjected to tests.

CONSOLIDATION OF DATA FROM MAJOR U.S. DISPERSION PROGRAMS

The data from the U.S. diffusion programs which represent a wide range of atmospheric stabilities where ground exposures were measured in some cases to distances of 20 miles from the source deserve further investigation in order that 1) evaluation of general diffusion models can be made or new models developed and 2) future experimental programs can be designed to provide definitive data based on inadequacies of past programs.

Table I summarizes those field programs with respect to tracer material and nature of the terrain which are discussed in this paper.

Figures 1, 2 and 3 summarize the results of these test series averaged in terms of the stability and the horizontal growth of the plume. On a logarithmic scale is plotted the normalized peak exposure (ordinate) having units of meters^{-2} and time of travel in seconds on the abscissa. Identification of the test series is designated by letters corresponding to those given in Table I, and curves associated with stable conditions are given as solid lines, whereas those conducted when the atmosphere was unstable are dashed. The number of experiments included in each curve is given in parenthesis. The very dark lines found on each of the three figures are the Hanford curves characterizing diffusion in very stable and very unstable conditions, and serve here to identify the relative positions of the curves in the separate figures. The Hanford curves have been further delineated

Variation of normalized exposure with time
for Prairie Grass and Hanford

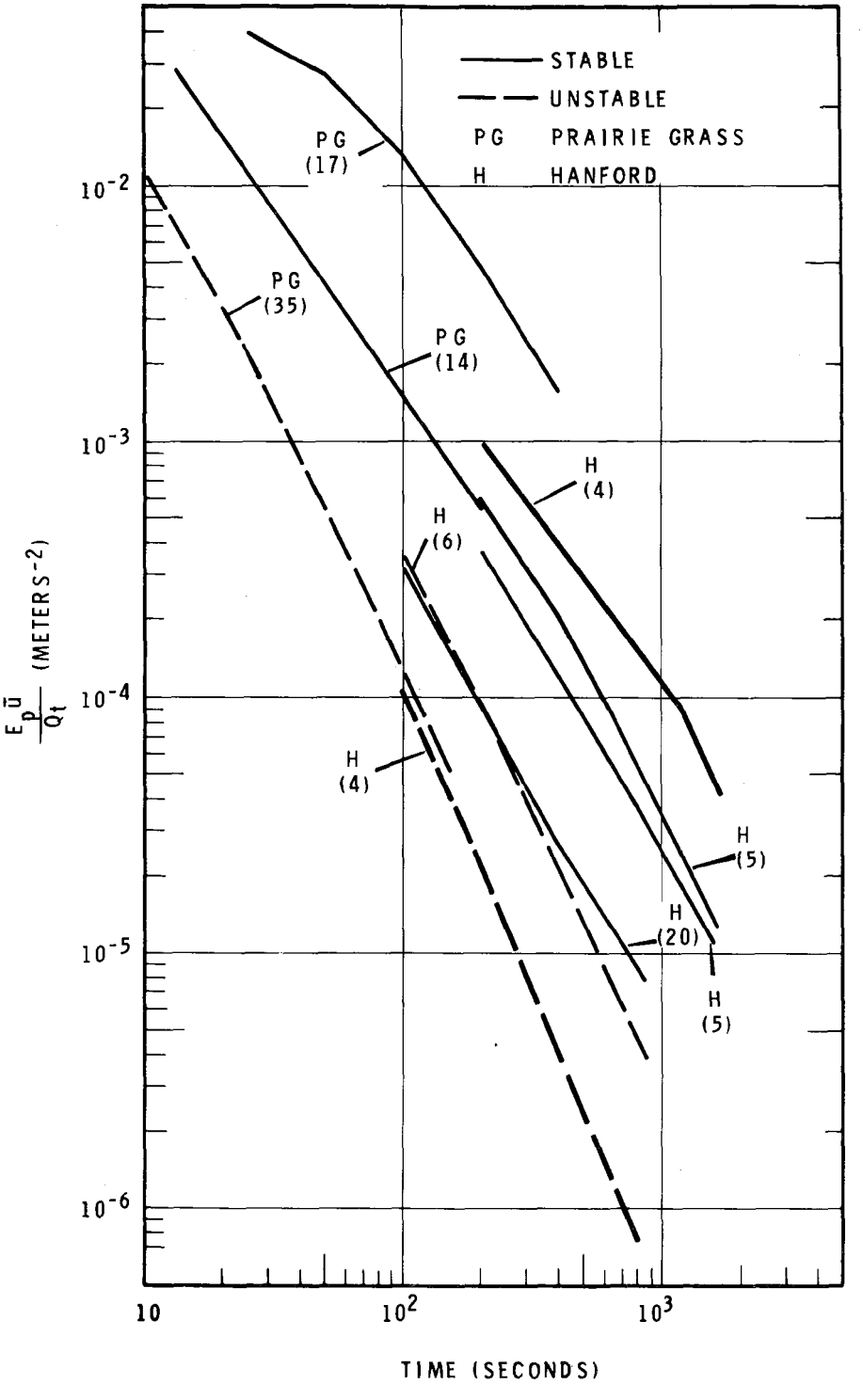


FIGURE 1

Variation of normalized exposure with time
for NRTS and Dugway, Utah

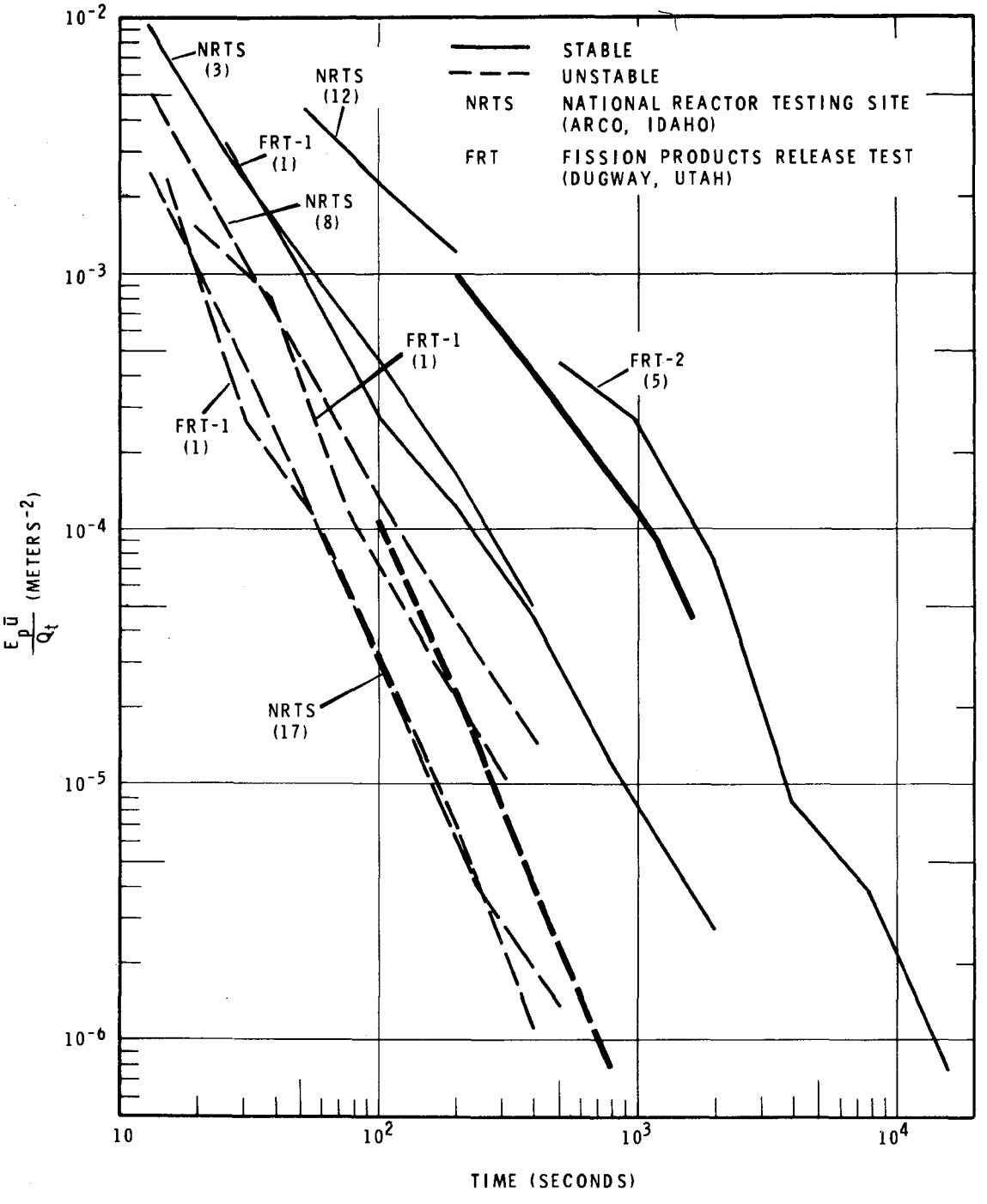


FIGURE 2

Variation of normalized exposure with time for
Cape Canaveral and Vandenberg Air Force Base

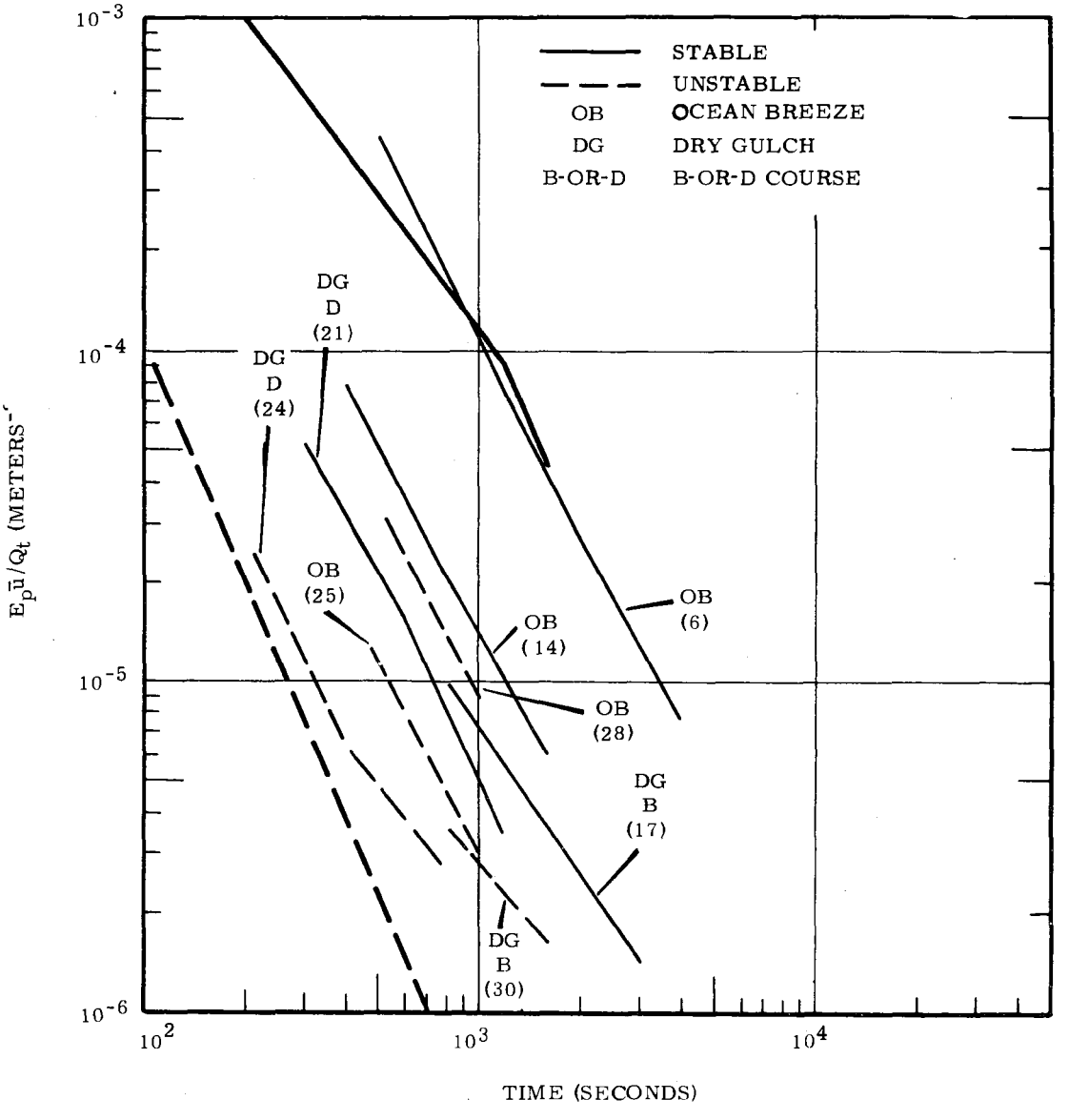


FIGURE 3

TABLE I

SUMMARY OF TEST SERVICES CHARACTERISTICS

Test Series	Tracer	Terrain	Vegetation	Location
Prairie Grass (PG)	Sulfur Dioxide	Flat	Mowed Grass	O'Neill, Neb.
Hanford (H)	Zinc Sulfide	Gently Rolling	1 m. Sage	Richland, Wash.
Ocean Breeze (OB)	Zinc Sulfide	Flat	1/2 m. Palmetto	Cape Canaveral, Fla.
*Dry Gulch (B) (DG-B)	Zinc Sulfide	Flat	1/2 m. Brush	Vandenberg, Calif.
Dry Gulch (D) (DG-D)	Zinc Sulfide	Rough Terrain	1/2 m. Brush	Vandenberg, Calif.
Fission Products Release I (FRT-1)	Zinc Sulfide and Fission Products	Gently Rolling	3/4 m. Desert Sage	Arco, Idaho
Nat. Reactor Test Station Series (NRTS)	Fluorescein	Gently Rolling	3/4 m. Desert Sage	Arco, Idaho
Fission Products Release II (FRT-2)	Iodine-131	Flat	Salt Flats	Dugway, Utah

*Two grids were used at Vandenberg. The brush was generally sparse, but was characterized by rough terrain. A few trees were located on both the B and D courses.

to point up the degrees of stability (i.e., very stable to slightly stable, etc.), thus accounting for six curves on figure 1 with the most stable conditions on the right and greatest instability represented by the dashed curve on the extreme left. Delineation of the curves were made on the basis of the stability (Richardson number) and surface wind direction variability ($\sigma_{\theta\bar{u}}$).

An attempt has been made to treat the data from other sites in the same manner, and thus reducing the variance considerably. These curves should be viewed, however, with the knowledge that all the available data were not consistent; that is where Richardson numbers were available at some sites, stability ratios were available at others and, also, the parameter $\sigma_{\theta\bar{u}}$ was available (at the time of writing) only for the Hanford, NRTS and Prairie Grass data. Thus the generalizations inferred from the figures should be valid, but modification using a consistent set of data for all series might eventually enhance these results. The data presently available support this premise and independent verification for the NRTS data has been made by Slade (private communication). Before proceeding with the relative comparisons, two important features inherent here require further amplification.

First, it will be noted that diffusion here is considered to be dependent on the time of travel, and not the distance from the source at which the sample was obtained. The travel time, t, was computed here from the ratio of the distance and the mean wind speed at the release height. This concept is consistent with the basic developments of G. I. Taylor and improves significantly the intersite comparisons. A good

example of this point can be made by examining the average very stable curves for Prairie Grass and Hanford. Using the distance-concept, Prairie Grass data indicate an order of magnitude higher exposure than Hanford at 200 meters; yet, if the time-dependency is assumed, the difference is reduced to a factor of four with indications that the curves are converging as the travel-time increases.

The second significant feature of this summary, which has been briefly referred to, is that of classifying the curves with respect to the parameter $\sigma_\theta \bar{u}$, as well as some measure of the thermal stability. σ_θ here is the standard deviation of the wind directions observed over the period of emission, and $\bar{u}$ is the mean wind speed in that period. This is an Eulerian parameter which is analogous to the Lagrangian quantity $(\overline{v'^2})^{1/2}$. Fuquay, Simpson and Hinds (1963), using Hanford data, have shown that the horizontal growth, σ_y, is proportional to $(\sigma_\theta \bar{u})t^p$, where p is near unity for small t and approaches 1/2 for t in the vicinity of 1000 seconds--a result analogous to the theoretical development by Taylor. The classification of the Hanford curves presented here with respect to $\sigma_\theta \bar{u}$ are given in this paper.

Considering diffusion to be time-dependent and by using $\sigma_\theta \bar{u}$ as well as a stability parameter to classify the data, the exposure differences which are observed between test sites are considerably reduced from those inferred by other analyses. The agreement shown in figures 1, 2 and 3 is generally good for data from tests obtained under diversified conditions and involving differences in experimental technique. The very stable curves at all sites compare reasonably well as do the unstable, and if a finer resolution of data can be achieved

by growth factors such as ($\sigma_\theta \bar{u}$), which is suggested here, the indications are that these empirical results are consistent. This is not to claim that the problems of general diffusion from ground source have been empirically solved, for this is clearly not the case. Channelled flow, for example, will yield results which deviate greatly from these averaged curves, making it clear that each problem should be analyzed with respect to its peculiarities. The studies at Vandenberg clearly demonstrate this. On the other hand, diffusion data which are presented here indicate that the differences which might be expected at these sites are on the average not great, giving some hope to developing models which are not severely contradicted by the experimental data presently available.

COMPARISON OF EXPERIMENTAL DATA WITH PREDICTION MODELS

Figure 4 further summarizes the data into groups that may be referred to as very stable, moderately stable, quasi-neutral and unstable. The limits of each of these classes correspond to the range of the data from the three preceding figures. The other curves given in the figure are the predictions of several of the models which are commonly applied at the present time. Of these, the Sutton diffusion model is the most well known. Cramer's curve, based on the Prairie Grass data, was one of the first to be developed from ground source experimental data, and is of interest particularly in the prediction of diffusion in stable atmospheres. Recently, Pasquill has presented a system for prediction based on a summary of experimental data and designed for ready application for those dealing with applied problems. Two of his curves characteristic of stable and unstable conditions are shown.

Comparison of experimental exposure data
with predictions from several models

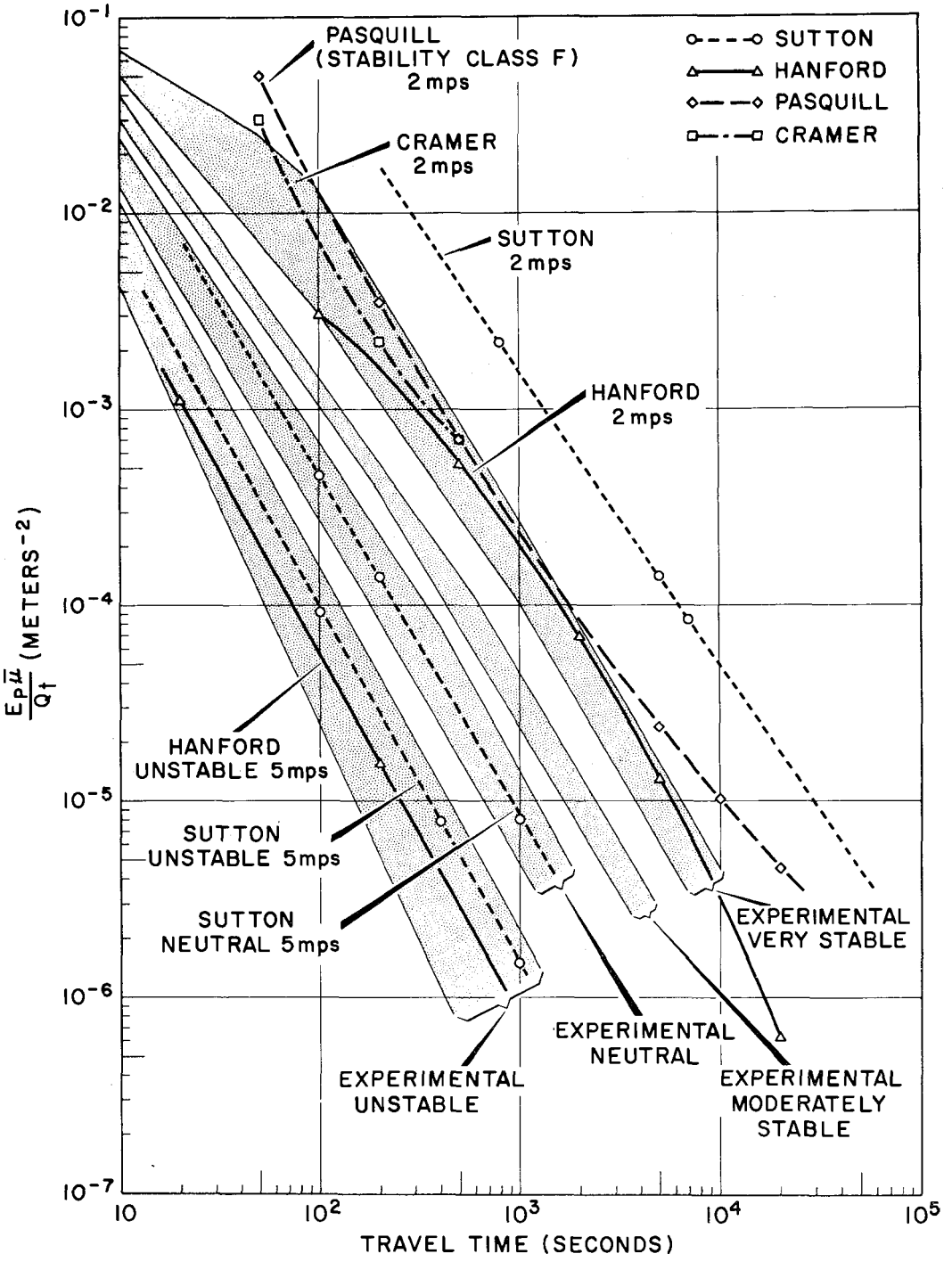


FIGURE 4

Finally, the Hanford curves are calculated from a model used at Hanford for several years, which attempts to account for the depletion of the cloud brought about by deposition on the surface. Obviously, these represent only some of the models which presently are available. Other models compare reasonably well with these and there is no major difference in the exposure values for short travel-times.

Figure 4 shows excellent agreement between the predictions of Sutton and Hanford for ground releases during neutral and unstable atmospheres. This is quite appropriate since the Hanford model for these conditions is Sutton's model with A. C. Chamberlain's modification to account for deposition and a Hanford innovation to extend the results to the unstable case.

It is in the prediction of ground source diffusion in stable cases that large differences between the models, the predictions resulting from them and the experimental data occur.

The models generally yield predictions of exposure which are higher than those which are observed during stable atmospheric conditions. For any travel-time, there is, at least, a one-order of magnitude difference between exposures which have been observed and those calculated. This differential appears to result primarily from the horizontal growth of the plume, so that the two experimental zones in Figure 4 represent narrow plumes (high exposures) and wide plumes (low exposures). Diffusion models yield predictions which more closely approximate the higher values. Better agreement between the observed and predicted values can be obtained by using higher values of the wind speed in the model. For example, the

Sutton predictions agree with the stable experimental data when the wind speed at the height of release is five meters per second. There is contradiction in such manipulation, however, for the atmosphere is rarely stable when the wind speed is this high near the ground. Wind data for the two-meter height obtained during the Prairie Grass and Hanford tests show that speeds of 2-3 mps are expected in moderately stable and very stable atmospheres and speeds in excess of 4 mps are quite rare.

SUMMARY AND CONCLUSIONS

The differences between observed and predicted exposures become very important at travel-times beyond 10^4 seconds. This corresponds to distances beyond 10 miles, which is the region in which greater demands for prediction are being made. Extrapolation of the Cramer, Sutton and Pasquill curves yield an order of magnitude difference at 10^4 seconds, and, because of their relative curvatures, this difference becomes greater as the travel-time increases. It is, therefore, important to exercise care in the extrapolation of any data which points up the need to re-evaluate these models which are generally applicable for short travel-times and determine whether extrapolation can be justified in light of the experimental data presently available. The Hanford curve results from a model which attempts to account for deposition. Although the agreement at short travel-times between the Hanford model on the one hand and the Cramer and Pasquill models on the other is good, the differences in curvature bring about great differences beyond ten miles. From the evidence at hand, the Hanford model appears to predict the exposures at the larger

distances reasonably well although exhibiting the same conservatism characteristic of all the other models.

Demands are increasing today for predictions to distances 10 to 100 miles from the point of release. To meet such demands, it is attractive to rely on those models which have proved reliable for the short range estimates. However, particularly in the stable case, it appears that the extrapolation may not be justified, and it is suspected that atmospheric mechanisms which are not fully understood at the present time must be studied and their effects accounted for. The effect of depletion of the cloud due to deposition is accounted for as if the cloud were depleted at all heights. Yet, deposition is a boundary layer phenomenon, depleting the lower layers of the cloud and, perhaps, not altering the dosage distribution at higher levels. Consequently, one must appraise the applicability of the dispersion model in relation to the needs of the applied problem to be solved, and these weaknesses clearly identified, in order to stay within the bounds of scientific knowledge.

REFERENCES

1. Barad, M. L., ed: "Project Prairie Grass." Geophysical Research Paper No. 59, Vol. I and II. Geophysics Research Directorate, Air Force Cambridge Research Center, Bedford, Massachusetts, 1958.

2. Barad, M. L. and J. J. Fuquay, ed: "The Green Glow Diffusion Program." Geophysical Research Paper No. 73, Vol. II. Geophysics Research Directorate, Air Force Cambridge Research Center, Bedford, Massachusetts, 1962.

3. Chamberlain, A. C.: "Aspects of Travel and Deposition of Aerosol and Vapor Clouds," AERE-HP-R-1261. September, 1953.

4. Convair, Division of General Dynamics Corp.: "Fission Products Field Release Test - 1." Convair Report FZK-9-140 (NARF-59-32T), September, 1959. (AFSWL TR-59-44), Forth Worth, Texas.

5. Convair, Division of General Dynamics Corp.: "Fission Products Field Release Test - II." Convair Report FZK-9-149 (NARF-60-10T), September, 1960. (AFSWC TR-60-26), Forth Worth, Texas.

6. Fuquay, J. J., C. L. Simpson and W. T. Hinds: "Prediction of Environmental Exposures from Sources Near the Ground, Based on Hanford Experimental Data." (Submitted to Journal of Applied Meteorology, 1963).

7. Haugen, D. A.: "Ocean Breeze." (To be published as a Geophysics Research Directorate Paper).

8. Haugen, D. A.: "Dry Gulch." (To be published as a Geophysics Research Directorate Paper).

9. Healy, J. W.: "Calculations of Environmental Consequences of Reactor Accidents." Interim Report, December 11, 1957, Hanford Report, HW 54128, unclassified.

10. Islitzer, N. F.: Personal Communication, 1963.

11. Slade, D. H.: Personal Communication, 1963.

12. Watson, E. L. and C. C. Gamertsfelder: "Environmental Radioactive Contamination as a Factor in Nuclear Plant Siting Criteria." Hanford Report, HW-SA-2809, 1963.

Session Chairman: Thank you, Mr. Fuquay.

Meteorologists really have very much in the way of fancy instrumentation and gadgetry. I think the next paper deals with something that is quite fancy. Mr. W. M. Culkowski, of the Weather Bureau Research Station here at Oak Ridge, will give the paper entitled, "Theta-N System for Turbulence Measurements."

THETA-N SYSTEM FOR TURBULENCE MEASUREMENTS

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and

Duane H. Turner

Weather Bureau Research Station
Oak Ridge, Tennessee

ABSTRACT

Recent advances in applied optical instrumentation have permitted an extremely accurate, reliable, and versatile wind statistics system to be developed. Its basic principle is to obtain the differential of wind movement directly, then obtain other information by simple logic circuits. This system eliminates the ambiguities of conventional systems.

INTRODUCTORY REMARKS

In discussing analogue devices for dispersion estimates, at the Seventh Air Cleaning Conference, I alluded to a crude digital system by Humphrey and Wong [1] which showed some promise for future use in turbulence research. Although simple in principle, it was neither easy nor cheap to produce a working system which would be of sufficient improvement over other wind statistics systems to warrant serious consideration as a research or industrial tool. Now, however, utilizing recent developments in the computer field we have a capability of data reduction far in excess of our detecting abilities. Our original goal was one degree accuracy, but we can now record sensor movement to 1 minute of an arc. The absolute simplicity of the form of the output data makes it amenable to paper, or electronic tape recordings, strip chart recorders, or data reduction at the machine itself. There is no problem of calibration, and very little trouble from line voltage variations. In short, there is nothing about wind vectoring that this system cannot examine.

THE θ-N CONCEPT

If the total travel (in degrees) of a wind vane per unit time is divided by the number of reversals of the wind direction per unit time, the result is the average travel of the vane per reversal.

$$M = \frac{1}{N} \sum \Delta\theta \qquad (1)$$

where

M = mean wind vane travel per oscillation

$\Delta\theta$ = degrees traveled per unit time

N = number of oscillations per unit time

The standard deviation of a Gaussian distribution is related to the modulus mean, M, by

$$\sigma = .3M \qquad (2)$$

With 25 or more oscillations, σ has a reliability coefficient of 95%. This criterion is easily met in daytime synoptic conditions within a few minutes.

THE SENSING SYSTEM

By employing a moiré [2] fringe of alternate light and dark sectors of a circle, the Optisyn [3] Corporation produces a high resolution shaft angle encoder. To be more precise, it produces a system of packages which convert changes in shaft angle into a series of right and left hand pulses which may then be operated on by simple sum and difference circuits. The unit at the Oak Ridge Weather Bureau Station is a 400 pulse per revolution model, although up to 20,000 pulses per revolution are available in this particular model. (I understand that shaft encoders are available with 1/100 of a second of an arc resolution, but these are of academic interest only as far as we are concerned.)

The first θ-N built at Oak Ridge is diagrammed in Figure 1. The Optisyn sensor sends out sine waves as the shaft rotates. The logic system determines whether the rotation is clockwise or counter-clockwise and shapes the resulting output into square waves on the appropriate (CW or CCW) channel. Wind vane travel (θ) information is picked directly off midway between the logic and photocell outputs, (for a more convenient impedance value) and the reversal (N) detector is placed on the outputs of the logic circuit. Both θ and N counters reduce the counts to numbers easily read from a strip chart. ($\Delta\theta$'s of 20,000 degrees/hour are not uncommon).

The dashed lines represent equipment to be added—a reversible, or ring, counter to indicate wind direction and the reference system for detecting accumulated position error.

For display purposes a second model was designed as shown in Figure 2. Basically, the functions are the same, but with a few refinements. By equations (1) and (2)

$$\sigma = \frac{.3}{N}\sum \Delta\theta = \frac{.6}{2N}\sum \Delta\theta \quad . \qquad (3)$$

Since our particular model has 400 counts per revolution,

$$\sigma = \frac{360^\circ}{400^\circ} \cdot \frac{.6}{2N}\sum \Delta\theta \qquad (3a)$$

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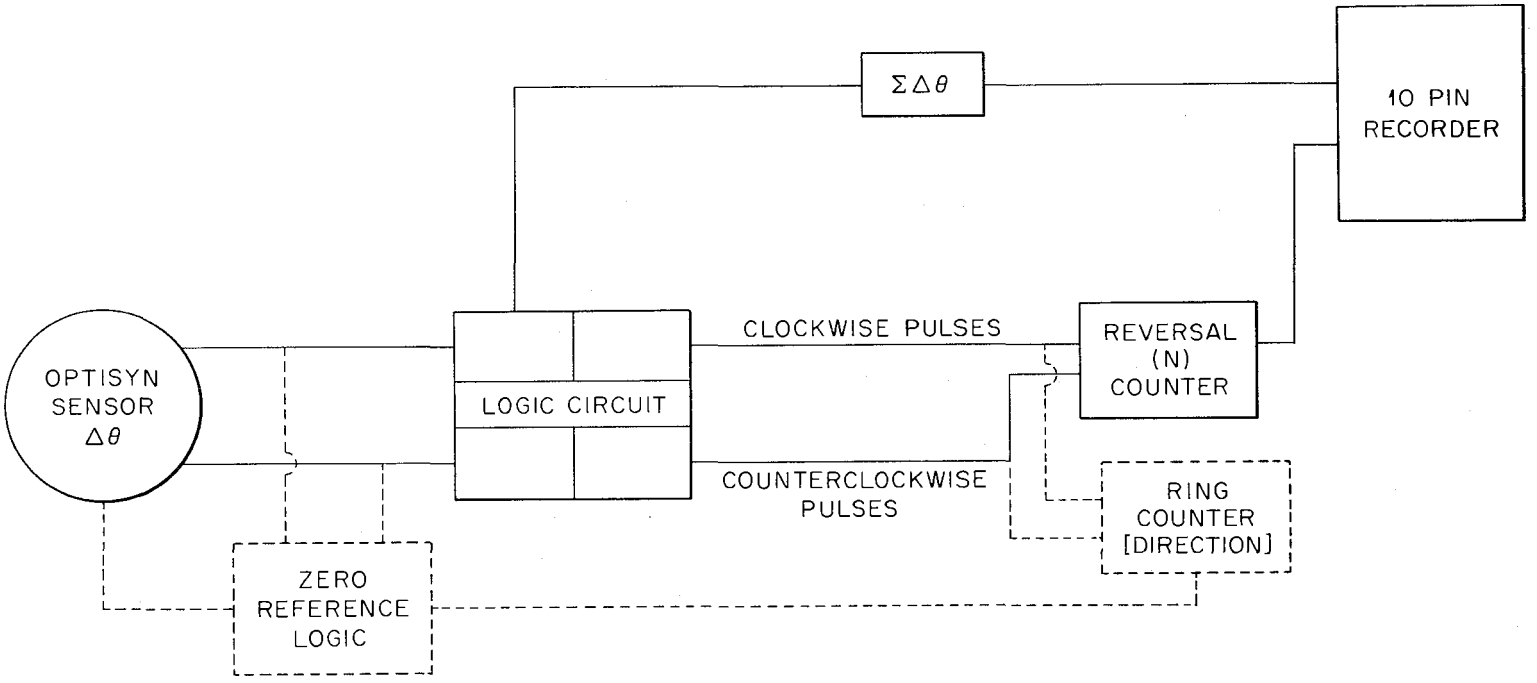


FIGURE 1

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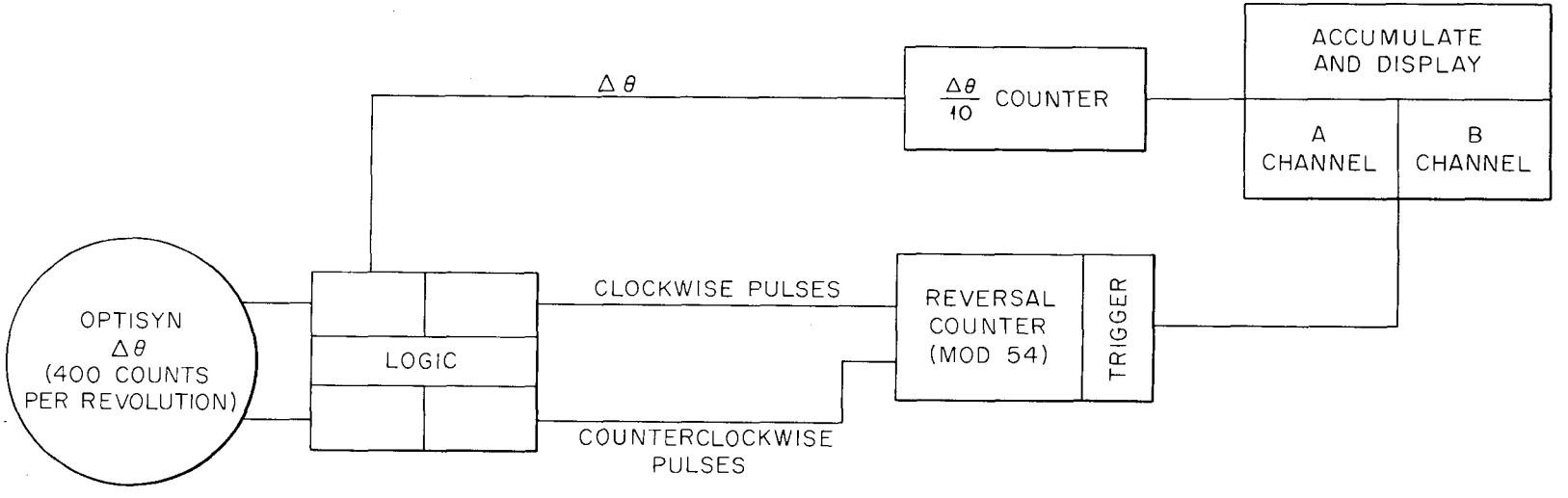


FIGURE 2

i.e.

$$\sigma = \frac{.27}{N} \sum \Delta\Theta \qquad (3b)$$

thus if N = 27

$$\sigma = .01 \sum \Delta\Theta \quad . \qquad (3c)$$

Therefore, if the readout is performed at the end of every 27 revolutions (54 reversals), the standard deviation can be read directly. To avoid decimals, the Θ counter reduces the count by 100. Thus, the readout is in whole degrees. The display can be by "Nixie" (i.e. light) tubes or conventional counters. For our model we chose conventional counters. By a switching arrangement, one circuit "holds" the last count while another is counting. An indicator light shows which channel is "holding".

DIGITAL TO ANALOGUE LINK

I'd like to stress here the basic difference between most wind systems and the present one. Other wind systems observe the direction first and then obtain the differential value. This system detects the differential, permitting other parameters to be obtained by integration. Thus, wind direction is obtained by

$$\Theta = \int_0^{\Theta} d\Theta (\text{MOD } 360°) \quad . \qquad (4)$$

Naturally, a zero referencing circuit is necessary for establishing an "initial condition", but this is a simple matter.

Equation (4) could be treated either by digital or analogue techniques, preferably digital. An improtant set of turbulence data, however, depends on the second derivative of Θ and this is best handled by analogue techniques [4]. Figure 3 illustrates a complete statistics system incorporating a straightforward digital to analogue link. One advantage of this circuit lies in the ability of the integrator to avoid the discontinuity at 360° = 0°. A special logic circuit would be necessary in Figure 3, for compatibility with the integrating networks. Pulses from the commercial system we now employ are 3×10^{-6} seconds in duration, a value far too low for this purpose.

SUMMARY

By employing a differential sensor, and integrating the movements of a wind vane, simple techniques for determining wind statistics are possible. The basic system is versatile, does not require periodic calibrating, avoids the voltage ambiguity inherent in conventional wind vane to analogue systems, and permits application of an unlimited variation of readout and data reduction systems.

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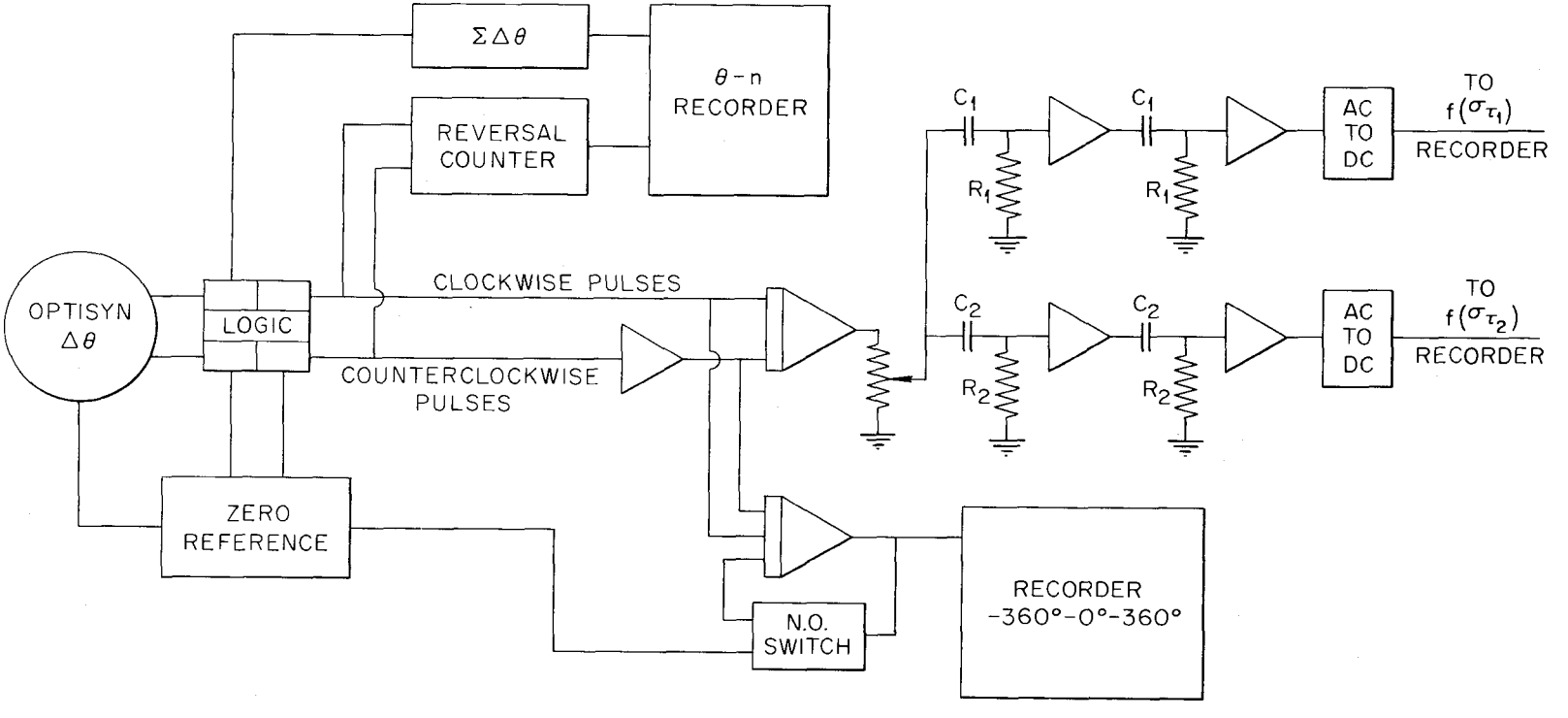


FIGURE 3

REFERENCES

[1] Humphrey, P. A., and L. J. Wong, 1961: An economical wind recording system. 191st National Meeting of the American Meteorological Society.

[2] Oster, G., and Y. Nishijima, 1963: Moiré patterns. Scientific American, p 54.

[3] Optisyn Miniature Optical Shaft Angle Encoder: Dynamics Research Corporation.

[4] Jones, J. I. P., and F. Pasquill, 1959: An experimental system for directly recording statistics of the intensity of atmosphere turbulence. Quart. J. R. Meteor. Soc., 85, 225-236.

FIGURES

Figure 1. Basic θ-N system.

Figure 2. θ-N system adapted for instant readout or display purposes.

Figure 3. Complete wind system for vectorial, statistical, and spectral investigations.

DISCUSSION AND COMMENT

The fixed source opposed to the light source has N light and alternate circles on one side on one band, and N-1 on the other, or N+1. As these rotate, a pattern of beats is produced. A very good analogy would be the way a wagon wheel looks in the movies. It sort of looks like it's going one way, and then it looks like it's going the other. Actually, it is the dark section beating against the speed of the film.

If you had just N and N+1 alternate light and dark sections, which you could do, you would have an alternate on and off system -- light-dark, light-dark, light-dark. By producing a moire fringe pattern, there is a continuous sign wave, which is a more amenable meteorologic circuit with a discriminating ability.

The basic unit costs roughly $700.00. There are other coders which can be bought for as little as $300. They operate either on a punch card principle, or a magnetic pick-off system, in an alternating system with a 10,000 cycle oscillation. The difference in the magnetic pickup of this data and the rotor determine the increment and direction traveled.

Session Chairman: The next paper is a duet by Mr. C. Hawley and Mr. E. G. Markee, USWB-IDO, entitled, "Controlled Environmental Radioiodine Tests." Mr. Hawley will present the first part and Mr. Markee will present the second.

STATEMENT BY MR. HAWLEY: Mr. Chairman, a word of explanation about our dual presentation. Originally, we were going to take the meteorological aspects, since this was an Air Cleaning Conference, and confine the remarks to the meteorological portion. As we were both going to be here we decided to wrap up the entire package including the biological aspects.

The CERT research project is a series of planned experiments whereby we intend to release radioiodine over pasture grounds and trace the meteorological behavior of the iodine through the milk cycle into the cow, feed this milk to human volunteers and thereby make a complete picture under actual field conditions. Hopefully, we will get some basic iodine behavior information which will be applicable to other programs but the point we are most interested in is the behavior of the iodine at the NRTS under our chronological and topographical regimes. We hope to get definitive information which we can apply to such things as reactor siting, safety analysis reports, and emergency actions following a large unplanned release of iodine.

This paper deals only with the preliminary experiments. Of course, we are looking for three basic relationships, or we are going to be; the relationship of air to vegetation, vegetation to milk, and milk to people. In order to do this, we had an ulterior motive in mind. As a part of the noxious weed control program in the desert, we wound up with approximately 2,000 acres of wheat grass which we would like to utilize. If we can prove that this will lend itself to this type of experimentation, we have a large, ready-made laboratory. The first experimentation may have left something to be desired. Currently, we are constructing an irrigation system, including a dairy barn, which we project will take care of us for about three years of experimentation whereby we can experiment with radioiodine and the various parameters; temperatures, pressures and heights, and, of course, distances. We hope to get some definitive particle sizing data.

I will turn the rostrum over to Mr. Markee, who will talk about the meteorology, and I will conclude the presentation.

CONTROLLED ENVIRONMENTAL RADIOIODINE TESTS (CERT) AT THE NATIONAL REACTOR TESTING STATION*

Earl H. Markee, Jr., and C. A. Hawley, Jr.

SUMMARY

The CERT project consists of a series of planned releases of radioiodine over different vegetation and during various meteorological conditions, with the prime objective being to measure the amounts of radioiodine through the air-vegetation-cow-milk-human chain. This paper deals with the first, or preliminary, experiment in the CERT series at the National Reactor Testing Station (NRTS) in southeast Idaho. The preliminary experiment consisted basically of releasing radioiodine (iodine-131) gas over a natural Crested Wheatgrass pasture and using the contaminated grass for milk cow grazing. The resultant radioactive milk was fed to seven human volunteers. It was desired from this experiment to establish under known natural release conditions three basic relationships:

(1) The amounts of radioiodine in the air to those on the soil and vegetation,

(2) The amounts of radioiodine on the vegetation to those in the milk, and

(3) The quantities in the milk to those in the human thyroid after drinking the milk.

* The complete details of this CERT experiment will be published in the near future as IDO report number 12034.

Two 11.5 acre pasture areas with an initial grass density of 150 g/m^2 and an average height of 13 cm were established, one for contamination (hot) and one for control and background (cold), (Figure 1). Five iodine 131 generators which used the process of "swaging" the iodine 131 gas with nitrogen gas were oriented along a 150 m line normal to the expected prevailing wind, to simulate a short line source. The source line was 50 m upwind from the "hot" pasture. A dense sampling grid based on pre-test meteorological studies, was established to 300 m downwind (Figure 2). Background activities on soil and vegetation, as well as grass consumption and growth rates, were measured before and after the release. Milk production and activity levels were measured. The six cows used during the test were 1200-1600 pound fresh pure-bred Holsteins, obtained from Montana State College. Arrangements were made to maintain the cows on their normal feed supplements and the cows were acclimated to the natural grass and new surroundings for two weeks prior to placing them on the contaminated pasture. The cows were milked at 6 A.M. and 6 P.M. daily. Milk from the evening and morning milking of one cow was combined, pasteurized, counted, and consumed by seven volunteers over a 39-day period. Human thyroid activities were measured with a NaI crystal, 256 channel analyzer, in a low background whole-body counting vault.

A total of 970 millicuries of iodine-131 gas was released at 1500 MST on May 27, 1963 near ground level over a 30-minute period under moderately unstable meteorological conditions and an average wind speed of 6.6 mps. About 13% of the total released iodine was deposited on the grid, with 1.5% being actually on the grass (Figure 3). The Crested Wheatgrass covered about 15% of the total plot, the remaining surface being soil cover. Deposition velocities ranged from 0.4 to 0.8 cm/sec, with an average of 0.6 cm/sec. The activity on the carbon fall-out plates was found to be representative of the grass measurements.

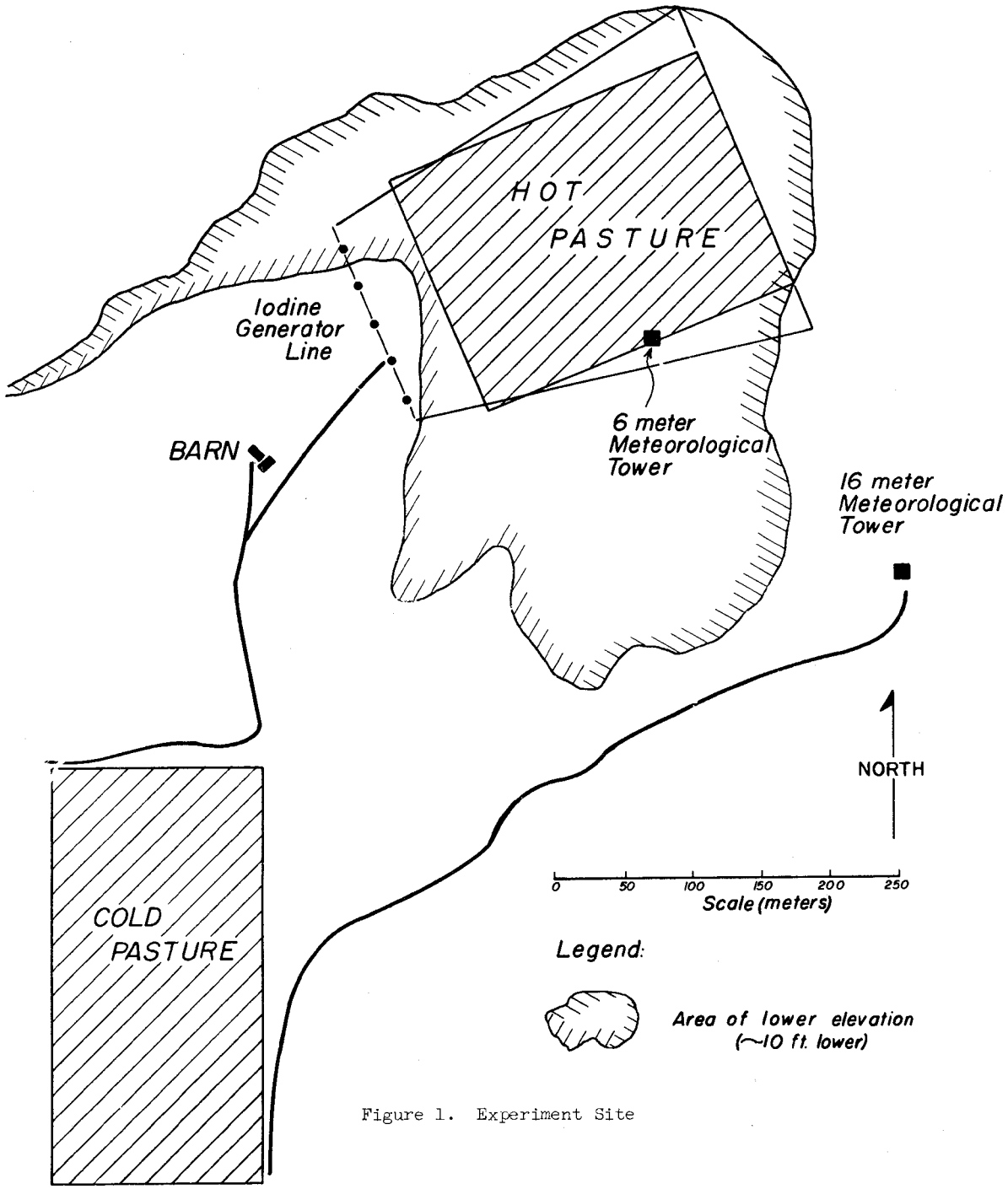


Figure 1. Experiment Site

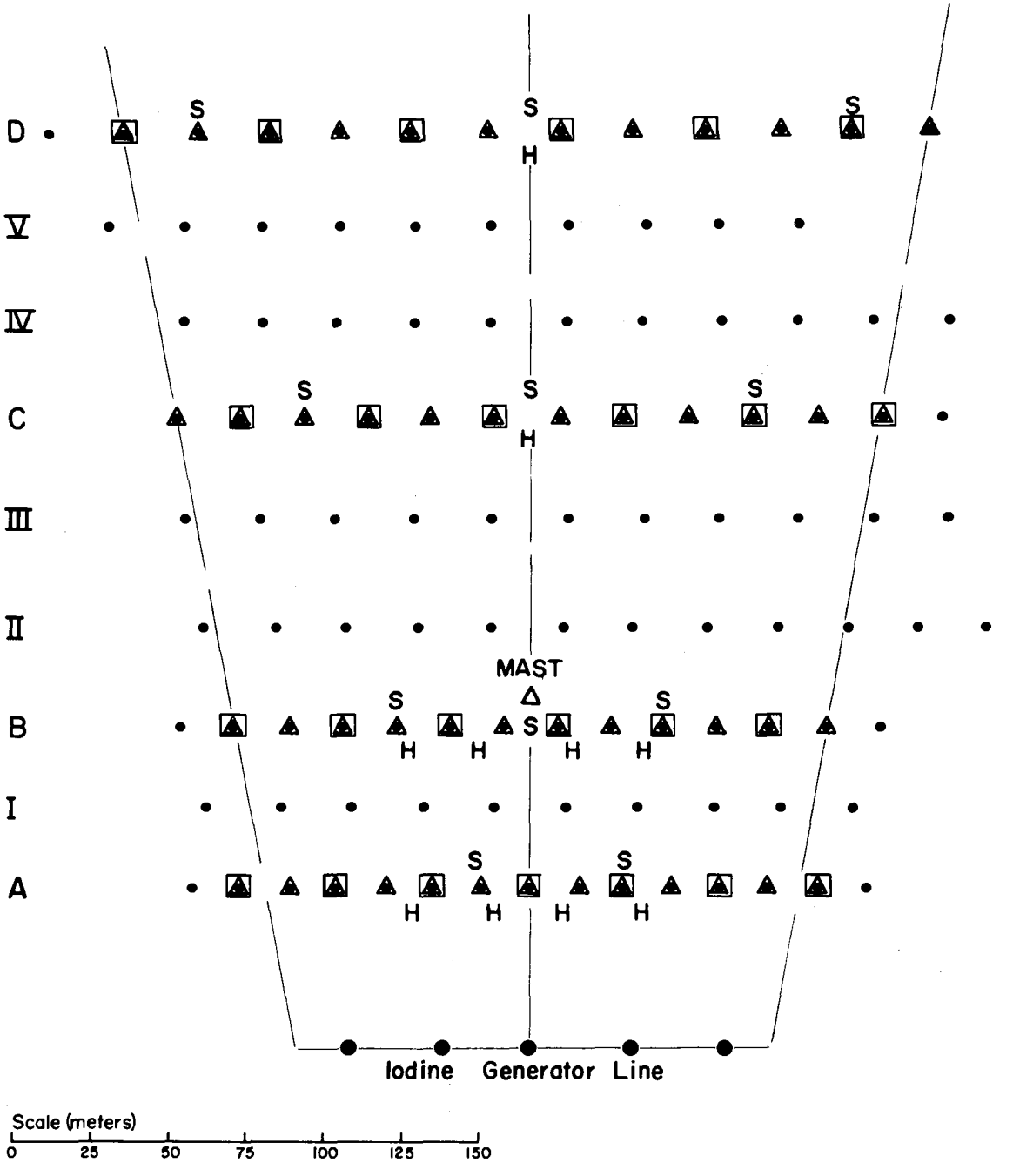
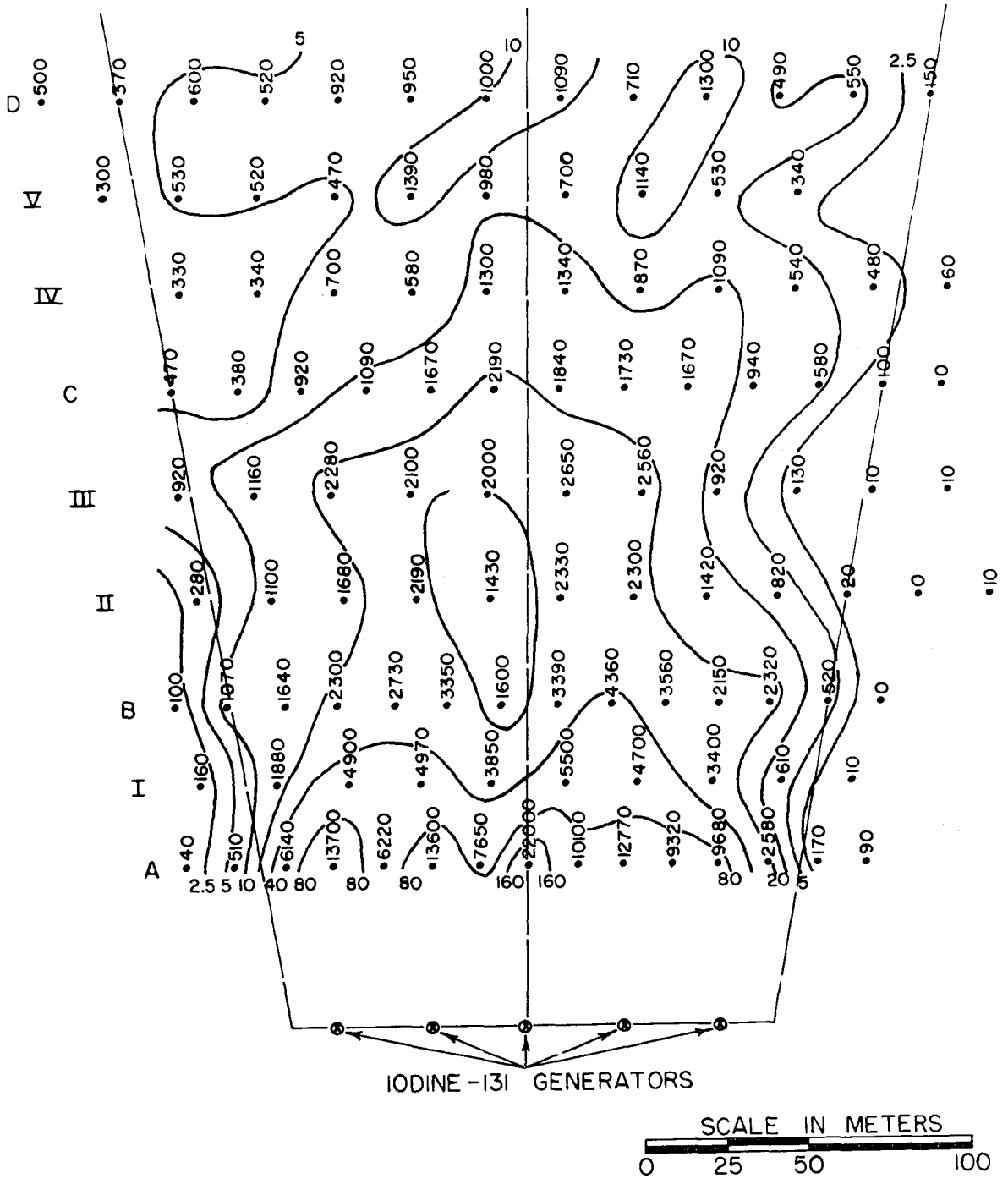


Figure 2. Sampling Grid

Legend:

- • Vegetation Samples
- △ Air Samples (Hi-Vol)
- □ Fallout (Carbon, Sand, Sticky Paper)
- S Soil Samples
- H Hanford Samplers

Figure 3. Initial Grass Deposition (μμc/gram)



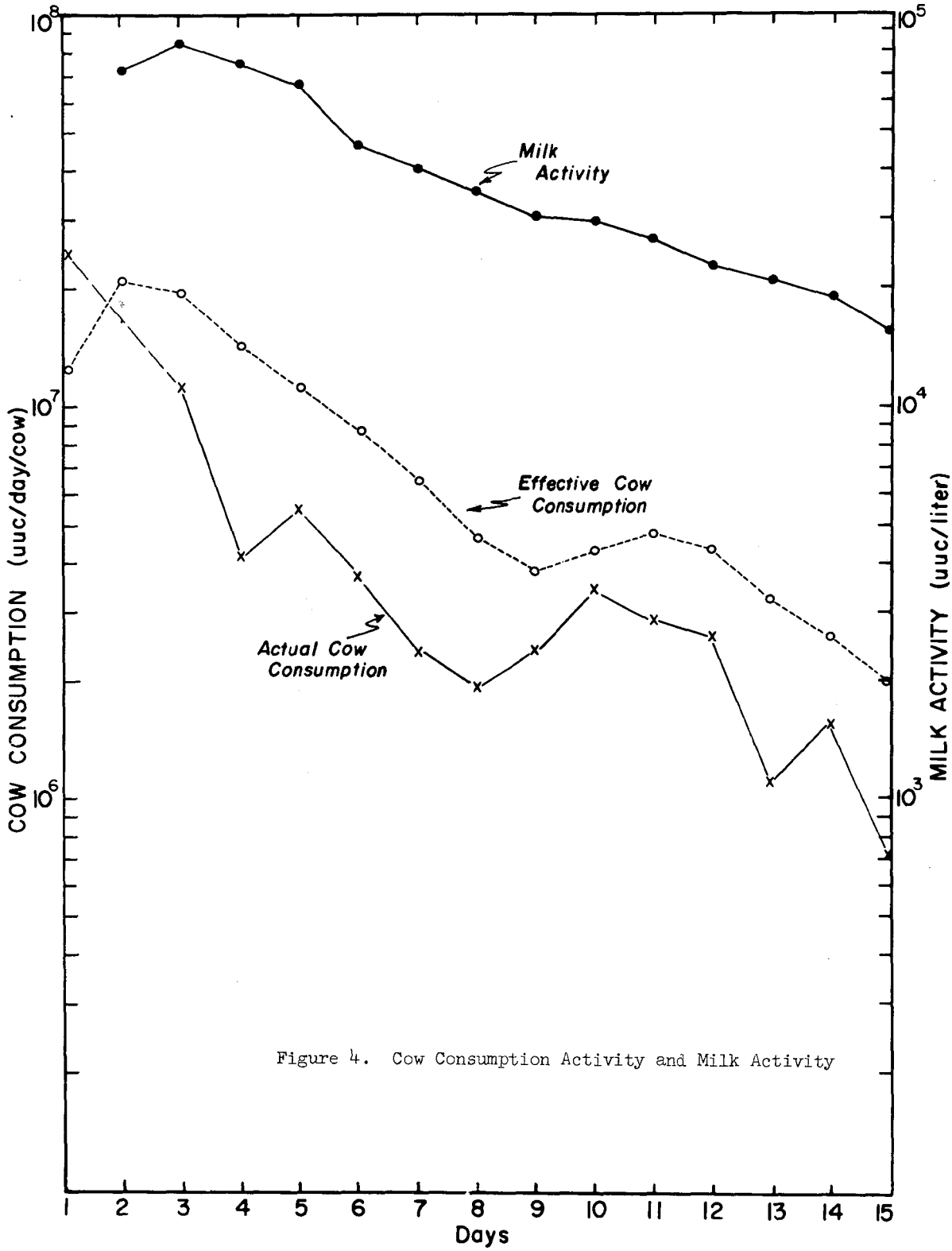


Figure 4. Cow Consumption Activity and Milk Activity

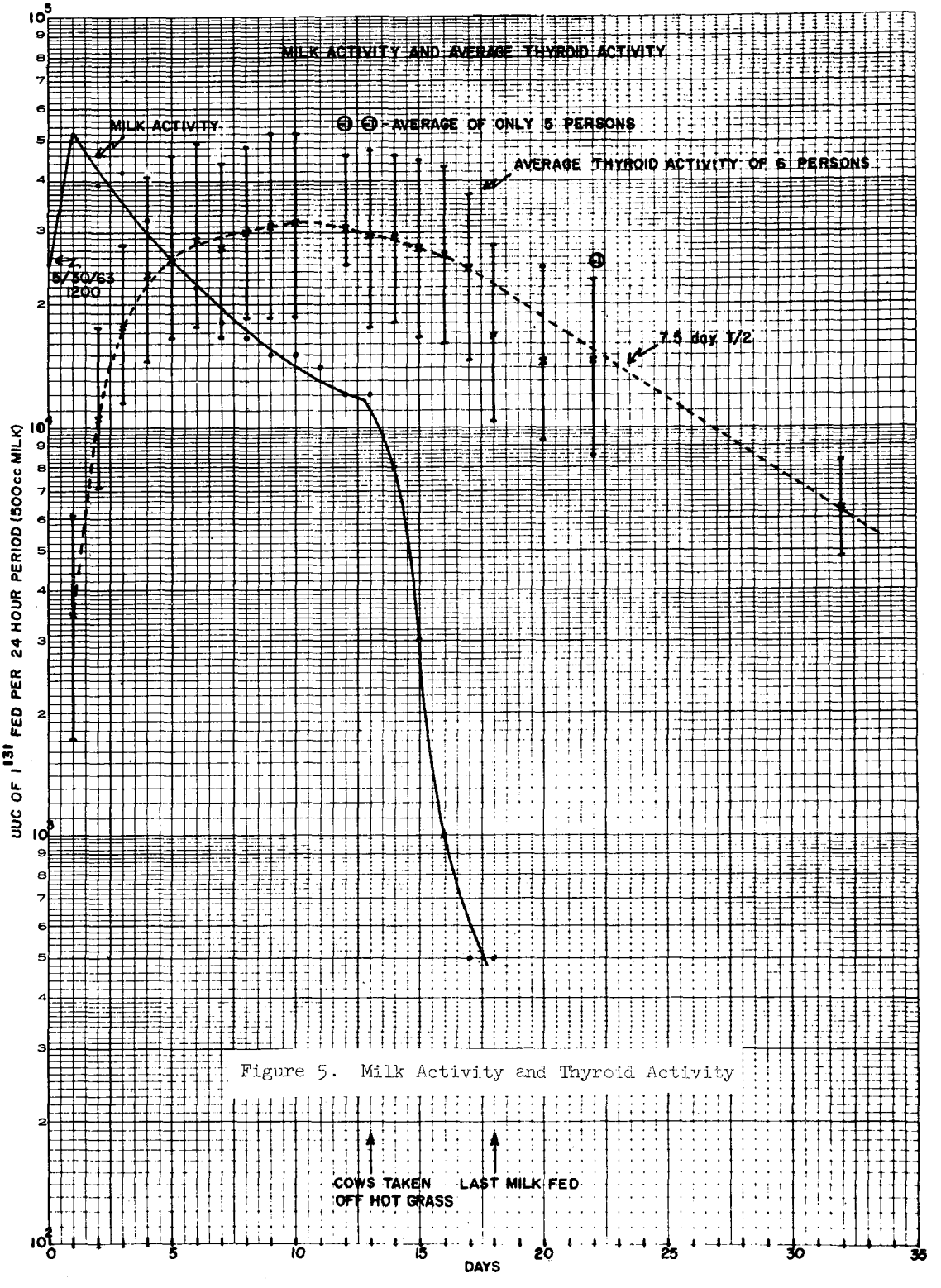


Figure 5. Milk Activity and Thyroid Activity

Controlled grazing which consisted of daily changes of 0.5 acre crosswind grazing strips progressing from 300 m downwind toward the source, enabled the quantitive measurement of grass consumption and activity. The effective half-life on grass was found to be 3.5 days. The comparison between grass activity and milk activity is shown in Figure 4. The effective cow consumption (Figure 4) represents the accumulation of activity within the cow from the current and previous days' grazing based on a one day "half-life" retention factor. The ratio of activities of grass and milk (pc/liter:pc/gm) was: 240 ± 35. The average thyroid uptake of ingested iodine-131 in milk was 19%. A model to predict thyroid activity levels was developed and shown to be quite accurate. The model is:

$$A_n = f \sum_{i=1}^{n} C_i \exp\left[-\lambda_E (T_n - T_{i-1})\right]$$

A_n-Activity in thyroid at end of n'th time

f - Uptake factor (0.19)

C_i-Activity ingested at beginning of i'th time interval

λ_E-Effective decay constant (thyroid)

T_n-Total time elapsed

T_{i-1}-Time from 0 to end of (i-1) 'th interval

Thyroid doses to the volunteers averaged 0.39 Rad. A comparison of the milk and thyroid activities is shown in Figure 5.

The preliminary experiment showed that the basic experimental procedures were adequate. Further tests in the series will employ the same general procedures in investigating the behavior of radioiodines under various meteorological and physical conditions.

CONCLUDING STATEMENT BY MR. HAWLEY: I should have made it clear earlier that the prime objective of the preliminary experiment was to establish techniques that we can use when we get into the actual irrigated pasture system.

The cows were forced to graze in premeasured strips so that we could get a reasonable measurement of the actual amounts of grass the cows were eating. They were kept on the whole pasture long enough to get an idea as to how much grass would hold these cows for a one-day period. This was adjusted as the grass grew. This is the real trouble with this grass; at various times of the year it grows just like fury, and it was necessary to keep measuring and keep adjusting. We hope with the first test on our irrigated system, where we can actually control the grass measurements much better, we will be able to throw out this one variable. In this thing here, we treated all six of our cows.

We had six 1200 to 1600 pound pure-bred Holsteins, all of which were fresh, which were borrowed from Montana State College. So we took these six cows, and because there was never a factor of 2 discrepancy between the cows, we felt we could treat them as one animal, as far as the data goes. The cows were milked at 6:00 A.M. and 6:00 P.M.

Session Chairman: Thank you, gentlemen, for a most interesting presentation.

The next paper is a substitution which I don't think you will be able to find on your program. Mr. W. J. Megaw, of the United Kingdom Atomic Energy Authority at Harwell, and the topic of this paper is entitled, "The Efficiency of Membrane Filters."

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(Approved for Publication)

AERE - R 4211

THE EFFICIENCY OF MEMBRANE FILTERS

by

W.J. Megaw
R.D. Wiffen

ABSTRACT

Experiments are described in which the efficiency of type AA millipore filter was determined at a particle diameter of 0.02 microns, using aerosols of potassium permanganate and radioactive tungsten. No significant penetration of the filter was detected either by particle counting techniques using a Pollak counter or by radioactive methods. These results contradict those reported earlier by Fitzgerald and Detwiler. It is shown that the performance of the filter in this size range is not dependent on electrostatic effects and is predictable theoretically if it is assumed that diffusion is the sole filtration mechanism.

Larger particles which are still, however, smaller than the filter pores and for which diffusion processes are ineffective are also trapped with efficiencies of 100 per cent. Removal of the electrostatic charge of the filter does not alter its efficiency and it is concluded that such particles must be trapped by impaction in the filter pores.

Health Physics and Medical Division,
UKAEA Research Group,
Atomic Energy Research Establishment,
HARWELL

January, 1963

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1. Introduction

Membrane filters are porous membranes composed of cellulose esters and can be obtained with mean pore diameters ranging from 0.01 to 5 microns and with porosities as high as 85 per cent. Although they might be expected to act primarily as sieve type filters, they have the property of retaining particles which are very much smaller than the pore size and further of retaining all particles in a very shallow surface layer.

The filters are good electrical insulators, having a specific electrical resistance of about 10^{10} ohm-cm and a dielectric constant of 4.5 (Spurny and Polydorova, 1961). It has been generally accepted that the performance of the filter and, in particular, the surface layer effect, were due to electrostatic forces.

The efficiency of "Millipore"[1] membrane filters has been investigated by Fitzgerald and Detwiler (1957). They passed an aerosol of solid potassium permanganate through a millipore filter and sampled wnstream of the test filter by means of another millipore filter. Silic replicas were then taken of the filters and examined by means of an electron microscope. The results of Fitzgerald and Detwiler, which are summarised in Table I indicate a maximum penetration of the grade AA filter (pore size 0.8 μ) at a particle diameter of 0.02 microns. The penetrations ranged from 25 per cent at a face velocity of 10 cm/sec to 56 per cent at a face velocity of 40 cm/sec. Corresponding penetrations of the type HA filter (pore size 0.45 microns) were 25 per cent and 76 per cent, respectively.

The curves given by Fitzgerald and Detwiler show that there is a greater penetration of the filter with the smaller pore size and also that maximum penetration occurs at a larger particle size for the filter with the smaller pores. To this extent they are surprising. They are contrary also to general experience in this laboratory, where for several years type AA millipore filters have been used routinely for the filtration of Aitken nuclei in the size range 0.01 to 0.1 microns in diameter, without any penetration ever having been detected. The method of measurement was such that a penetration of 0.1% would have been detected with ease.

---

[1] Millipore Filter Corporation, Bedford, Massachusetts, U.S.A.

TABLE I

Penetration of Millipore filter by $KMnO_4$ aerosol

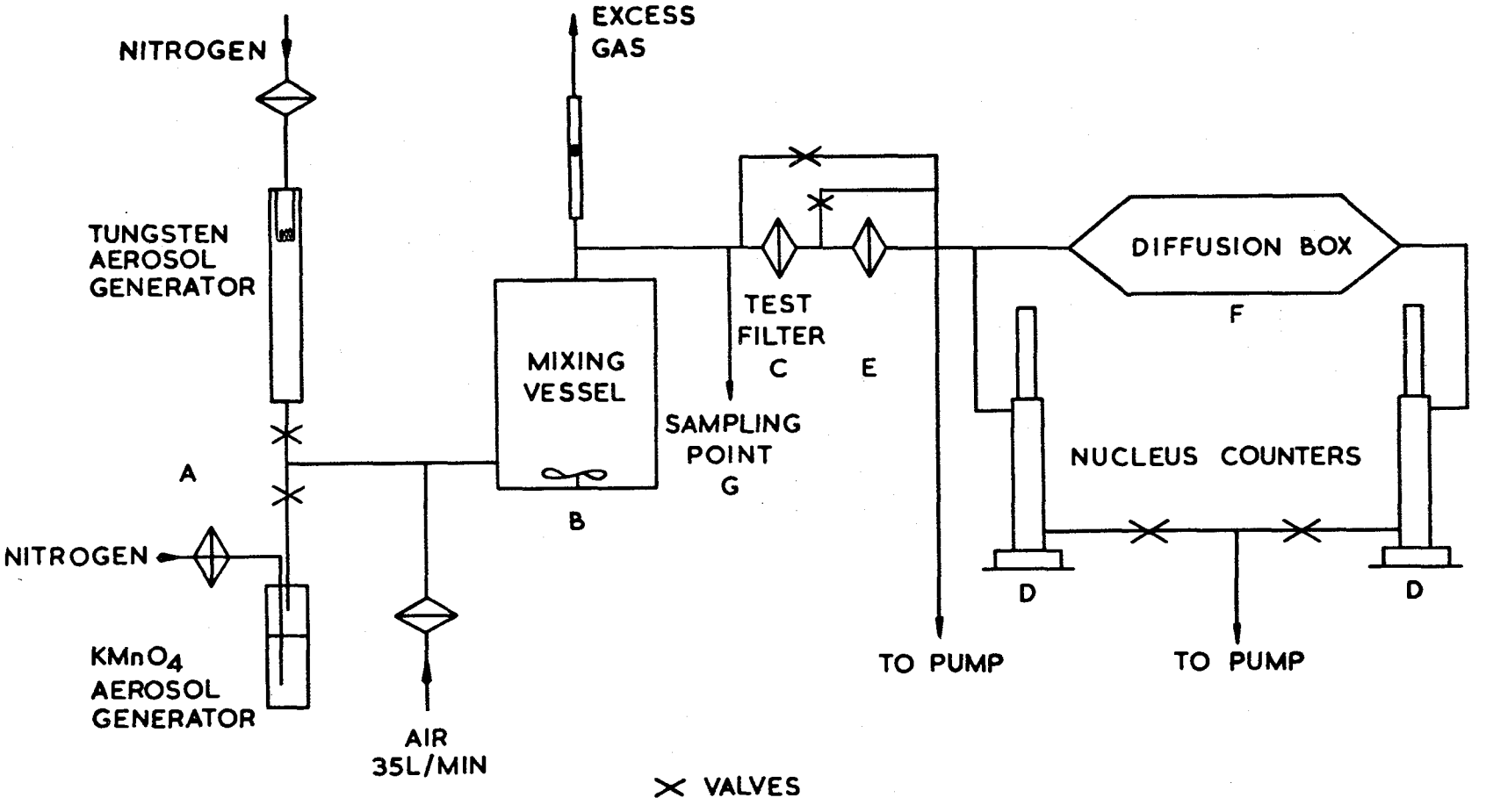
(Fitzgerald and Detwiler, 1957)

Particle Diameter Microns	Air Velocity cm/sec	Percent penetration of AA Millipore filter (pore size 0.8 μ)	Percent penetration of HA Millipore filter (pore size 0.45 μ)
5×10^{-2}	10	1	5
	20	5	2
	40	13	12
2×10^{-2}	10	25	25
	20	35	35
	40	56	76
8×10^{-3}	10	10	3
	20	17	6
	40	46-53	50

It was therefore considered desirable to perform further penetration tests on the type AA millipore filter. The experiments were carried out at particle sizes and face velocities as near as possible to those at which Fitzgerald and Detwiler found maximum penetration.

2. Experimental Method

A diagram of the arrangement of the apparatus is given as figure 1. The test aerosol was generated at A and passed through the chamber B, where it was diluted and dried, and then to the test filter C. The concentration of the aerosol could be measured by means of a nucleus counter at D. The nucleus counter used was similar to that described by Metnieks and Pollak (1959). At the overpressure used (160 mm Hg) the counter would have caused condensation on and hence detected particles down to a diameter of 2.5×10^{-7} cm. The useful concentration range of the instrument is from 50 to 300,000 particles per cm^3. A backing filter of the same type as the test filter was placed at E. The mean size of the aerosol could be determined by passing it through the diffusion box F, from which the diffusion coefficient could be determined by the method of Nolan and Guerrini (1935). Provision was made for sampling the aerosol at G by means of thermal and electrostatic precipitators so that the size distribution could be determined subsequently by electron microscopy.



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FIG. 1. ARRANGEMENT OF APPARATUS

2.1 Experiments with a potassium permanganate aerosol

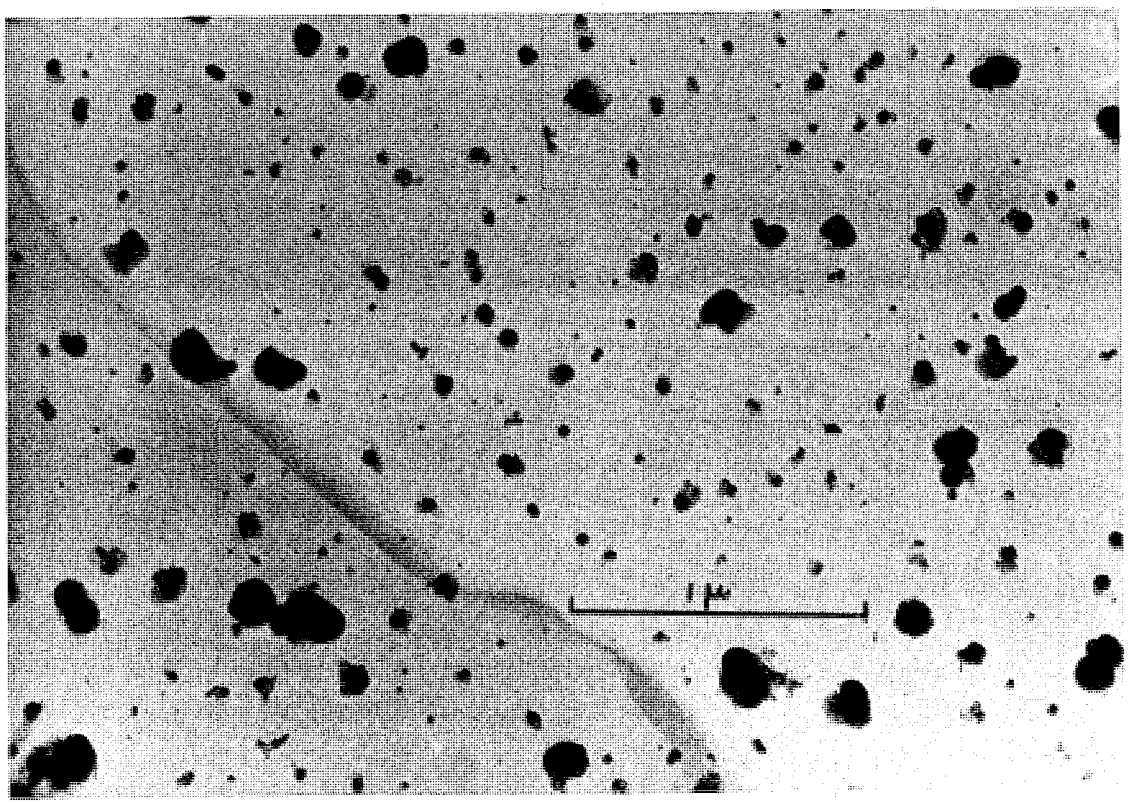
These preliminary experiments, using a similar aerosol to that of Fitzgerald and Detwiler, were undertaken to determine whether some property peculiar to the permanganate aerosol was responsible for the penetration of the millipore filter.

The aerosol was generated by atomising a 0.1% solution of potassium permanganate. An electron micrograph of a sample of the aerosol obtained by electrostatic precipitation is shown in figure 2, and the particle size distribution obtained from this micrograph is given in figure 3. The geometric mean particle diameter by count was 0.024 microns and the geometric standard deviation, 3.0. The diffusion coefficient of the aerosol as determined by the method of Nolan and Guerrini, was 8.23×10^{-5} cm^2 sec^{-1}, corresponding to a 'mean' particle diameter of 0.026 microns. The results of measurements of the penetration of this aerosol through a type AA millipore filter at a face velocity of 40 cm sec^{-1} are listed in Table II. In nine separate tests no significant penetration of the filter was detected. Periodic tests were also made on less efficient filters as a check on the downstream detection system. The penetrations found for these filters were of the order expected and are also listed in Table II.

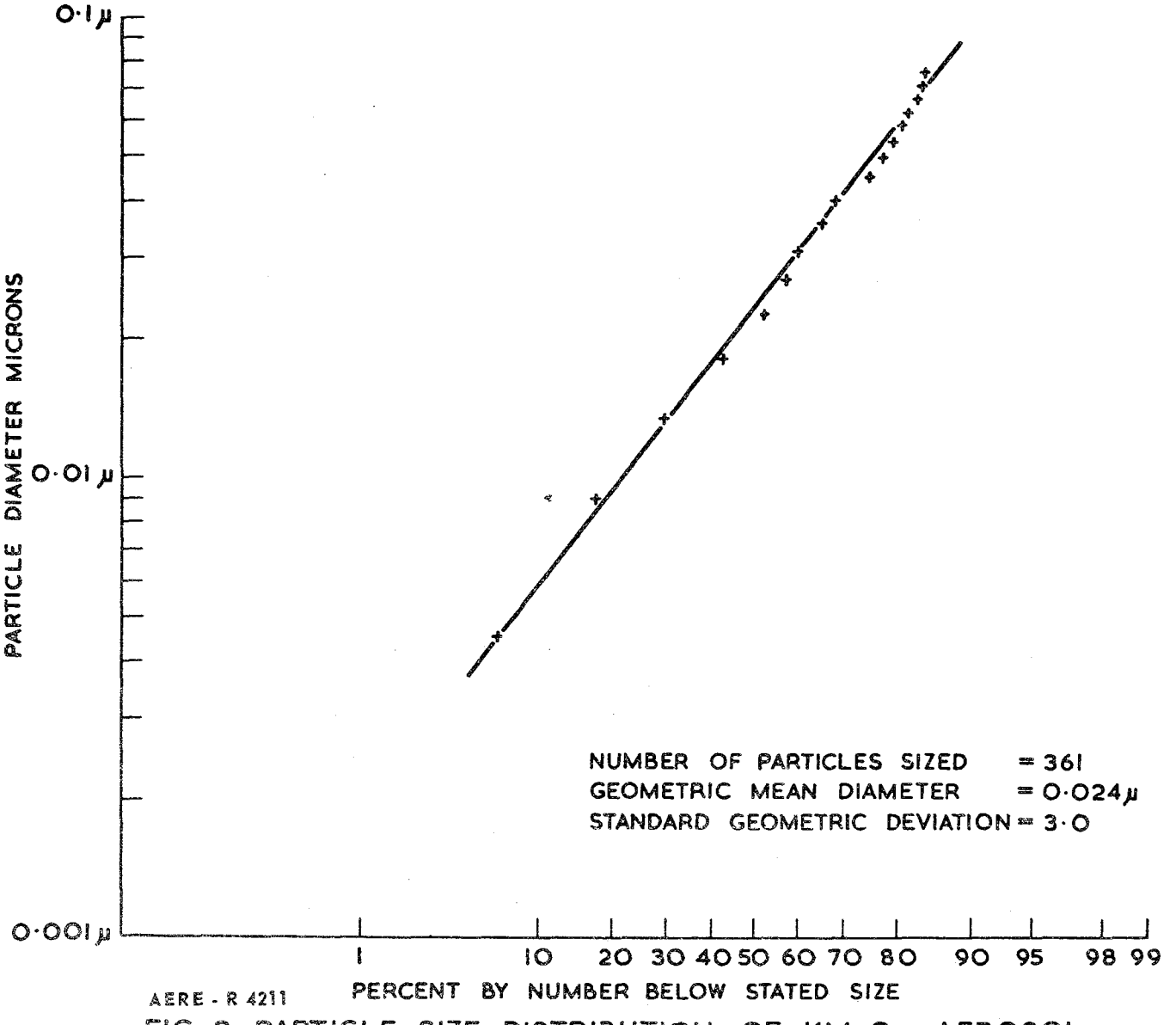
2.2 Experiments with a radioactive tungsten aerosol

The method of particle counting using the Pollak counter is extremely sensitive and has the additional advantage that the sensitivity is independent of particle size. It is however, rather indirect and it would have been useful, as a check, to compare electron micrographs of simultaneous samples taken from upstream and downstream of the filter. The efficiency of the type AA filter was so high, however, that it was not possible to obtain a downstream sample. A second series of experiments was therefore undertaken in which a radioactive aerosol was used. A sample was taken on a second AA millipore filter downstream of the test filter and the radioactivity of the two filters compared. This method of testing a filter by using an identical filter to take a downstream sample was used by Fitzgerald and Detwiler and is valid for a particular size range provided that penetration of the filter in that range is less than 100 per cent and is independent of aerosol concentration.

A tungsten wire was irradiated in the Harwell reactor Bepo for 30 minutes at a flux of 10^{12} neutrons cm^{-2} sec^{-1} and the aerosol



AERE - R 4211 FIG. 2
POTASSIUM PERMANGANATE AEROSOL



AERE - R 4211

FIG. 3. PARTICLE SIZE DISTRIBUTION OF $KMnO_4$ AEROSOL

TABLE II

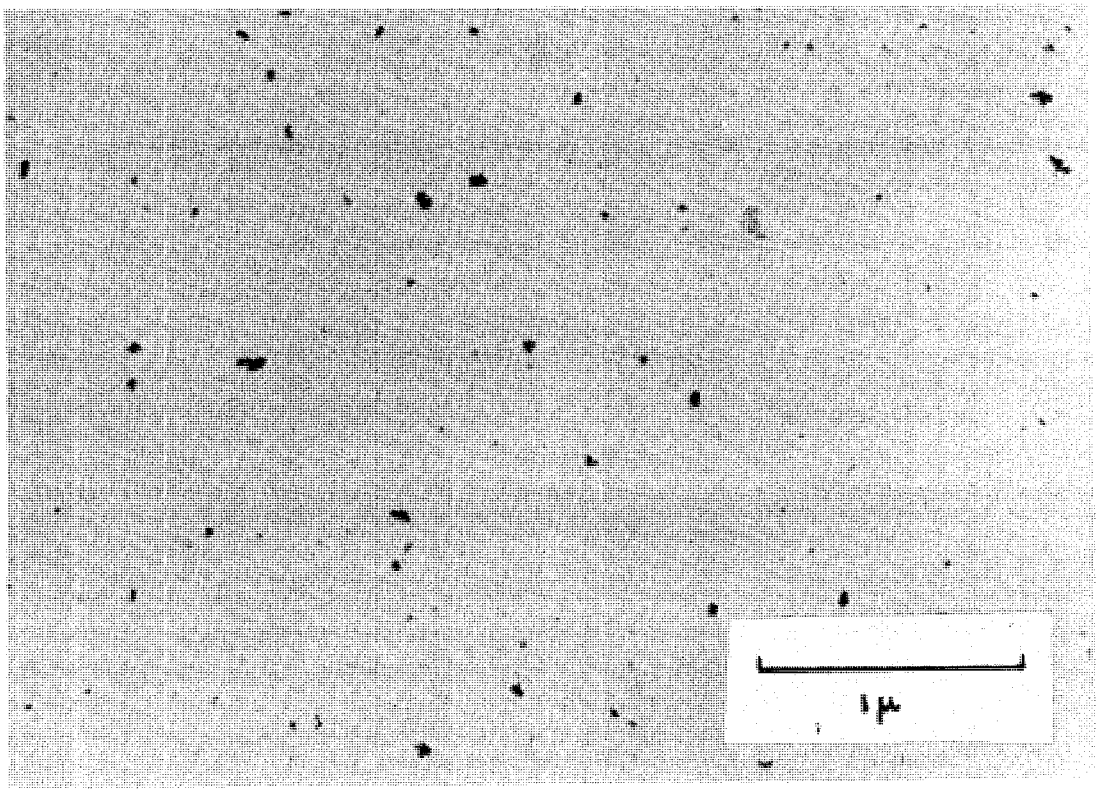
Tests with $KMnO_4$ aerosol

Date of Test	Type of Filter	Face velocity cm sec^{-1}	Pressure drop cmHg	Mean particle diameter as determined by diffusion box microns	Particle Concentration cm^{-3} measured with Pollak counter	
					Upstream of Test Filter	Downstream of Test Filter
29/12/60	Millipore AA	40	9.0		$> 3 \times 10^5$	< 10
		40	9.0		$> 3 \times 10^5$	< 10
30/12/60	Millipore AA	40	9.6	0.026	2.5×10^5	0(4 tests)
	Whatman 541	40	1.8	0.026	3.0×10^5	2.7×10^5 (2 tests)
2/1/61	Millipore AA	40	9.2	0.039	2.0×10^5	0(3 tests)
	*GFA paper	40	4.2	0.034	2.0×10^5	425 (3 tests)

*GFA paper is a high efficiency glass fibre paper manufactured by H. Reeve Angel and Co. Ltd., 9 Bridewell Place, London, E.C.4.

generated by heating the wire to a temperature of 1000-1200°C in a current of filtered nitrogen. The size of the particles was measured by means of a diffusion box as previously described, and could be adjusted to the required diameter of 0.02 microns by altering the temperature of the wire and the velocity of the gas flow past it. An electron micrograph of a sample of a particular aerosol taken with a thermal precipitator is given in figure 4, and its particle size distribution in figure 5. The geometric mean diameter by count is 0.0165 microns. The 'mean' particle diameter indicated by the diffusion box was 0.017 microns. The results of the tests are summarised in Table III and again show no significant penetration of the millipore filter by the tungsten aerosol. It should be remembered that in the radioactive method the results are proportional to mass of material and not numbers of particles as with the Pollak counter, and that in the present instance the radioactive method is therefore probably the less sensitive.

It is a common belief that the high efficiency of membrane filters is due in part to their electrostatic charge. If this were the case it might be expected that the filtration efficiency would depend to some extent on the humidity of the air. In some of the tests mentioned in Table III the relative humidity of the air was increased to 90-100 per cent by the addition of steam. There was no apparent effect on the efficiency of the filter. Two further tests were performed in which an attempt was made to discharge the filter, during filtration, by irradiating it with electrons from a Kr^{85} source mounted close to the filter surface. The arrangement is shown in figure 6. The strength of the source was 10 mc and a rough calculation gave the radiation dose to the filter as several rad hr^{-1}. The dose rate measured by a radiation monitor type 1349 was 1 rad hr^{-1}. The tests on the irradiated filter were carried out using both relatively dry air and very humid air. No penetration of the filter was detected. The experimental conditions and results are summarised in Table IV.



AERE - R 4211 FIG. 4
TUNGSTEN AEROSOL

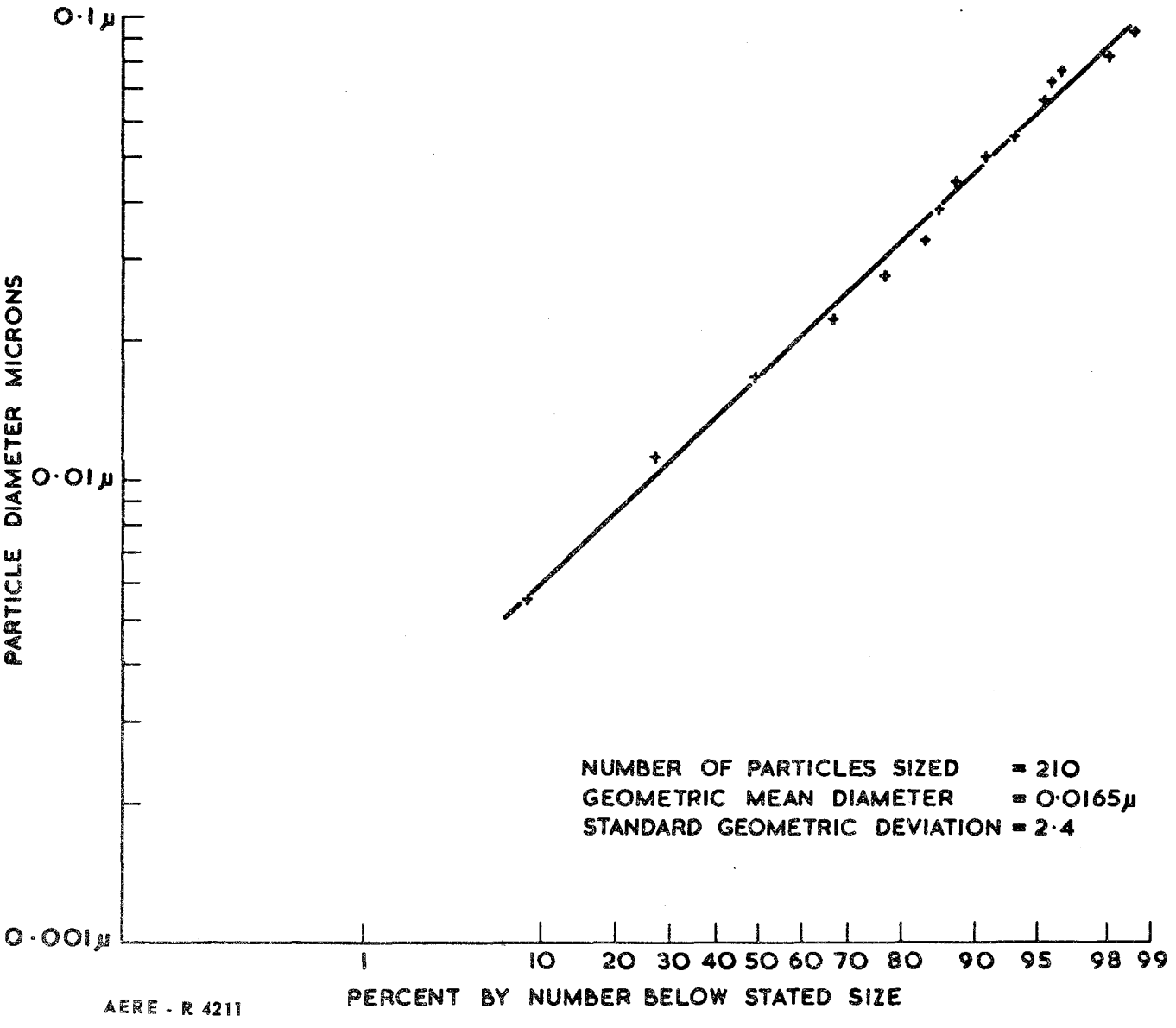


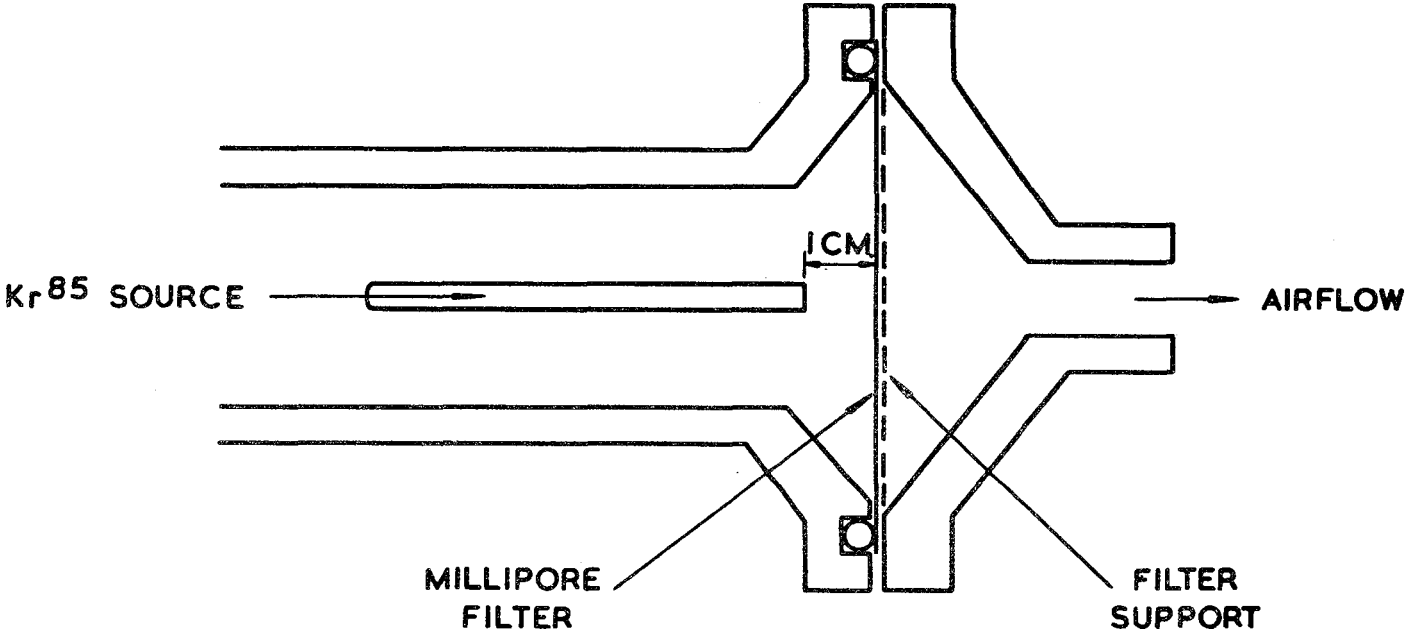
FIG. 5. PARTICLE SIZE DISTRIBUTION OF TUNGSTEN AEROSOL

TABLE III

Tests with radioactive tungsten aerosol

Date of Test	Type of Filter	Face Velocity cm sec^{-1}	Pressure drop cmHg	Mean Diameter (microns) by diffusion box	Particle Concentration cm^{-3} measured with Pollak counter		Radioactivity of Filters d.p.m.		Relative Humidity %	Duration of Test mins.
					Upstream of Test Filter	Downstream of Test Filter	Test Filter	Backing Filter*		
28/8/62	AA Millipore	40	10.8	0.010	8.4×10^4	0	7.4×10^4	0 ± 1	15-20	40
31/8/62	"	40	11.4	0.017	2.7×10^4	0	7.1×10^3	0 ± 0.7	15	60
6/9/62	"	40	12.1	0.020	8.1×10^4	0	1.8×10^7	0 ± 0.9	15-20	100
14/9/62	"	40	12.0	0.017	4.4×10^4	0	1.04×10^5	0 ± 0.5	75	140
20/9/62	"	40	12.0	0.008	2.18×10^5	0	1.58×10^5	0 ± 1.0	15-20	120
21/9/62	"	40	12.1	-	-	-	6.8×10^4	0 ± 0.4	90	70
24/9/62	"	40	12.0	0.008	2.06×10^5	0	7.8×10^4	0 ± 0.5	96-98	300
25/9/62	"	40	11.5	0.009	2.38×10^5	0(10 tests)	-	-	98	60
25/9/62	"	40	11.5	0.020	7.2×10^4	0(10 tests)	-	-	98	60

* The limit of accuracy quoted is one standard deviation.



AERE - R 4211

FIG. 6. ARRANGEMENT FOR IRRADIATION OF MILLIPORE FILTER

TABLE IV

Tests on irradiated filter using radioactive tungsten aerosol

Date of Test	Type of Filter	Face Velocity cm sec^{-1}	Pressure drop cmHg	Mean Diameter (microns) by Diffusion box	Particle Concentration cm^{-3} measured with Pollak counter		Radioactivity of Filters d.p.m.		Relative Humidity %	Duration of Test Mins.
					Upstream of Test Filter	Downstream of Test Filter	Test Filter	Backing Filter		
3/10/62	Millipore AA	40	11.5	0.020	3.1×10^4	0(5 tests)	-	-	20	20
4/10/62	"	40	11.2	0.010	1.6×10^5	0(3 tests)	3.28×10^5	0	98	25
4/10/62	G.F.A.	40	3.1	0.010	1.6×10^5	140 (2 tests)			98	
4/10/62	G.F.A.	40	3.1	0.017	2.16×10^4	80			98	

3. Discussion of results

The results given above show clearly that there is no appreciable penetration of type AA millipore filter by particles of diameter 0.02 microns at a face velocity of 40 cm sec^{-1}. These are the conditions for which Fitzgerald and Detwiler (1957) report penetrations of 50-100 per cent. The possibility that the disagreement is due to differences in the humidity of the gas or removal of the electrostatic charge on the filters in one or other of the experiments has been eliminated by tests with air at a relative humidity of 98-100 per cent and by removal of the electrostatic charge on the filter by irradiating it by electrons from a Krypton-85 source. No penetration of the filter was detected in either case. Fitzgerald and Detwiler collected the particles passing the test filter on a second millipore (type HA) filter, made a silica replica of this filter and evaluated it with an electron microscope. They do not give examples of the electron microphotographs in their 1957 paper. Examples are however given in an earlier (1955) paper in which millipore filters were used to evaluate other types of filter. In these photographs the unexposed (control) millipore filter is quite different in appearance from both the test filter and the downstream filter and in addition, even allowing for losses in reproduction the analysis of the photographs would appear to be difficult. It is noteworthy that Borasky and Mastel (1956) in a comparison of methods of sampling for electron microscopy conclude that the silica replication technique is the least reliable of the methods they considered.

The efficiency of the membrane filter can be estimated on theoretical grounds if the following assumptions are made:-

(1) the pores in the filter material are cylindrical holes in the direction of flow,

(2) retention of particles occurs only by diffusion of particles to the walls of the pores,

(3) particles are not re-entrained after deposition.

Then, by the equation for diffusion in a circular tube given by Fuchs (1955), we have,

$$\frac{n}{n_o} = 0.82\ e^{-3.66\mu} + 0.097\ e^{-22.2\mu} + 0.0135\ e^{-53\mu}$$

where $\mu = \frac{Dx}{R^2 \bar{u}}$ and $\frac{n}{n_o}$ is the fraction of particles of diffusion coefficient D penetrating a tube of radius R and length x at a velocity of $\bar{u}$. This equation is very similar to Gormley and Kennedy's (1948) form of Townsend's (1899) equation which has been shown by Chamberlain and Dyson (1956) to describe accurately the diffusion of thorium B atoms to the walls of a cylindrical tube.

By applying the equation the fraction of incident particles penetrating a given thickness of filter can be calculated and this has been done for a selection of particle sizes in Table V.

TABLE V

Calculated penetration of type AA millipore filter assuming that retention of particles is by diffusion to pore walls only

(a) penetration to a depth of 10 microns
(b) penetration of whole filter (150 microns)

Particle diameter microns	Diffusion constant $cm^2\ sec^{-1}$	Face Velocity $cm\ sec^{-1}$	Velocity in filter pores* $cm\ sec^{-1}$	Percentage penetration	
				(a) to depth of 10 microns	(b) of whole filter (150 microns)
0.005	1.9×10^{-3}	40	50	-	-
0.01	5×10^{-4}			1.0×10^{-8}	-
0.02	1.3×10^{-4}			0.21	-
0.03	6.6×10^{-5}			4.0	-
0.04	3.5×10^{-5}			16.5	1.24×10^{-10}
0.05	2.75×10^{-5}			28.6	1.35×10^{-6}
0.06	1.65×10^{-5}			39.6	2.24×10^{-4}
0.08	1×10^{-5}			52.3	0.034
0.10	6.7×10^{-6}			61.8	0.45

*estimated from face velocity assuming a porosity of 80%.

It is apparent from Table V that, neglecting other modes of filtration, diffusion to the pore walls would ensure a one hundred per-cent efficiency of the filter up to a particle diameter at least of 0.05 microns and would also account in this size range, for the observed fact (e.g. Kubie, Jech and Spurny, 1961) that membrane filters retain all particles in a very shallow surface layer.

The experimental results have also confirmed that in the size around 0.02 microns diameter the filtration efficiency of membrane filters is not dependent on any electrostatic effect. As the particle size increases retention by diffusion to the pore walls becomes less effective and at a particle diameter of 0.4 microns penetration of the filter would be about 70 per cent if diffusion was the sole mechanism of filtration. As the particle size increases however, filtration by impaction in the filter pores, which are in reality probably rather tortuous, becomes increasingly important. Additional tests with a methylene blue aerosol also showed no detectable penetration when the

filter was irradiated. The geometric mean diameter of this aerosol was about 0.05 microns, but two per cent of the concentration of 10^6 particles cm^{-3} were greater than 0.4 microns in diameter. It is apparent that in this size range also the filtration efficiency of the millipore filter does not depend on electrostatic forces.

References

1. Borasky, R. and Mastel, B. (1956). Electron microscopy of magnesium oxide particles collected on membrane filters. HW-46122.

2. Chamberlain, A.C. and Dyson, E.D. (1956). The dose to the trachea and bronchi from the decay products of radon and thoron. Brit. J. Radiology, 24, 342, pp.317-325.

3. Fitzgerald, J.J. and Detwiler, C.G. (1955). Collection efficiency of air cleaning and air sampling filter media. K.A.P.L. 1463.

4. Fitzgerald, J.J. and Detwiler, C.G. (1957). Optimum particle size for penetration through the millipore filter. AMA Arch. Ind. Health, 15, 3-8.

5. Fuchs, N.A. (1955). The Mechanics of Aerosols, Moscow.

6. Gormley, P.G. and Kennedy, M. (1948). Proc. R. Irish. Acad. 52, 163.

7. Kubie, G., Jech, C., and Spurny, K. (1961). Filter penetration by aerosol particles. Collection Czechoslov. Chem. Commun. 26, 1065-1071.

8. Metnieks, A.L. and Pollak, L.A. (1959). Inst. Adv. Studies Dublin. Geophysical Bulletin No.16.

9. Nolan, J.J. and Guerrini, V.H. (1935). Proc. R. Irish Acad. 43A, 5-24.

10. Spurny, K. and Polydorova, M. (1961). Collection Czechoslov. Chem. Commun. 26, 921-931.

11. Townsend, J.S. (1899). Phil. Trans. A 193, 129.

DISCUSSION AND COMMENT

Session Chairman: Perhaps we had better discuss Mr. Megaw's presentation at this moment.

HACL Comment: We have a filter in this country that was charged by passing air through it. It had polyvinyl rubber fibers. We had some tests with this as to discharge, and so on. We have measured the Millipores, as you know, in a Faraday cage and have found a fair net charge on them. But, if you take off the charge you do not see any difference in performance. So, I think your conclusions are correct. I was not familiar with the K. Spurny reference. I do not know how recent that is.

Comment: The Spurny work was all done in the past year.

Question: If these results were obtained from the AA filters, what would you expect with HA?

Comment: Well, they have that much smaller pore size, so I think they must be that much better. I think someone has shown recently that people tend to use Millipore filters that are far too good for what they want. Quite often you can get very good performance with a filter with perhaps a 3 or 4 micron pore size, with consequent saving in pressure drop.

I don't suppose it is worth mentioning, but I cheated a little bit in that we once actually did find some penetration through a Millipore filter. This was when we were trying to use it to get a narrow cut of particle size, to get an almost homogeneous aerosol of about one or two microns. Technically, if you want to do it, you light a cigarette and hold it quite close to the paper. We did get some penetration, but we certainly ascribe this penetration to constant condensation from gaseous material in the cigarette smoke after it has passed through the filter because of the tremendous pressure drop there.

Question: Do you suppose the Fitzgerald and Detwiler discrepancy here, which is a rather major one, is attributable to the holder of the filter papers and that this is really a leakage around the seams?

Comment: That might be so. I have been discussing this by letter with Fitzgerald for the last two years. I am going up to see him next week and talk to him. Perhaps only one of us will come away from there, I don't know.

Session Chairman: Thank you, Mr. Megaw.

Mr. Brion of the French Atomic Energy Commission will give the next paper after a very short break, the title of which is "Filter Efficiency and Clogging."

FILTER EFFICIENCY AND CLOGGING

J. Pradel, F. Billard, G. Madelaine and J. Brion

Service de Controle des Radiations et de Génie Radioactif
Centre d'Etudes Nucléaires de
Fontenay-aux-Roses (Seine)-FRANCE-

ABSTRACT

It is generally admitted that filter efficiency increases with clogging. Experiments, conducted with three kinds of aerosol show that efficiency may decrease with clogging, especially when filtering oily aerosols.

INTRODUCTION

When working, an air filter undergoes alterations. The most noticeable effect is the resistance increase which is often given to point out clogging. Efficiency is generally considered as unaffected or improved by clogging.

In order to precise that point, we have undertaken some experiments which are described in this paper.

TEST RIG

A spherical chamber - see fig. 1 - contains a test aerosol. Two filter holders, one with a clogged sample, the other with a new one, are connected to the chamber. Air is drawn through each filter, alternately, by the circulating pump of a particle counter.

TEST AEROSOLS

Three kinds of aerosol have been used:

A. smoke generated by a smoke-producer called "smoking rope."
B. local atmospheric aerosol.
C. smoke generated by a smoke-producer called "milk sugar smoke-producer."

Photomicrographs of aerosol A and C are given fig. 2 and fig. 3, respectively. Aerosol A appears as structureless particles - when ignited, the "smoking rope" produces tars which look like oils on a filter -. On the opposite, aerosol C consists of cubic crystals of ClK.

Measured with the "Royco" particle counter, aerosols A, B and C appear with a maximum number of 0.3-0.4 micron diameter particles and a major particle diameter of 1.2 micron.

FILTER SAMPLES

Most experiments have been made with alfa paper filter, giving 3 per cent methylene blue penetration. Few other experiments with another filter, giving 25 per cent methylene blue penetration, have led to similar results.

Effective area of samples was four square centimeters - 0.62 sq. in.

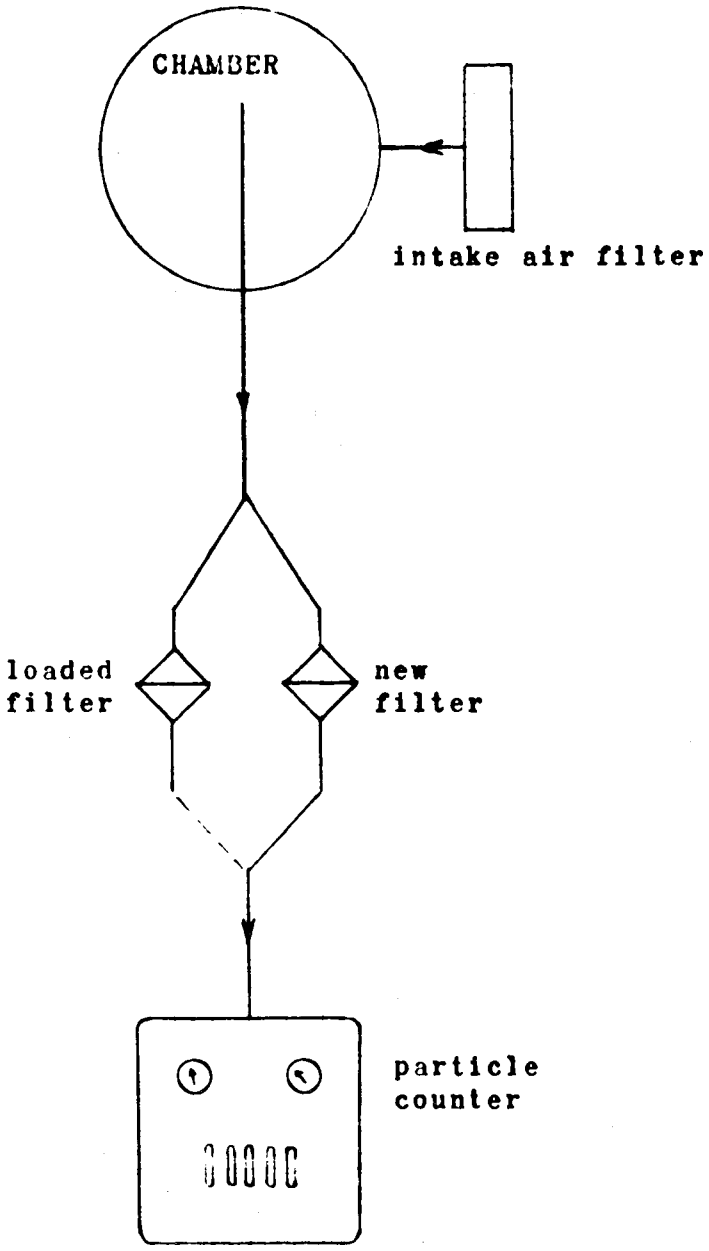


Fig. 1 - TEST RIG DIAGRAM

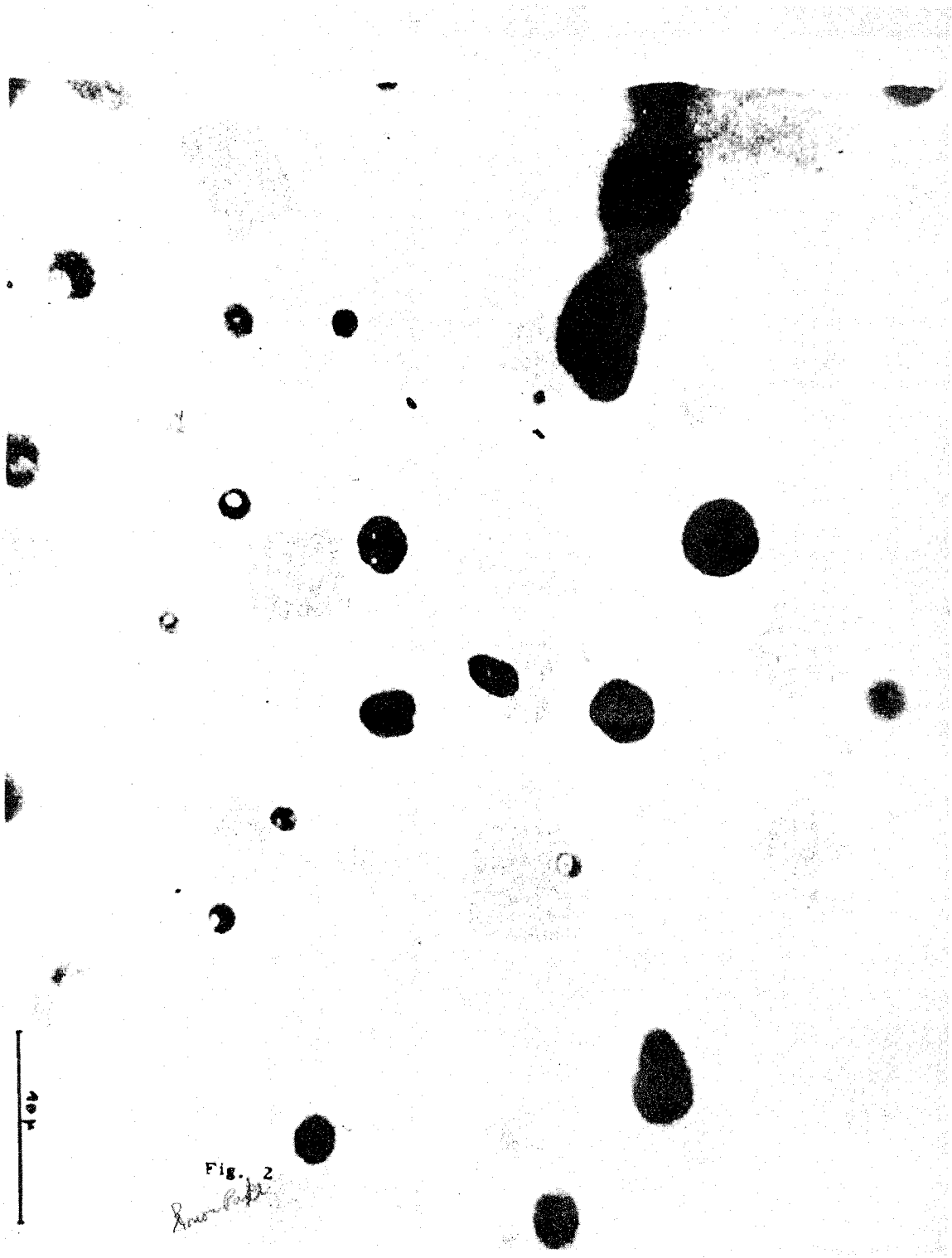


Figure 2

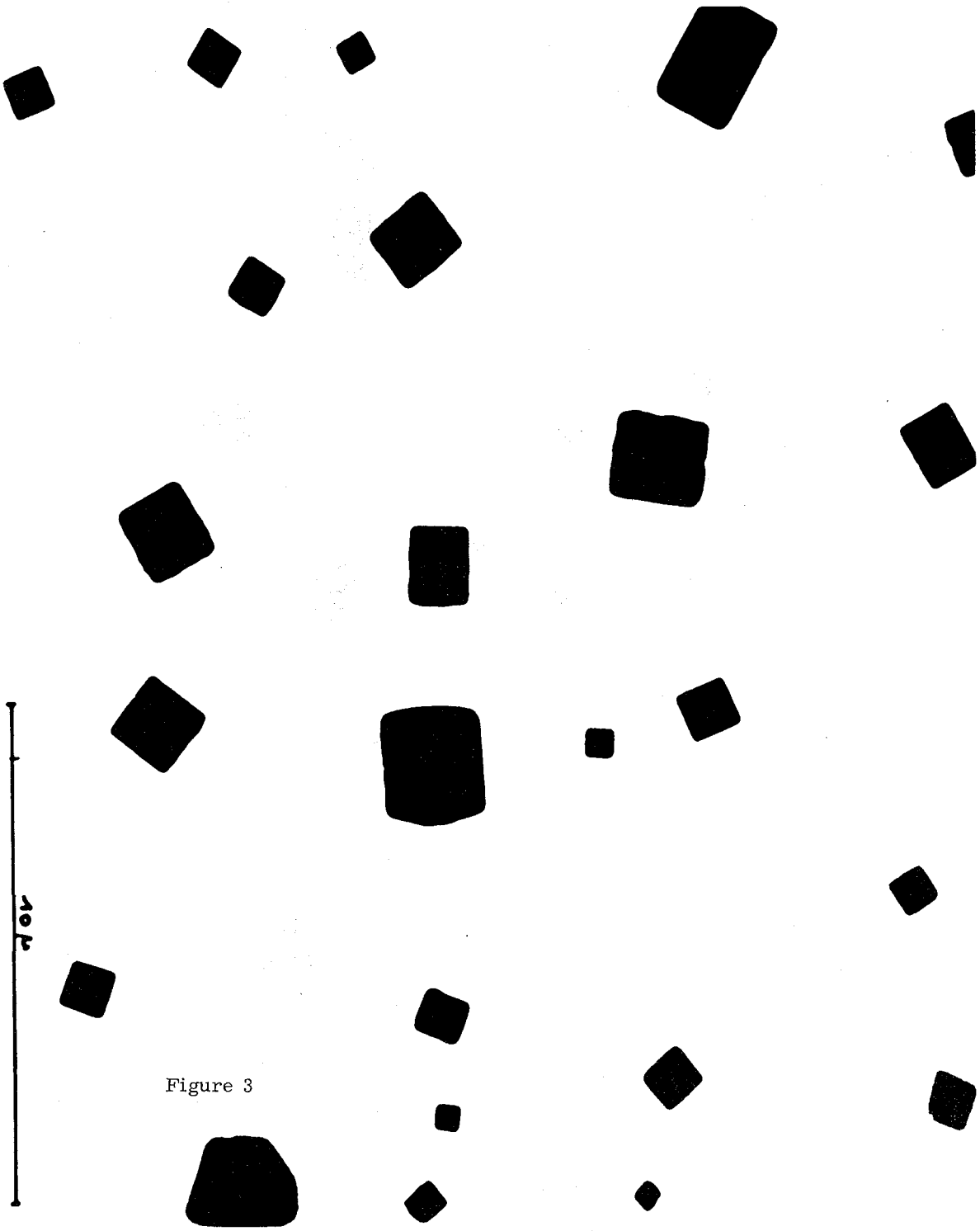


Figure 3

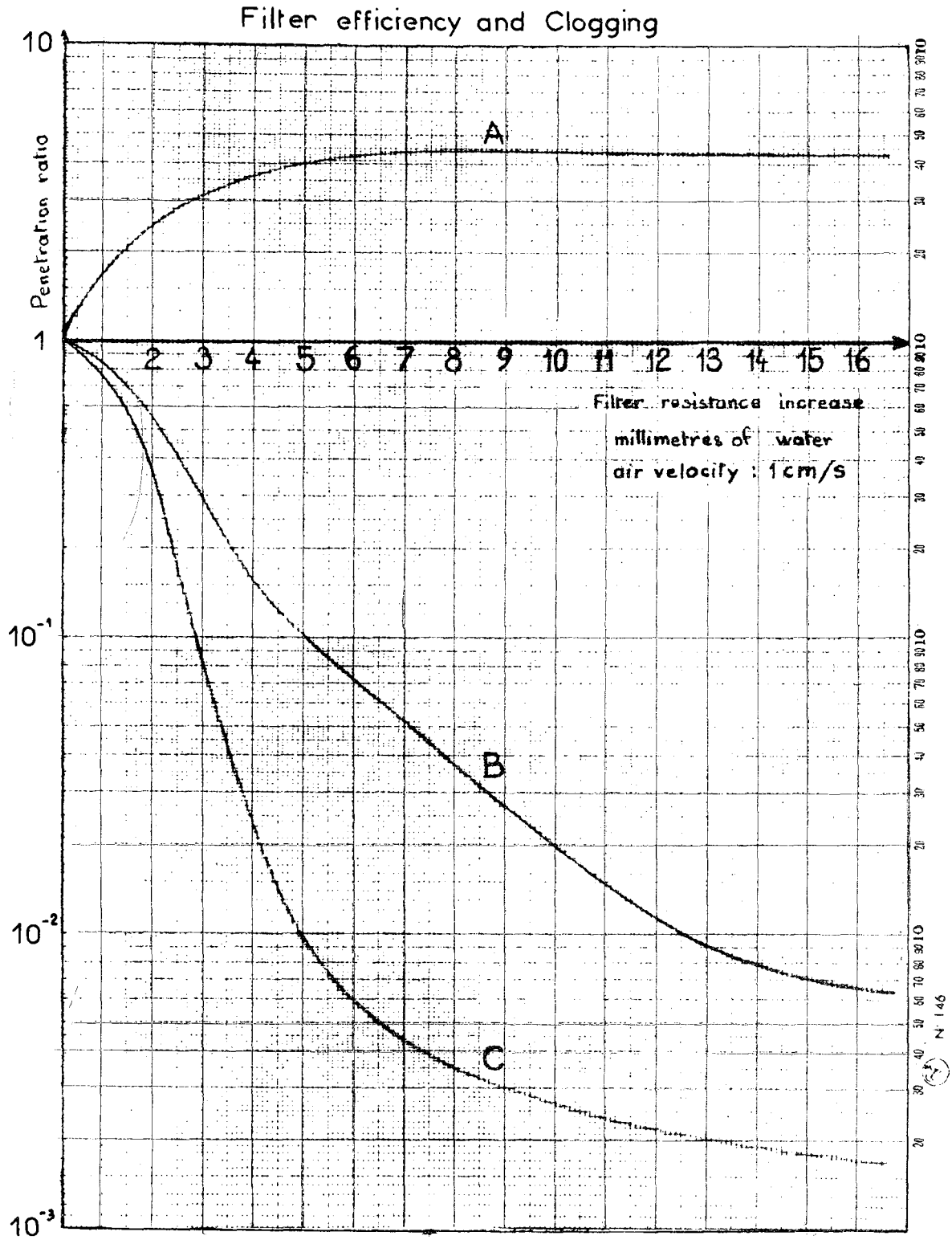

Filter efficiency and Clogging
Penetration ratio
10
1
10^{-1}
10^{-2}
10^{-3}
A
B
C
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Filter resistance increase
millimetres of water
air velocity : 1 cm/s
N° 146

Figure 4

EXPERIMENTS

Filter samples have been loaded up to different rates with the various aerosols. Loading was achieved with an air velocity of fifty centimeters per second - 100 Feet/min.

Penetration tests have been carried out with aerosol A in the chamber, and few checking tests with aerosol C have given similar results.

The particle counter was alternately connected to the new filter sample and to the loaded one. It counted the particles coming through the filters, within the size range 0.3 - 1 micron.

Air velocity was one centimeter per second - 2 feet/min. - which is the normal value for these filters.

RESULTS

Fig. 4 curves show the connection between efficiency, expressed by the ratio of the loaded filter penetration and the new filter penetration, and clogging, pointed out by the resistance increase in millimeters of water - 0.04 inch of water.

One can see that clogging with aerosols B and C increase efficiency up to one hundred times and more, whereas clogging with aerosol A decrease efficiency down to three or four times.

CONCLUSION

On the opposite of most dusts, some aerosols may lower filtration efficiency when loading filters. It seems that filter structure is damaged by a physical and/or a chemical action produced from tarry or oily aerosols. It might be of interest to know whether DOP aerosol, used for filter tests, is able of such an action.

DISCUSSION AND COMMENT

Comment: If you have any questions, I would advise you to speak slowly, or, if there is someone who is able to translate, I should be very glad to answer.

Session Chairman: We will withhold any questions, for now.

I have been informed that we have with us Mr. Wim Walrave of the Netherlands who may have a paper to present or may want to discuss off-the-cuff what they are doing in his country. Is this the case?

Comment: It is not the case. Thank you

Session Chairman: In which case, we will then ask if there are any questions on the three papers which have been presented?

Comment: I might mention that the Department of Agriculture in Maryland, has been studying decontamination of farmland and has been using some techniques that we might want to look into.

Session Chairman: If there are no other questions, this is not quite the end of Session VII. We have a movie Dr. Silverman will narrate entitled, "High Expansion Foam Test." He might want to say a few words about that.

COMMENTS BY DR. SILVERMAN: I hope you haven't been waiting with bated breath for this movie, because it is an attempt to answer some questions that were raised when we proposed the foam technique for containment studies. Of course, some of the more skeptical architects and engineers asked, "Well, how high can you push a column of foam?"

We said, "With a 1000-to-1 ratio, we ought to push it almost as high as a column of air." Well, it turns out that if you want to prove this, you have to go through with what I might say is valid experimental proof. So, we looked for a facility where we could perform the experiment. Thanks to the Atomic Energy Commission's decision to drop the EOCR, we found a building at Idaho in the Central Facilities area, and were able to get the Safety Group at the Idaho Operations, who had a High-X foam generator on a truck, to run this series of tests for us.

This test followed Murphy's Law, I'm sorry to say, because one of the things that happened was that we told them we would like to have them put a stabilizer in the foam. This was fine. They would be glad to do it, and the company shipped out the stabilizer without the solvent, so it had lumps in it and we got a wet foam.

It wasn't too bad. The tower you will see here in the film is about 72 feet high and the major part of the cross-section is about 19 feet by 16 feet. The volume is about 30,000 cubic feet, and it should have taken three minutes to fill the tower. Instead, it took twenty minutes to reach the 51-foot level, and then the fan, which only has a static of three inches, began to overload.

We are indebted to Mr. Richard Beers of the Idaho Safety Group for running this test, and since you might find the movie a little monotonous, so I have asked them to run it at sound speed even though it was taken at silent speed.

ROUND TABLE SESSIONS

General Chairman - D. C. Costello

GENERAL CHAIRMAN: Good morning, gentlemen. We are starting our round-table discussions this morning to add a little flavor to the Conference. We have finished our formal presentations. We would like to announce that the sessions will be conducted in a very informal manner.

We have received a tremendous response to the notices sent to your offices asking for questions. We tried to group answers to the questions into certain subject areas; there are probably some that will not be answered.

Each of the round-table chairman has organized his own session and there may be no uniformity in the pattern in which each is conducted; in general, I believe they will be well organized.

We want to have all participants feel free to ask questions; break in at any time and keep lively discussions going throughout the day.

You might also think about that part of the program at the conclusion of the round-table discussion. We want to discuss where to hold the next Conference. You might like to suggest how we organize the next Conference. Any other suggestions you want to pass on to Mr. Belter and Dr. Silverman will be appreciated.

PANEL A - ROUND TABLE SESSION
Thursday Morning, 24 October 1963

IN-PLACE FILTER TESTING

PANEL CHAIRMAN: The panel members for Panel A, In-Place Filter Testing, are:

R. W. Schneider, ORNL, Chairman
E. C. Parrish, ORNL
J. A. Young, NRL
J. J. Croley, SRP
F. E. Adley, HAPO
J. W. Thomas, HASL

We have heard a lot about the ability of high efficiency filters to remove particulate matter efficiently and effectively in the micron and submicron range. Filter systems can be highly efficient if the systems are properly constructed and the filters are properly installed.

As users, we must remember that we often put our knees, fingers, toes, and maybe other items, through the filter media. If we do not go to this trouble, we install the filters improperly. Or, if we install the filters properly, we have another problem with continuous leakage through the filter housing itself. In other words, the proof of the pudding is to run an in-place filter efficiency test after the operational filters are in place.

All of the quality-control procedures from the start of manufacture of the high-efficiency filter through the Quality Assurance Stations are extremely important, but today most of us stop at this point; actually, we have stopped one step short of doing the job right, and that is the in-place test. We cannot be assured that we have an efficient system unless the system is tested in situ with the high-efficiency filters in place. We can take all the precautions that we wish, but if we do not determine the efficiency of the system, we do not know what it is.

I am not trying to say that the system must be as efficient as the individual filters, because in some cases we can tolerate less efficiency; but the fact is that if the systems are not tested, we do not know what we have.

For the record, so that you will have reference material, there are two reports which cover a good portion of in-place testing: NRL Report 5929, "Studies of Portable Air-Operated Aerosol Generators," by W. H. Echols and J. A. Young; and, ORNL Report 3442, "Tests of High-Efficiency Filters and Filter Installations at ORNL," by E. C. Parrish and R. W. Schneider. The Proceedings of the 7th Air Cleaning Conference, TID-7627, has several excellent references. The last is USAEC Report TID-7023, "Inspection, Storage, Handling and Installation of High-Efficiency Particulate Air Filter Units," by H. Gilbert and J. H. Palmer.

Before we ask for questions, I have requested each panel member to take a few minutes to discuss a phase of filter testing, in-place testing, or other topics relative to the title of this panel session.

NRL PANELIST: I want to take just a few minutes to mention two studies which have been accomplished in the last two years ar NRL. The first has already been mentioned, and that is the study of portable air-operated aerosol generators. These units have found wide use for in-place testing.

The other study is that which we have just completed; the report is not yet available. On the shock and vibration characteristics of high-efficiency filters, we had each of the three manufacturers of filters in this country prepare for us, under careful control using paper supplied by the Navy, a number of filters. Each of these filters were evaluated as to efficiency and resistance characteristics. These were then subjected to the Navy standard shock and vibration tests. The objective of this study was to determine if the filters, as they were being produced, and as they were being produced in the finest quality, could withstand standard Navy shock tests, which evaluate the proposed use in environment aboard ship.

Each of the filters successfully passed the vibration tests, a series of tests in which a filter is subjected to an increasing frequency in amplitude in a very regulated and standard pattern. The filters were evaluated as to efficiency and resistance before and after this series of vibration environmental tests, and then the filters were subjected to the shock tests. The filters were subjected to an increasing repetitive blow on the frame which houses the filters, not the filter itself, and it was found that all the filters passed the vibration environmental tests. None of the filters were able to pass the shock test. This report should be available in a matter of a few months for your evaluation.

Of course, since the 7th Conference we have been continuing our studies of the methods and techniques for in-place filter evaluations. I want to point out, however, that there is much more than merely measuring the filter efficiency. One must also be aware of other problems of air balancing, air-flow distribution, pressurization, and the whole endeavor which we prefer to call the system evaluation. The in-place testing is a part of this overall system evaluation.

ORNL PANELIST: We feel we have come a long way since the Seventh AEC Air-Cleaning Conference. At that time we had tested only one or two systems in situ, and today at ORNL we have tested about 2,000 systems in place.

The test of filter systems in situ is not difficult. The procedure used by ORNL consists in discharging an aerosol produced by atomizing liquid DOP with compressed air into a convenient air intake ahead of the filter bank. The concentration of the unfiltered smoke is measured by drawing a sample from the duct ahead of the filter bank and passing it through a forward light scattering photometer. The concentration of the filtered aerosol is then measured from a sample withdrawn downstream of the filter. The filtration efficiency of the system is calculated from the two concentration values. In general, the in-place test is conducted according to this procedure, but in a few instances it has been necessary to modify the basic techniques to circumvent physical limitations imposed by the particular installation.

Several slides will now be shown.* The first shows the removal of an upstream sample during an in-place test. The downstream sample will be withdrawn from the pump discharge, so that we will be sure to have a well-mixed, representative sample.

When an in-place test shows that the efficiency of the system is unsatisfactory, the source of the leakage can be found by probing the downstream side of the filter bank. Leaks are indicated by the erratic behavior of the needle on the amplifier when the probe picks up unfiltered aerosol particles.

The results of the first in situ tests of the 486 different systems will be shown by the next slide. It seems reasonable to expect that the filters serving chemical laboratory hood exhausts might have lower first-test efficiencies than systems handling air that was essentially free of chemical vapors, and the two categories were inspected accordingly. It appeared, on the average, that small systems containing one or two high-efficiency filters should give a higher first-test efficiency than systems with a greater number of filters, so Category 2 has been subdivided to show this trend. Only installations containing one or two filters are tabulated in Category 1, since very few of our systems serving laboratory hoods exclusively contain more than two filters. The term "first-test" is intended to mean the first in situ test of a particular system, and bears no relation to the age of the installation, or the length of time the filters were in service prior to the test.

On the basis of the tests, and experience in general, we can draw some conclusions. It is relatively easy to achieve acceptable system efficiencies in small single- and double-filter installations. No significant difference is apparent between the Categories 1 and 2. High efficiency is more difficult to achieve in the larger systems. Only 31% of the systems containing 3 filters or more ran an efficiency of 99.97% or better on the first test, as compared with about 76% for the smaller installations.

In a few instances low efficiencies were found to be the result of corrosive attack of the media. In one such case the system efficiency was 2%. In general, however, efficiencies less than 99.97% were attributed to faulty installation of the filters, damage to the filter media during installation, gasket leakage due to inadequate compression, and inadequacies in the filter housing and filter mounting frames.

New systems of all sizes have a reasonably good chance of passing a pre-operational in situ test if close attention is given to details of design and construction, and if the filters are properly installed. Two new systems of 30,000 and 80,000 cfm showed efficiencies of better than 99.97% on the first

* Illustrations not available

tests, and on two subsequent tests, without the need for remedial measures.

We found that most existing systems can be tested in situ, but the task is usually easier, and more economical, when new installations are designed for, and existing systems are modified to facilitate in-place testing. Our experience at ORNL indicates that in-place testing is a convenient and reliable tool for verifying the adequacy of systems and for locating sources of leakage, yet the cost represents a very small fraction of the cost of the building.

HASL PANELIST: I would like to make a few remarks on the significance of the pinhole effect, as far as in-place testing is concerned. One of the most important things that one should bear in mind is that filters may give a low efficiency at low flow rates than when tested at the rated flow. Perhaps some maintenance man would get the idea if you are operating below capacity, a filter may last longer and work better, but this is not necessarily true, and this should be looked out for.

Particle size is not so important in in-place testing as it is in evaluation of filter materials, which follows from the fact that if one had leaks, then the penetration is a strong function of particle size. To emphasize this point I would like to show one of my previous slides, which you have already seen, Number 6. You notice those two curves at the bottom are for two different aerosols with no pinholes, and the two curves at the top are for the two different aerosols with pinhole. If one curve is subtracted from the other, the small aerosol curve on the top with the pinhole, and the small aerosol curve on the bottom, effect of the pinhole can be determined. Doing the same thing for the bottom curve, the differences are going to be nearly the same; this is experimental evidence that it does not make too much difference on the particle size, as far as the penetration to a pinhole filter is concerned. This is important in in-place testing.

Some have raised the question that we test on 0.3 micron smoke from a thermal generator but use the air-operated generator on in-place testing. These results seem to indicate that use of air-operated generators is not as bad as some might think; we are happy to note this, because it would be next to impossible to try to use a thermal generator for in-place testing.

SRP PANELIST: Our containment vessels were shown yesterday. Two things, I think, stood out with our testing. One, we were very much surprised at the number of rejected filters we obtained. We just completed one round of reactor testing. Out of the first two banks in the first reactor we rejected approximately 32 filters, which was rather astounding. This continued through the third bank at the same ratio. We talked with our maintenance people, and things improved considerably.

The other thing I think interesting about it was the rate of pluggage of our filters. We have not installed the pre-filters in the vessels yet. In filters that have been in service for as much as eight to eighteen months we are getting Δ P's across the bank of up to 4 inches; the rated flow is around 0.9 to 1. So, we are running into some problems in that respect. Our manner of testing, of course, is the customary one. I don't think I need to go into any detail there.

HAPO PANELIST: Before I touch on nuclei counting, I would like to get into one other possible method of evaluating filters. I might mention that our particular group at Hanford is not in the routine in-place testing program; my remarks are more or less on some work we have done in our own interests and on a call-in basis for special, particular jobs.

I would like to touch on some of the HASL remarks about the pinholing effect. The first slide shows what we found with respect to single specimens on which we were able to run tests on air flow in the device, and, without removing it, adding a 1/8" hole to the paper. Curve A is essentially the filter in its original condition; curve B, after we added the 1/8" hole. We subtracted the two to obtain curve C. The calculation was simply an orifice calculation.

The next slide is the same thing on an expanded scale. We took a 1,000 cfm filter, and using the standard E-18 DOP Tester were able to show these effects. The bottom curve is essentially a good filter with a penetration rating of .01% at a rated airflow of 1,000 cfm. As the capacity drops, the penetration also reduces. After this, we added two 1/8" holes to this filter, consecutively. The first hole produced the middle pair of curves resulting in an inverse relationship between airflow and penetration. The first pair of curves in the center of the slide represents the holes in the upstream and downstream positions; the larger or higher penetration occurring when the hole was in the downstream position indicating, possibly, that the orifice flow on the discharge side was not interferred with by separators. The top pair of curves is essentially the same thing, with two 1/8" holes in the filter essentially in the same position.

The next slide was based on a similar type of test, with a selection from filters which we happened to have at the testing station. Those filters had roughly .01% penetration and showed an inverse relationship, similar to those experienced with the hole added to the filter.

The curves above .01% penetration essentially indicate that, probably in some cases and certainly in others, a defect in the one with the hole, while the other filters appear to be of good integrity.

To me, condensation nuclei counter is a rather new instrument. People have been working with the instrument or the principle for quite some years, but our engineering laboratory in Schenectady developed a prototype earlier this year which was made available. I was interested to see what this would do in the way of evaluating a filter's performance. I was largely interested because it is so sensitive that it will read from ten to several hundred thousand nuclei per cc.

The instrument weighs a little less than 200 pounds and is portable or mobile. I found that functionally it was a real good instrument.

We performed tests with 1,000 cfm filters and compared with them the DOP results, finding there was no good quantitative relationship, which was rather disappointing. More work is required to determine the relationship. Roughly, it appears that the penetration was about 0.1 of that found by DOP. We ran a series of filters and found out that the results varied roughly in that proportion.

In addition to the single filter test, we applied it to a bank of filters handling about 1,000 cfm. To deal with nuclei we fed a sodium chloride mist from the regular atomizing or aspirating type generators, and put the sodium chloride mist into the gas feed with an acetylene torch where it was essentially burned inside the acetylene flame; this is a simple and easy generator to devise and it worked very well.

In a system with 100,000 cfm capacity, we could maintain a nuclei count of about 1.25 million nuclei per cc on the upstream side.

We were able to run a series of eight tests on this particular bank, and we did not know the exact condition of the bank at the time, but the tests

ranged from 0.08% penetration to 0.2% penetration, with an average of about 0.12%. Applying 0.1 velocity relation between DOP and nuclei, I would say that this particular bank had a penetration of 0.12%. Whether this is right or not, I don't know, but based on Parrish's earlier presentation, 0.8% of his results fell within this group; it is reasonable to expect that this could have been operating somewhere in that range.

We have used uranine for special tests on custom made, high-efficiency filters at Hanford. We find uranine to be a good test method. It is simple; it is inexpensive, very sensitive, and testing can be accomplished with the class of instruments found usually in most laboratories.

PANEL CHAIRMAN: We are now going to declare the session open for informal discussion. Any question pertinent to the subject of in-place testing or the testing of individual filters is fair play. In addition, one panel member can question another panel member; or, if we get a question from the floor and I ask one of the panelists to answer, if any of the other panel members object or has a different idea or a different interpretation, by all means he is obligated to speak up.

QUESTION: When generating a heterogeneous aerosol, as with a portable NRL generator, what efficiency are you really measuring? Is this a count efficiency, or is this a mass efficiency, or surface area efficiency? If two experimenters use the generator, both with the same diameter, but one with a sigma of about 1.2 and one with a sigma of close to 3, will they get identical results if they test it on the same filter?

NRL PANELIST: First, what you are actually measuring during an in-place test are the deficiencies in the filter. If one takes a piece of filter paper with a holder that one knows has absolute integrity, and measures the difference in penetration between, say a 0.3 micron of a heterogeneous aerosol and one of these aerosols which has a light scattering mean diameter on the order of 0.8 or count mean diameter on the order of 0.3 or 0.4, one does obtain a difference in penetration. When this is done on a large scale with a filter with some 200 sq. ft. of total surface, then one finds that the penetrations may be of the same order of magnitude, and often are. This is not because of the difference in penetration through the paper, but because of the penetration through the holes or leaks. It is not dependent upon the size of the aerosol particle. Does this answer your question?

QUESTION: That answers the second part, but I just wonder what kind of efficiency we are measuring, whether it's just a relative number?

NRL PANELIST: You have a relative number. This depends upon the light scattering chamber. This is what you are using to detect the particle concentration.

ORNL PANELIST: We have a number of different generators of the same construction at ORNL and we use them interchangeably and we can duplicate our results very well.

QUESTION: I would like to find out the recommended treatments for in-place testing of filters.

ORNL PANELIST: The frequency with which filters need to be tested is something that everybody will have to settle for individually. We have systems that are on a frequency of once every six months. We have others that are on a frequency of once every three months, and we occasionally have systems that are tested once a month, and we've had occasions with systems that were tested

once a week.

QUESTION: Has the nuclei counter test been used on large filter banks at HAPO?

HAPO PANELIST: No, except for this one test. Our results are limited. Naturally, we had the instrument on a short-term loan and did limited testing. We only used it on one bank which had been in for some years actually.

QUESTION: On the NRL vibration testing was the efficiency of the filter tested, or was this just a physical test?

NRL PANELIST: The efficiency of the filter was determined after each of the vibration studies; efficiency of resistance was determined before and after the vibration, and then before and after the shock studies.

ORNL COMMENT: With regard to the previous comments about efficiency, my opinion is that if penetration through filters is released, then you are measuring the number or per cent that gets through. Actually, if the penetration is 1%, then 1% of the aerosol particles get through if it is due to leaks through pinholes. But if the particles are going through a filter with selected removal of certain sizes, then all you are measuring is a light scattering of the aerosol coming out, and it does not represent a change in number concentrations.

HACL COMMENT: I would like to throw a little controversy into this discussion because I think the question of whether you should use a liquid or a solid aerosol doesn't seem to have been identified here as a problem, and I think the vibration test question which preceded would indicate that if you tested a DOP, which is a liquid aerosol and it soaks into the fibers, you couldn't see any effect of vibration on release of deposited material. I would for that reason, if for no other, lean towards a solid aerosol test, and I would like to hear some discussion on this subject.

NRL PANELIST: The shock and vibration tests were not designed to study fundamentally the effect on filtration, but the effect to the particle. We wanted to know if these filters could withstand the environment to which they would be subjected. We feel that a much more fundamental study is required to answer the latter question, and we are sure there would be a difference between liquid and solid aerosols. We used DOP simply because it was quick, easy, and convenient, and not for any other reason.

PANEL CHAIRMAN: I would like to add to that point. From the ORNL standpoint, we were faced with a problem of testing systems in-place, and these ranged anywhere from 25 cfm up to 200,000 cfm. We needed a method of generating enough smoke in order to get a reasonable upstream concentration, and this is one reason we went to the liquid aerosol or DOP. We have run thousands of filters through the rig, and we were testing the individual filter and not looking for leakage in the system. After running several thousand, we found that at rated flow we correlated with the Quality Assurance Stations at Edgewood and now at K-25. The correlation was excellent. So we felt that any number that we got was comparable to any number the Quality Assurance Station got. We were not particularly interested in fundamentals of particle physics, or anything else. We wanted to be able to duplicate the Assurance Station results so that our numbers would have the same meaning.

QUESTION: I would like to ask a question on the status of the filter problem and its testing with respect to national standards. Are there standards for testing and are there standards for the installation of filters?

PANEL CHAIRMAN: I know of no standard. Of course, for the testing of new filters by the Quality Assurance Station, there is a military standard. It is an excellent question and I suggest that it be brought up again.

QUESTION: In connection with use of an absolute filter what efficiency is the minimal acceptable? Would you say that a penetration of .01%, more or less, is satisfactory?

ORNL PANELIST: We cannot tell any operation how efficient to be. Our radiation safety and control people have a release which requires filter systems to be 99.95% efficient, or better, unless they can show cause why they should accept efficiencies that are lower than that.

HAPO PANELIST: We have at Hanford the equivalent of the Oak Ridge testing facility, and at times have filters coming through from the different sites, where the filters are going to be run at considerably different flow or capacities than the rated capacity.

You will recall the curves that were shown earlier; if a filter has a pinhole and is satisfactory at the rated airflow, and then operated at a different airflow, there could be penetration which is considerably different, or non-acceptable according to the AEC standards.

PANEL CHAIRMAN: Some of the systems at ORNL under construction will be handling contaminants. Filters for these have come from the Assurance Station for testing at the rated flow. We are checking those filters through at 100% of rated flow, and at 20% of rated flow looking for pinholes. We are finding a few. These are being sorted out and not being used for the particular facility.

A pinhole test was run yesterday or the day before on our rig and we found a particular filter that ran 99.962% efficiency at rated flow, and it was down to 99.62% at one-fifth rated flow, a significant drop. Of course, in this particular case the pinholes were artifically introduced, but this really makes no difference.

COMMENT: First, I would like to say how much I agree with Mr. Thomas on the fact that pinholes are not highly selective; and, as the velocity goes up, the penetration certainly goes down.

Secondly, we have found at CDEE after having put artificial pinholes in corners of filters, that the particulately laden air from these slow leaks have followed the flow line a long distance down the ducting. Depending upon where you sample, you can get factors of penetration varying by a fraction of 0.25. I would also like to know what mixing has been carried out in the ducting after the filter?

NRL PANELIST: We recognize this problem and attempt at all times to make sure that we have representative samples upstream and downstream. Depending on where the blower is we have found that the best way to get a good sample is to take a sample after the aerosol passes through the blower. The blower has low removal efficiency, but it does an excellent job in mixing. Another technique which we often use in our system, which is smaller than at ORNL, is to use manifold sampling techniques; but we are constantly aware of this difficulty.

NRL PANELIST: Have you done any filter evaluation with your salt technique, either with a portable rig or at another installation other than in a laboratory?

CDEE COMMENT: No. All we have done is to test the filters in the laboratory, and we have never done any <u>in situ</u> testing on big installations. We have

tested 1,000 cfm filters. We have also tested for leaks in the filter. What we haven't done is to test one of your 20,000 cfm units.

SRP PANELIST: I understand that ORNL has been testing large banks in situ, whereas SRP has only tested individual filters in each of these banks. Now how do you obtain representative sampling on a bank of 100 filters at 100,000 cfm?

ORNL PANELIST: Whenever we can, we go downstream of the blower. If we cannot do that, then we try to take enough samples at whatever point is available to assure that we are not missing leakage because of transportation or channeling.

PANEL CHAIRMAN: We do put in one other thing. When the probe is shoved into the duct, we move the probe around to try to cover a number of points in the duct and look for any erratic behavior of the amplifier. If the needle jumps, that is an indication that there is leakage and that you must look closer.

COMMENT: I was interested in what was said about use of nuclei counters in testing filters. This surely must be a function of the particle size of the aerosol you are using. Have you ever used a micron DOP smoke? I think you are still working on this. It certainly works on things wettable, such as polystyrene. If it does work with DOP, I think the results must be the same.

HAPO PANELIST: They may or may not be the same, but I agree with you 100% that more work is needed on this particular point. If it has not been explored, it should be.

The way we performed this particular test was to feed in the aerosol a considerable distance upstream from the filter bank, probably 100 feet. Assuming we obtained good mixing by the time the leak in our contamination concentration arrived at the filter bank, we sampled about 100 feet or so downstream from the bank. There is a relationship, I am sure, between the nuclei size, which can vary upwards from 0.001 microns to some substantially larger figure. I am sure it has some effect on penetration.

HAPO PANELIST: Were the Navy filters tested standard filters with rubber cement, or were they the glass-pack type?

NRL PANELIST: We actually did both to evaluate the standard construction, and to a degree the effect of the glass packing. In both cases, vibration was not the problem. The shock treatment was severe; in fact, it tended to blow the filter elements right out of the case. I was quite interested in the way the filters actually were damaged. I think it will be our conclusion that the only answer to making a filter of the type acceptable for the environments which we are considering would be to decrease the span; that is, to utilize perhaps a 1 x 1 filter and to improve the shock isolation techniques of installing the filter in the housing.

QUESTION: In what direction was the shock compared to the orientation of the filter?

NRL PANELIST: Actually it was at an askew angle, so that the filter was held in a position to achieve a certain intensity of blow calculated from each of the three directions following standard methods that have been developed over the last twenty-five years.

HAPO PANELIST: Did you find any appreciable difference or increase in the deterioration of the middle frame?

NRL PANELIST: No. Actually the range in which the filters failed were for

approximately the same severity of blow for all types of filters evaluated.

COMMENT: I am particularly interested in any techniques for large bank DOP testing or solid particle testing of particular filters when activated carbon beds are installed downstream from such filters. What is the method of downstream sampling? Should it be upstream or downstream of the carbon filters? With regard to Dr. Silverman's point, when a liquid aerosol may be used, does anyone recognize the possibility that penetration of a liquid aerosol through the particular filter may be trapped on the carbon filter, and thus not give an indication of penetration by sampling made downstream of the carbon filter bank?

HASL PANELIST: I would like to make a few remarks on this question of liquid versus solid aerosols for testing. It is my belief that if you run short tests on the order of, say one-half to two minutes, and you have small particles of under 1 micron, it won't make the slightest bit of difference in the penetration values you get, assuming, of course, that the particles have the same density. It seems to be just a matter of which is the most convenient and easiest test to use; there shouldn't be any difference in the penetration. I cannot see any theoretical reason why there would be the slightest difference in penetration of a liquid and solid aerosol of the same density, provided the particles are small enough not to blow off the filter. So I think it's a matter of convenience.

Carbon beds are very inefficient on particles, particularly the larger ones. There will probably be some removal by the carbon. It would probably be best to sample upstream from the carbon, but I don't think there would be a big difference.

HAPO PANELIST: We ran some of the nuclei counting tests on filter bank evaluation. Our particular case was a bank of about 100,000 cfm filters backed up by the charcoal bank a few feet downstream, which would make detecting penetration particularly difficult if the samples were taken between the banks. We went downstream about 100 feet, but we have to go about the final analysis in a round-about way. We were able to determine what the holdup was in the charcoal bed to make a correction for that. In this particular case we had a rather common commercial charcoal filter in use, and estimated our particle size about .007 microns. With that particular condition we had a penetration or an efficiency of about 24% or 25% in the charcoal bed. We just assumed this as a correction factor and determined what the absolute filter bank was doing from that. It is not accurate, but it was the best we could do.

SRP PANELIST: I would think that with a well-installed absolute filter, a rather high-efficiency bed, that the penetration of the DOP into the charcoal would be relatively minor.

ORNL PANELIST: This, I think, is true. We had several systems that had charcoal either following or ahead of the filters, and we found that it makes no difference. As a matter of fact, on a small system we ran a duct test, and without our knowledge the charcoal filter had been substituted for the particulate filter and we were surprised to find the efficiency at zero.

HASL PANELIST: I would like to make a few remarks about deficiency of carbon beds for taking out particles. Everybody knows that if the particles are the size of gas molecules, there is essentially 100% efficiency. That is because of the high diffusion rate of gas molecules; this is a mechanism that gets particles over to the surface of the carbon where they can be absorbed. So we can expect small sized particles, such as .007 micron, are going to diffuse and we can expect some deficiency, probably something like this. If we use .007 micron, we might get 25% removed. Now if we use .07, a few per cent

removed; and, larger than that practically nothing until the particles are so big they begin to impact on the carbon. Then the carbon acts like a filter. For very small particles in the Angstrom Unit, we can expect efficiency from a carbon bed, but certainly not for particles as large as DOP. If I wanted to worry about this, I would worry about the DOP vapor using up some of the sites on the carbon.

ORNL PANELIST: Another thing that we need to consider is sampling location in an in-place DOP test, and what kind of roughing filters are installed. Frequently we find that the roughing filters are efficient enough to cause an appreciable drop in concentration before the aerosol gets to the high-efficiency particulate filters.

COMMENT: I would like to ask for some definitions of pinholes. Mr. Thomas' paper yesterday described a leak of 1 cfm at 1,000 cfm for total filter capacity. In doing a little simple arithmetic and accepting his premise that this was turbulent flow through the hole, using a Reynolds Number of 5,000, it turns out that this pinhole is about $\frac{1}{4}$" in diameter. What kind of pins were you using?

HASL PANELIST: That was a hypothetical example; the pressure drop across the pinhole is a square root function and the rest was lineal. The biggest pinholes we made were about $\frac{1}{2}$ mm in diameter. That does not represent any experimental results; I hope we got the point across, but that is all we intended to do.

COMMENT: This is my point exactly. I think your analysis is not completely accurate on the basis of your premise, because if we had two pinholes perhaps a few thousandths of an inch in diameter, and we have the equivalent of a $\frac{1}{4}$" hole, we would end up with about 30,000 pinholes, or something on that order. At that point, we no longer can be sure that we have turbulent flow. We will have, in effect, capillary openings and we would expect to get streamline flow through such openings, just as we do through the paper. And if this is so, I would then expect it to be 1:1 with the filter material.

HASL COMMENT: I don't agree with you. Maybe I don't know my fluid mechanics; but, if we have a capillary tube, we will have pressure drop through the body of the capillary and pressure drop at the ends. But whether we have turbulent flow or not, we still have the square root relationship at the end of a capillary tube. It doesn't matter whether it's streamline or turbulent flow, the pressure drop is the square root of function.

COMMENT: If you are thinking of the streamline flow as being the Reynolds Number around the individual fiber, as you do in a very porous bed, when you get into porosities of 98% or 99%, this gives you quite a different situation. Some analyses of work on fibers with cross-flow seem to confirm the fact that with a fairly dense packing of 20% or 30%, we get truly streamline flow through the filter, and it behaves as a series of parallels, pipes of capillaries.

HASL COMMENT: I will agree that if a pinhole is small enough it would not act like the pinholes I am describing. I guess I'll have to say that my paper applies to pinholes that are not of microscopic size.

PANEL CHAIRMAN: On this question, we have put pinholes in our filters; and, believe it or not, we used pins to put them in. So I guess we can call them pinholes. But this is neither here nor there. We ran the particulate filter over a range of flow, took the efficiency versus flow, and it does fit what you would expect with laminar flow to the paper and turbulent flow through the hole.

Whether this was a coincidence or not, I won't say; but the data consistently repeats itself.

COMMENT: I don't doubt the observations which you and many other people have made. This is not the issue. It is the explanation for the phenomenon that I'm calling for. One reference Mr. Thomas did not quote in his paper was some work that was done by Smith and his coworkers at A. B. Little several years ago, in which bond paper was used; they were quite surprised to find that a pinhole through a piece of impervious paper would take out something like 35% of the atmospheric dust. This is a true removal phenomenon, and, because of the flow rates they were using, it generated a great deal of turbulence at the entrance to the pinhole. This turbulence, in effect, centrifuged the particles to the outside of the hole, and after some time, a ring of dirt could be observed around the pinhole. This suggests a different type of action than the one we have been talking about.

PANEL CHAIRMAN: Before we continue with the questions, there are a few points that haven't been brought up that I think are important. I would like to ask a series of four questions just to bring out these points. The questions I have are these:

1. Is in-place testing difficult?

2. How much does it cost to get into the business?

3. How many in-place tests are conducted a year at ORNL?

4. How long does it take to learn the technique so that it can be applied effectively and efficiently?

ORNL PANELIST: In answer to your first question, in-place testing is not difficult; it is a very simple procedure.

To answer the fourth question, I would say that with one or two days of practice someone would be competent to run in-place tests employing the technique used at ORNL.

To answer the second question, I think the necessary instrumentation and generating equipment could be obtained between $1,000 and $2,500, depending on the size and number of installations that had to be tested. The difference in cost, of course, is in the generating equipment.

At ORNL the number of in-place tests conducted in a year would be approximately 1,000; probably a few more. We have made a few improvements in the last few months that will enable us to test faster. Ordinarily, four people comprise the in-place testing crews.

SRP PANELIST: The difficulty with the testing depends on where you are testing. If you are 50 feet up on top of a building, in a 40-ft. aluminum housing with 4-ft. innerspacings, it can be a problem; and, if you are using building air to pull through the filters, don't do it in February.

ORNL PANELIST: Perhaps I misunderstood the question, but the difficulty was with the technique. You are absolutely right about the difficulty of testing certain systems. Sometimes it is tremendously difficult. Large temporary ducts may have to be constructed in order to introduce aerosol in order to get well-mixed representative samples upstream of the filters; occasionally it is necessary to add to the downstream duct in order to get a representative downstream sample. The availability of compressed air in sufficient quantities is another

problem. Occasionally, we need to employ a construction type compressor with high output capacity and use the entire output on the larger systems.

QUESTION: Is the equipment for conducting these tests commercially available?

ORNL PANELIST: The equipment is commercially available. The instruments we use were developed by the Naval Research Laboratory. They are being manufactured by more than one manufacturer. Generating equipment is available, too. I don't believe there were any generators commercially available at the time we needed ours, so we built our own, using recommendations of NRL.

QUESTION: What per cent of flow is needed to get an optimum DOP test; that is, how slow can you go and not get into problems of pinhole effect, et cetera?

PANEL CHAIRMAN: The pinhole effect probably must always be present to some extent, and in many cases there is an advantage in testing a system at less than rated capacity because it does magnify the pinhole effect. On the other hand, I would not make it a general rule that it is desirable to test all systems at less than rated flow, because I can think of filters mounted on the downstream side of the filter frame, so that as you increase the flow, there is an unseating tendency which might produce gasket leakage. Therefore, my recommendation would be to test the rated flow to take care of the possibility of unseating the gaskets if they are mounted so they can be unseated, and also test at less than rated flow. I think this would take care of both complications.

QUESTION: Has anyone made an attempt to determine where and why these filters fail, and has any attempt ever been made to repair them?

NRL PANELIST: The answer is yes to both questions. What we have done many times is to tear the filters down. After looking for the source of the leak, we can dismantle a filter and find out the source; usually it's a hole. It is also true that we have repaired filters many times where the leak is obviously around the seal or where the end flap may have slipped. We have actually repaired filters; we don't recommend it as a matter of course.

SRP PANELIST: We find a lot of defective filters in our systems, primarily due to installation damage. If they were not too hot, radioactively speaking, we let them cool a bit and sent them back to the manufacturer. We did successfully repair these, by the way, in the past, and we then put them back in service at a very nominal cost.

PANEL CHAIRMAN: On Tour B and Tour E, you will see the filter testing equipment in operation. As a part of the tour we plan to conduct an actual in-place test on a small system. What will be shown in that small in-place test is representative of tests on systems up to 100,000 to 200,000 cfm.

If you have high-efficiency filters and if you need high-efficiency filters, you need the in situ tests.

In conclusion, we have considered all the questions that were submitted; they have either been answered by a panel question, or they were answered by the questions coming from the floor. I will also be free for most of the rest of this day, and tomorrow at the in-place test and the test at the rig. If you would like to see something that we haven't planned please ask, and we will try to demonstrate.

I would like to thank the panelists for their participation.

PANEL B - ROUND TABLE SESSION
Thursday Morning, 24 October 1963

SPECIFICATIONS, MAINTENANCE, AND MONITORING OF FILTERS

PANEL CHAIRMAN: We feel that Panel B, Specifications, Maintenance and Monitoring of Filters, will give you as much activity as did the last one, and that the information we bring you, of course, will be within the topic shown on the program.

Members of the panel are:

Humphrey Gilbert, USAEC, Chairman
Leonard Horn, UL
R. Mitchell, BMI
J. L. Murrow, LRL (Livermore)
S. E. Smith, UKAEA

Mr. Smith has already talked to you. He needs no further introduction. However, probably this should be supplemented a little bit. Some time ago, I contacted two friends in Great Britain and said, "You know my interest in the filtration business. For the 8th Air Cleaning meeting whom do you recommend that I contact in UKAEA?" And both of them, unhesitatingly, said, "S. E. Smith, of Aldermaston."

Mr. Smith, in addition to being senior member of the staff of the Atomic Weapons Research Establishment at Aldermaston, has been on the BSI Committee for Standardization, or I might say, for Re-Standardization, of the methylene-blue test, and he is also on the Committee for the Sodium Chloride test, with Mr. Dorman. Mr. Smith, as a panel member, will assure that we have the viewpoint of our fellow-workers on the other side of the Atlantic, to see if we really have advanced as we think we have.

Mr. J. L. Murrow is an industrial hygiene engineer with the Lawrence Radiation Laboratory. He has been engaged in the fire penetration study of filters, and while at Berkeley, was instrumental in developing a criticality-safe local exhaust system for machining fissile material. He made his fire-penetration studies in June of this year and this will be the topic of his discussion.

Mr. Leonard Horn is Associate Managing Engineer of the Electrical Department of Underwriters' Laboratory. Some few years ago he went to the reactor school at Argonne National Laboratory due, primarily, to his interest in atomic energy. He is quite a frequent face around the Atomic Energy Commission in Washington, and whether he has the title officially, or unofficially, he is looked at as a liaison engineer with Underwriters. At least all the AEC people,

when they have fire-protection problems, immediately search out Mr. Horn. Mr. Horn, of course, has been busily engaged in developing a Standard for fire tests of filters covering routine surveillance of manufactured items, which is consistent with the little, familiar UL label I am sure you have seen.

Mr. Ralph Mitchell is from Battelle Memorial Institute, where he has been located about 12 years in the Environmental Mechanics Research Group. He has investigated filter ventilation for one of the larger filter companies in the country, and in addition, he has investigated cigarette filter design. Consistent with this, he has also done lung retention studies for the tobacco industry.

Mr. Mitchell has been the chief investigator on a year-long project to develop a small-system, qualitative, in-place test, and we would like Mr. Mitchell to tell you about that now.

BMI PANELIST: I will try to describe the program which has been going on at Battelle in developing more or less an economical system for in-place filter testing of small filters and some of the strange findings that have evolved out of this program.

The system we are using, more or less, consists of a conventional aerosol package. We have a highly-fluorescent, oil-soluble tracer dissolved in Freon, and most of our tests have been with Freon-12 to obtain high pressure. We varied the particle size of the aerosol, which was produced by varying the concentration of the dye in the package, the pressure of the propellent, and essentially orifice diameter.

We evaluated a few materials as far as compatibility, plugging of the orifice, and what not, and we overcame these difficulties; we looked into the toxicology of the situation, and finally more or less settled on a package which we thought was suitable for filter evaluation.

We began penetration tests with filters which were supplied to us, and found in the initial tests we could get reproducibility. The penetration values obtained were quite a bit less than what we might expect. The filter was much more efficient with these materials. To check this, we reviewed the particle size of the solid aerosol particles. Now these particles which we produced are solid dye particles, completely solid, because essentially the only solvent we have is the Freon-12, and maybe a little co-solvent to prevent flashing at the orifice. So we end up with a solid dry aerosol particle, which is non-hydroscopic. We generated some aerosols, dibutylphthalate, and found particularly a quarter higher magnitude of penetration with essentially the same filters.

As we began running more tests on these filters, we had a fairly limited number of filters to evaluate, and there was no real good source of getting a large number of filters. We found as we ran our tests our penetration values went up. This is the same thing that Mr. Modrow was reporting on yesterday. This concerned us quite a bit, because we knew essentially our source strength was disseminating an aerosol of a known concentration, and we kept picking up more material on the downstream side of our filter. We are evaluating our penetration by generating a known concentration of aerosol, sampling upstream, though we didn't have to, because we always put up a known amount of the tracer. We sampled the downstream side of the filter and most of our tests, what we are using at the present time, is a high-volume sampler, with the Hurlbut all-glass filter paper in it, which produces the volume sampling rate of the high-volume sampler at about 14-$\frac{1}{2}$ cubic feet per minute.

When we began the investigation we thought maybe the material was coming off the duct itself, because in other programs we had run other tracer studies in this duct. We coated our duct walls with plastic materials. It didn't help the situation any.

Then we looked at the filter itself, and it was getting pretty hot on the downstream side of it. After that we thought maybe the material itself, the dye, might be causing some chemical reaction with the filter material, so we sent some of these filters to Oak Ridge to have them evaluated. They checked on DOP, and then we began a study to find out what was causing this phenomena, and found we were getting unloading with this load of about 2-½ grams of the dye deposited on a standard 1,000 cfm filter.

The first slide was made with UV light, and it shows a deposition on the upstream side. In this case we cut a section out of the filter and opened it up at the middle, at one of the folds. The absence of color locates the separators in back of the filter. The yellow is the fluorescent dye which we were generating. The second slide is the reverse side of this filter showing that the yellow dye is migrating through the filter media. In looking at this filter we saw little hot spots, and tried to make a filter media concentration profile, cutting it with microtome. We found that all the mounting media itself would dissolve the filter, and therefore could not get a concentration profile; we were hoping to be able to get a color picture.

The third slide shows a cross-section of the filter paper at one of these hot spots. This essentially indicates the variation in thickness of the filter media itself, and we got quite a step function. We have another slide of another hot spot showing just a regular crater effect. The filter thickness at this hot spot is roughly a factor of two difference.

This is as far as we have gone with this program in trying to find out why the filters are unloading. At the present time, we are running some tests with boron oxide fumes. We have collected the material downstream, but we haven't analyzed it as yet.

As far as our in-place filter testing, we have incorporated some dibutylphthalate in our package, so we are ending up essentially with a slurry, or you might say, with a particle which is liquid; it is essentially a slurry. In effect we have the dye, which is not soluble, and the dibutylphthalate in that it is in suspension, and we have run quite a few preliminary tests with this, showing we can get very good, high penetration values much different than if we didn't have the dibutylphthalate.

UL PANELIST: In 1958, Mr. Humphrey Gilbert of the U. S. Atomic Energy Commission Industrial Safety and Fire Protection Branch requested that Underwriters' Laboratories, Inc. give consideration to the development of requirements covering the testing and listing of high efficiency air filter units commonly employed in the ventilation and air filtering systems of atomic energy installations. At that time several of the component materials used in the construction of filter units were quite combustible and serious fires had occurred in filter banks. The development of units with better resistance to heated air and fire seemed highly desirable and Mr. Gilbert suggested that the experience and "know-how" of the Laboratories in the general field of fire protection would be useful in carrying out such a project. In addition, considerable trouble was being experienced with regard to perforation of the filter media prior to installation of the filter unit in the protected premise and it was felt that the Laboratories field inspection staff could make a real contribution to the quality of these units as they are shipped from their manufacturer's plants. We agreed to undertake this work and since 1958, we have been struggling

with the problem of establishing standard test methods which would assure improved resistance to the effects of fire in ventilating systems. Mr. Gilbert has suggested that the status of our work be reported to you today.

Following meetings with filter unit manufacturers, personnel from the AEC, the Edgewood Arsenal and the Naval Research Laboratory a First Edition Standard UL 586 was released dated September, 1959. The subsequent testing of commercial production samples of filter units in general use soon indicated that the performance levels which had been recommended by the Advisory Group were unduly high and apparently could not be attained by the designs and constructions of units then in production. Since that time much experimental test work has been carried out and one revision of our Standard dated October, 1962 has been circulated for review. Comments received, plus further testing with improved apparatus, has resulted in a second revision proposal which is now in the mail. A number of tests upon several samples of filter units in current production gives us a fair degree of assurance that units being currently supplied to your facilities will meet these latest requirements which in our opinion establish a reasonable safety performance level for units subjected to occasional or accidental operation under conditions of fire, heated air, moisture, cold and loading. It should be emphasized that this Standard contains a minimum of construction specifications and comprises, in the main, a series of tests and desired results to establish reasonable performance under the conditions which have been mentioned. Thus, any construction which meets the desired test performance stated in the Standard is acceptable and is eligible for the Laboratories' Label. Also, these requirements are minimum requirements, since the above-Standard performance of any construction is certainly desirable and is likewise eligible for labeling.

I have neither the time nor the desire to bore you with a long discussion of the details of our Standard, the developmental history of each test, etc. Instead, I will merely mention that our current proposal makes use of the following five tests - Heated Air Test, Moist Air Test, Low Temperature Test, Spot Flame Test, and Loading Test. The common feature of most of these tests is the measurement of filter unit penetration before and after each test, employing a dioctyl pthalate (DOP) generator, a forward light scattering photometer and electronic percent penetration indicator identical to the portable units which are currently being employed at AEC installations for in-place filter system testing. Limits are specified for percent of DOP penetration after each test.

To save time, let us proceed directly to a series of slides which illustrate the test equipment. Test details will be given with each slide.

Slide No. 1 shows an over-all view of the test duct employed for the DOP Penetration, Heated Air, Spot Flame, and Loading Tests. The duct is approximately 27 by 27 in. in cross section and 15-$\frac{1}{2}$ ft long, with a constant-speed blower supplying air to the upstream end of the duct. The air supply is metered by a venturi-flow meter and the blower is provided with an adjustable air intake opening.

Slide No. 2 is an over-all view of the upstream test apparatus, showing the percent of DOP indicator equipment, DOP generator, the venturi-flow meter, and the blower.

Slide No. 3 shows the interior of the test duct set up for the Heated Air Test, with the filter unit and the flame arrester removed. Air in the upstream section of the duct is heated rapidly by several gas flames and the duct is provided with a transite barrier to provide reasonably uniform temperatures across the filter unit face. The test consists of 5 min operation with the air heated to 700 plus or minus 50 F. Our current Standard proposal

limits percent of DOP penetration to 3 percent following this test.

Slide Nos. 4, 5, and 6 are photographs taken during Heated Air Tests. Incidentally, Mr. Gilbert is not an employee of Underwriters' Laboratories, Inc.

Slide No. 7 illustrates the arrangement used in conducting a Spot Flame Test. This test attempts to simulate the impingement of burning particles, such as small pieces of flaming pyrophoric metal, upon the upstream face of the filter unit. The flame is produced by a Bunsen burner adjusted to a blue cone tip temperature of 1750 plus or minus 50 F. The flame is applied for 5 min with the blue cone touching the surface of the filter unit. One test is conducted with the flame applied to a top corner of the filter unit in such a manner that the tip of the blue cone contacts the frame, filter pack and sealing materials. The test is also conducted at three points across the filter face. Inasmuch as the temperatures are sufficient to melt fiberglas filter media, no DOP penetration test requirement is applied following the Spot Flame Test, the sole criteria being the requirement that after removal of the test flame, there shall be no sustained flaming on the downstream face of the filter unit.

No photographs are available of the Moist Air, Low Temperature, or Loading Tests. The Moist Air Test consists of subjecting a filter unit sample for a period of 24 hr to a static atmosphere having a relative humidity of 90 plus or minus 5 percent at a normal room temperature of 77 F. In the Low Temperature Test a sample is placed in a static atmosphere at 27 plus or minus 3 F for a period of 24 hr and in each of these tests it is required that there be no change in the percent of DOP penetration measurements made before and after the Moist Air and Low Temperature exposures.

In the Loading Test, extreme loading of the filter unit is simulated by completely covering the upstream face of a test sample with a single layer of heavy kraft paper. The unit is then placed in the test duct and the blower equipment adjusted to provide a pressure differential of 10 in. water column across the filter unit. This differential is maintained for 5 min. As in the preceding two tests, it is proposed that there be no change in percent DOP penetration measurements made on the test sample before and after the Loading Test.

The final series of slides are photographs of samples subjected to the tests which have been described.

Slide No. 8 is a photograph of the upstream face of a sample subjected to the Heated Air Test. Its percent of DOP penetration before test was measured to be 0.008 and its penetration after test was measured to be 0.042.

Slide No. 9 is a second sample subjected to this same test. Its percent of DOP penetration before test was measured to be 0.002 and after the test the penetration was measured to be 0.28. You will note that a small hole appears to be melted in the media and separator close to the bottom edge of the unit where maximum heated air temperatures occurred. You will recall that our present proposal for percent of DOP penetration following this test is 3.0.

Slide No. 10 shows a unit subjected to the Low Temperature Test and slide No. 11 is a sample subjected to the Moist Air Test. In both cases, there was no change in percent of DOP penetration measurements made before and after the tests.

Slide No. 12 shows the upstream face of a unit subjected to the Spot Flame Test while slide Nos. 13 and 14 are close-ups of those areas which suffered the

greatest destruction during the test. It was noted that no burning, scorching, or discoloration of the downstream face of this filter unit occurred and reviewing the sample from this face, no evidence of the Spot Flame Test can be detected.

As I have mentioned, a draft of our latest proposal is now in the mail and we anticipate final action on the proposal in the very near future. As compared with our present requirements the proposal represents a reduction in the severity of our test program and we do not anticipate too many objections. As I have mentioned, and as can be seen from the slide illustrations, representative production samples of filter units now being supplied to your facilities appear to comply with our current proposal and if these requirements are adopted it is expected that high efficiency air filter units bearing our Label will be available in the near future.

LRL PANELIST: This work was an effort to carry on from that which Mr. Palmer did at Hanford several years ago. As nobody else took up the work, Mr. Gilbert asked me if I would perform tests on some filters that had been developed in the meantime. I was able to have some sheetmetal work done officially; we assembled equipment that we hoped would work for a test similar to Mr. Palmer's.

However, when we were ready to test the filters Mr. Gilbert felt that the testing at elevated temperatures was more important than testing for fire intrusion, so the tests were conducted with equipment that wasn't exactly designed for the kind of test that we tried to make. We are hoping that future tests after modifications to the equipment will be more precise and reproducible.

However, I do feel that we did gain some information from the series of tests last June, and are looking forward to continuing the tests at elevated temperatures in the future.

I have a few slides that show the equipment and the result on one kind of filter. The first is a diagram of the equipment. On the far left is the housing to hold the filters without a positive clamping device, but the filters are set in against a bearing surface for the gaskets. The five gas-fired burners can be adjusted for flow and temperature; any one or all can be used at a time.

We can use up to 24 thermocouples as required and record on a strip-chart recorder. The other parts are: viewing ports; Pitot Tube to indicate the flow rate; a slide valve to adjust the flow rate; and, a Lamb-type air mover to provide suction for the system. The eductor eliminated the problem of high-temperature gas going through a centrifugal blower.

The next slide is a close-up of the apparatus, showing the burners and their positioning. The left side of the system has been removed to show the filter in position. The track that holds the burner on the left side is missing, so the burner assembly must be held in place. The marks on the side wall are placed to give us a reproducible position of the burners from the face of the filter.

The next slide shows one of the filters tested. This was a special filter with the frame made of "Novaply," a chip-board material. Otherwise, it is pretty much of a standard filter, with a rubber cement, glass-fiber filter medium, and aluminum separators.

After the test was over and the DOP tests had been run on the filter we cut it up, and took a close-up photograph. This is on the upstream side,

showing some charring of the frame material at the upstream side, and some surface charring of the rubber adhesive, but the adhesive was still in pretty good shape. You could tear the filter media or aluminum separators before you could loosen them from the frame. This indicates that the seal was still essentially intact.

The next slide is the downstream face of the filter, 180° from the last slide, showing that the gasket material, the filter media, and the adhesive were all in good condition.

The next slide is a trace of the various temperature points. The one on the far left indicates the downstream total air temperature after dilution. The thermocouple was placed downstream almost to the air mover. The three on the far right were at the top of the filter, on the face towards the burner. The next two were on the face of the filter about half way down. And the one at the bottom of the filter was on the side toward the burners. The horizontal lines are increments of 30 seconds, indicating that the filter test was something in the order of five to six minutes. The lines are a little erratic and we do not feel that they indicate a good, reproducible type of test. We hope to improve these in the future and continue with the tests for evaluation of other filters.

Several other filters were tested in a similar manner. Most of them held up well, some perhaps a bit better; some a little worse.

An additional benefit from the test was for our Fire Department members of which observed and participated in some demonstrations. We first used an old CWS type filter, one with cellulose-asbestos filter medium and kraft-paper separators, and fired it. After taking the burners away, it continued to burn quite rapidly. The Fire Department had an opportunity to try to put it out. They used powder, CO_2, foam, and portable water type extinguishers. The only suitable way to extinguish the fire was to take the filter out of the system, tear it apart with an ax, and douse it with a bucket!

We then put in one of the newer style filters with a retardent-treated plywood frame, newer adhesives, asbestos separators, and glass-asbestos filter medium. It was fired in the same manner. After removing the flame it was completely self extinguishing in a few moments. The Fire Department is happy that the filters installed at IRL are of the new type!

UKAEA PANELIST: Rather than commenting on the presentations, just now, I would prefer to say a few words about the UK approach to the problems of filter designs, specification, maintenance and so on. I think we have in some respects a rather different philosophy of approach to the use of filters and their design. We have been talking about the wooden-framed 1,000 cfm type filters. We would regard these in many cases as inserts for use in cases. The first thing I think I would like to say is that we don't use extensively, at all, any filters other than metal-framed filters. That is to say, the insert is contained in a metal, rectangular frame, and the whole of the construction, other than the paper and the cement, is of metal construction.

There are slight differences to the design in detail. One particular one, I think, that would be worth mentioning, if you can remember the last slide that the UL Panelist showed, was a detail of the folded material with the corrugated spaces between. In our designs we have a rounded, beaded edge along the front of the corrugated spacer where it is in contact with the paper. I suggest that this might be one of the locations where you get pinholes occurring.

In using what we call non-combustible metal filters there are differences in our installation philosophy. In some cases they are used in what I call wall frame construction, which is common over here, but in other cases we tend to use inserts put into canisters. There are two ways of doing this, or three ways altogether. One is to put the insert into a case and seal one of the leading edges into a frame inside the case. The cases are metal, and they have conical ends. This is to say that the residual sealing problem, when installed, is simply that of making a seal in a circular section duct. I know this construction is more expensive than the simple, rectangular frame. These units can be of a type in which the whole canister with the contained filter is thrown away after its period of use. In another form the insert is capable of being taken out of the canister and the canister is re-used, with a new insert. With the third method there are end pieces which reduce the square section to a circular section clamped to each side of the insert, upstream and downstream.

We have been evolving specifications to cover the supply, manufacture, design and testing of these units. In fact, at the moment, we have specifications to which manufacturers are expected to supply inserts both 1,000 cfm inserts and the 200 cfm size.

The specifications include: dimensional tolerances of the cases; the type of design for sealing either into the canister or into the framework; the penetration and the pressure drop; the maximum mechanical strength across the unit; temperature resistance; the amount of filtering area used; the type of spacers and their design; the general construction, material and rigidity of the frame, particularly the flange faces; and, the cement which is used. Separate specifications cover the paper and gasket to be used. By that I mean the gasket by which the insert is sealed into the frame or canister, not that between the paper and the frame. These specifications cover both the throw-away type of unit and the replaceable types of unit.

We have codes of practice which are, to some extent, still in the course of development; the codes include the canisters I referred to of both replacement and throw-away types and for the end pieces which are used in some cases. We are hoping in the not-too-distant future to develop and to apply a similar type of specification for pre-filters to be used in conjunction with the high-efficiency units.

I would like to add that we distinguish, in the testing of these units, between proof tests which are used to test each unit, and type tests which are not done on each unit, but are done in order to satisfy one's self about the particular supplier.

As far as maintenance is concerned we feel that one of the advantages that comes from the use of the canister-type filters, is that unlike the wall units it is possible in almost all cases to work with fairly simple methods for breaking flanges with a sound technique and a minimum amount of protection for the operator.

PANEL CHAIRMAN: Thank you; we appreciate the viewpoint of the U. K. Atomic Energy Authority on the problems which are rather common to us.

The work that Mr. Horn is doing at Underwriters' Laboratories is prerequisite to the establishment of a federal quality products listing, or QPL, for a military filter specification. When the QPL is established we will recommend the new specification for a filter which is MIL-F-51068. This is a specification drawn together out of the experience of the U. S. Navy, the U. S. Army, and ourselves, and some research work done by Arthur D. Little over the period of the last three years.

There are four basic differences between the one which you know as the AEC Health and Safety No. 120 specification and, briefly, these are they: Filter efficiency will be 99.97 instead of 99.95 percent. In other words, penetration will be reduced to 0.03 from 0.05 percent. The allowable resistance for a new filter will be 1.0" water gauge, compared to 0.9". We have been using 1.0" for the past two years because of the insistence on greater tensile strength in the media, and on water-proofing, which have their effect on resistance. Thirdly, the new specification will require that the filter be tested at 100% and 20% rated flow, and this is in deference to those installations using a 1,000 cfm filter at 300 cfm; the pinhole effect, large or small, will probably be significant. Finally, filters with a face size 24" x 24" will be equipped with a 1/4" mesh hardware cloth protective screen over both faces. This is a damage-prevention measure. In the tests run at Underwriters' Laboratories, it has proved also to have just a a little bit of effect as a fire-screen.

Here is a small demonstration unit made up to the specifications of MIL-F-51068, and you appreciate that it has the hardware cloth face on it. This would not be required on those units which are less than 24" because damage experience does not show the need on units which are 12" x 12" and such smaller sizes.

One item on results on the Quality Assurance Stations at Oak Ridge and Hanford. Table I shows percentage of total filter rejections which were given to you in 1961 at Brookhaven, for the first half of 1961, and those for the first half of 1963. It is rather obvious that the improvement has been great in the quality being delivered to the program, as reflected by Station tests.

TABLE I

AEC FILTER TEST FACILITY RESULTS

	Percentage of New Filters Rejected, By Cause				
First Semi-Annual Period	Manufacturing Deficiency	Excess Penetration	High Resistance	Carrier Damage	Total
1961	1.1	3.5	9.3	1.0	14.8
1963	0.1	0.5	0.5	0.2	1.3

I find that the volume of high-efficiency filters coming into the program has increased about 60%, that will be the increase for this year. I do not find that the requirement of reactor confinement or containment accounts significantly for the increase. It seems that more filters are going to the same purchasers, which raises a point that has been brought out in the last three meetings. "Have you examined your airstream to be sure that you are required to use a high-efficiency filter?" This should be done. These are expensive filters, and where they are not needed, certainly we would hope they would not be used. Sometimes filters of less efficiency might be put in place.

QUESTION: I would like to address a question to the Chairman relative to the military specification. One pertains to the gasket thickness. I note UL mentions the 3/16" gasket. We prefer a thicker gasket because of the variations in the surface, in a practical installation, to get a seal. As an example, we found that it took a 700-pound load on a 24" filter to effect a seal. To overcome this, at least in part, our specifications call for a 3/8" thick gasket, unless otherwise excepted by the individual specification.

I am curious to know if the specification for integrity of the frame will be included in this Military Specification or anything regarding the tightness or integrity of the frame construction itself?

PANEL CHAIRMAN: Well, the recommended specification on which you purchase would be the military specification. The UL Standard would, of course, conform.

The gasket in UL says "not less than 3/16 in." I was looking for the provision in the Military Specification. I don't find it just now but my impression is it is a $\frac{1}{4}$" gasket.

The third amendment to the Military Specification is now under way, which has to do with the item you mentioned about frame integrity, particularly at the joints. We found that the specification was deficient in that it required no adhesive completely across the inner face of the frame, as well as the joints; but insofar as the frame joint test, there is no provision for it.

QUESTION: I would like to ask the UL Panelist two questions. When will the qualification program be in effect for UL? Second, since most of the tests so far have been made on plywood frames, are these tests equally applicable to the metal frames?

UL PANELIST: I would like to be able to say that we can get labels by perhaps January 1, 1964. On the other hand, I have been at this five years and I have learned to be very cautious about statements. But we do think we are much closer than we ever have been to completing a program and getting labels, and my guess is if we are lucky it may be only a matter of two or three months.

As far as the plywood and the metal frame tests are concerned, we have experimentally tested one unit in a metal frame, but it is the only experience we have had with a metal frame. Does that answer your second question?

COMMENT: Primarily it does, but we do have the problem that a good many of our frames will be metal, and we just wanted to know if the tests will be equally applicable at the time the qualification program goes into effect.

UL PANELIST: Yes. As far as we know there is nothing in our Standard that says you could not use metal, and I believe it will pass as well as any of the other frames.

QUESTION: I would like to direct this question to the Panel Chairman. With respect to this military standard you quoted a specification value for rated flow of a maximum penetration of 0.03 percent. Has a value been set up for penetration at the lesser rate of flow?

PANEL CHAIRMAN: I think that it is in the specifications here. The specifications were handled by the Specification Group at Edgewood, and were of primary concern to the Engineering Group. I would have to check the item in the document, the specification, before giving you an answer.

QUESTION: I noticed, in examining the color slides by both the LRL and UL Panelists, that there was a very perceptible difference in the appearance of the filter, top to bottom, on the High-Temperature tests, and I noticed, in the LRL curves of temperature, that there was approximately a 500° differential between top and bottom. First of all, for temperatures specified at some particular value, is it the intent that the highest temperature recorded on the filter will be the one that meets this test? Should an average temperature be considered; how will this be arranged?

If there is a single filter in a duct, then obviously the temperature differential which observed is perhaps a fair test, but would it be a fair test if there were a bank of filters, perhaps eight or ten high? In that case, the very top filter would be subjected to the highest temperature over its entire face. What effect would this have on acceptance tests?

LRL PANELIST: As far as our tests were concerned the equipment was designed for fire intrusion. We tried to put together a system for checking at elevated temperatures. The equipment, I hope, will be modified so that we can eventually get fairly uniform temperatures from top to bottom.

As you observed, in a bank one filter at the top will probably be fairly heavily exposed, and the one at the bottom will not be. This is pretty much the same as one filter in a test being hot at the top and cold at the bottom. It makes little difference in that respect except that, in the bank of filters, the top filter will be exposed over its complete periphery instead of just a portion of it.

These tests were not designed, and never will be designed, for acceptance tests; they are only for experimental filters to see how different equipment or supplies will work under some given set of conditions.

UL PANELIST: I would like to say that I agree with the LRL Panelist. At least the UL approach is to test a filter as a unit and obviously we cannot be concerned too much with how these things operate in a bank. In the test apparatus that we have designed, we are attempting to operate at the maximum temperature; not the average temperature, but the maximum temperature, at 700°F., and that is why you noticed the filter samples had less of a heated area at the bottom of the filter. It is a very tough job in a reasonable filter test duct to get uniform spread of heat, and we have been fighting this thing for a long time; the pictures you saw are about the best we have been able to do so far.

PANEL CHAIRMAN: I would like to augment that. From the tests at temperatures higher than the 700°F. where we had penetration through the seal, you might say it appeared that the thin veneer layer of plywood was involved in the combustion at the juncture of the pack. This was one of the reasons that prototypes were tested at Livermore. One of these prototypes was made with "Novaply," which is a trade name, or chip-board; but I guess the generic definition is particle board. It appeared, this is not conclusive, we might get more fire resistance in the frame, in the wood frame, from fire-resistant treated particle board than from the treated AA exterior grade plywood. This still is under examination. The higher temperature at any one point is the one, I believe, that Underwriters' Laboratories has always construed to be the upper limit of the test.

QUESTION: I would like to direct this question to the UL Panelist. I believe you mentioned setting up some sort of a 3.0 percent penetration limit on flame intrusion test. What is the basis of this value?

UL PANELIST: I was afraid someone was going to ask me that. I think I will have to ask the Panel Chairman for his explanation of the basis. As far as Underwriters is concerned, we have leaned very heavily upon the field experience that you have had in this area, and in trying to evaluate a spot flame test it was very evident the filter was going to fail. The temperatures are high enough to melt a hole in the filter by this method. If this is the Heated Air Test that you were talking about, then it is the 700°F. test and it was recommended by the AEC that perhaps an efficiency of 97.0 percent would be satisfactory.

PANEL CHAIRMAN: The tests that have been run at 700°F. show no penetration thus far greater than 1.0 percent. I think our philosophy is to live with a fire-resistive filter; not fire-proof or non-combustible, because of cost. We can do this, but we want the maximum barrier, so we have an arbitrary figure of 3.0 percent penetration through such a filter after a Heated Air Test for five minutes at 700°F.

COMMENT: The experience at the Hanford Filter Testing Station on filters that I have seen going through, and others could elaborate on this even more, we are getting an increasing number of metal-frame filters. I would guess the figure is now running somewhere between 25 and 30% of the filters coming through. Many of them seem to exhibit what appears to be a weakness in the frame joint, which we certainly have undergone on the plywood frames in the past, but the metal ones certainly seem to lack rigidity. These do, however, pass the standard DOP and resistance tests in many cases. We have also had some notable failures.

With this, there has been quite a trend among these metal frames for them to be stainless steel, which cost-wise, is a tremendous increase. I would like to hear some of our contractors answer why they are buying metal frames and why all the stainless steel?

BNL COMMENT: The main reason we are buying stainless steel frames is the problem of waste disposal. We want something we can use again. We take the filter media out, clean up the frames, and send them back to the manufacturer where they are rebuilt. We can then package the filter media in a small space for waste disposal.

COMMENT: This is an interesting point; I have never heard this reason given. The latest comparison I have seen shows a cost of $43 for a 1000 cfm plywood frame unit with the stainless steel listing for $525. I don't quite see the economics.

BNL COMMENT: I guess you can buy them at that price. We have not paid any such price for ours; the ones we are buying are about $120. We are returning the frames, and then our new replacement filters actually cost less than if they were plywood. There is an initial investment, but when you consider that you have to pack these used filters and haul them anywhere from 100 to 400 miles to get rid of them it is a real saving if you can bale them and decrease the space; that is why we think we are making money on this.

PANEL CHAIRMAN: I think that the activity level also might be a factor in refilling a frame.

UKAEA COMMENT: Well, as far as metal-framed filters are concerned, I would make it clear that the metal we use is mild steel, but they are, of course, more expensive than the wooden ones. We recognize this, but we are willing to accept this extra cost for the advantage we think it gives.

As far as the sealing problem is concerned, I would agree that there is a sealing problem which can, we feel, be overcome. There are two methods known for doing this, and we have in fact tested both, which we regard as satisfactory from the point of view of the seal of the filter material to the case; we have, in fact, tested such filters which have been in use for some period of time.

But, I would nevertheless agree that a lot more work could be done to evaluate the satisfactoriness of the seal after use.

PANEL CHAIRMAN: I have an answer for a question posed earlier concerning the percent penetration at 20% of rated flow. The percentage limit is also 0.03, the same as the rated flow.

COMMENT: At Hanford, we have had a little experience over a period of time with respect to the penetration of the over-all filter, including gasket leakage and frame leakage, in addition to the filter penetration of the core itself. I think I am obligated at this point to indicate that we had a shipment come in just before I came on this trip and it exemplifies the point I am trying to make. These filters were good filters based on visual inspection; they were well made and it was obvious there was care taken in their fabrication all the way through. But the design was such that it made us question whether or not the overall penetration might be as good as it was supposed to be. We ran the regular performance test and found that they were well within the 0.05 percent maximum penetration limitation. We have a modification on our testing facility which can demonstrate the overall penetration of the filter, including the frame-joint leakage. As we suspected, we could put them on the floor and lean on them, exert a little pressure, and they would sway back and forth out of the 90° angle; this was true even with those of exemplary construction.

With the half-dozen or so filters that we tested, the highest one had overall penetration about 3 to 5 times the penetration of the core. This is an indication that leakage does go high. I think this is something that warrants further consideration in the program, where the overall penetration is of consequence and can be serious in application.

COMMENT: Another comment to add to the metal-frame problem relates to my former employment at General Atomics. We had satisfactory experience with wooden frames through several filter fire experiences, and yet, due to conservatism, operations personnel insisted on ordering metal-frame filters.

I am also interested in a case of fires of filter loading, whether aluminum separators will stand as much as the asbestos ones. My feeling would favor, perhaps, the asbestos; I do not know what the test would be.

COMMENT: If you can promise you will have a low-temperature fire, the aluminum separators would be all right. In fact they would be better, because they tend to distribute the heat through the filter evenly; we found this in the test at Underwriters in February. But, if you have a high-temperature fire, and this is the usual case - a fire in the range of 1250°F to 1500°F, the filter with aluminum separators will carry away almost explosively because they melt so fast. There the asbestos separator certainly is an improvement. I will admit I belong to the asbestos separator school, rather than the aluminum.

PANEL CHAIRMAN: Asbestos mineral needs a binder of some type to hold together in the form of paper. We have run an analysis of asbestos paper that has shown as much as 29% organic binder. You might keep in mind that fact when considering which separator to choose.

I would like to digress just one moment before we close. We have been considering the combustible make-up of filters for quite a few years, stemming primarily from the early desire to incinerate the cellulose-asbestos types, and recover the then scarce uranium metal. There was a research report at one time which had a page and a half to the effect that if the filters can be incinerated, they can also burn in place. This was patently ignored for quite a few years although we had glass paper available for filters. Mr. Palmer

should get a lot of credit for bringing the attention of this problem of filter combustibility to the atomic energy program; he worked under very difficult circumstances to make a small voice at Hanford known to a fairly large program. He did the early fire tests under quite difficult conditions, as Mr. Murrow indicated, sometimes unofficially. Frankly, the atomic energy program is indebted to him for his earlier efforts, and I rather suspect that the Western World is too.

May I take this opportunity to thank all of the panel members for their excellent presentations. We appreciate their efforts and thank all of you for your questions and comments.

PANEL C - ROUND TABLE SESSION
Thursday Afternoon, 24 October 1963

OTHER KINDS OF FILTERS, EVALUATION METHODS AND PROBLEMS

a. Super-efficiency
b. Roughing or Prefilters
c. High Temperatures
d. NaK, Na, Special Problems
e. Other Test Methods

PANEL CHAIRMAN: We have a rather interesting panel session in Panel C, Other Kinds of Filters, Evaluation Methods and Problems. I would like to comment that we regret one of our panelists, Mr. D. E. Fain, ORNL, for reasons beyond his control could not be present this morning. Therefore, the final composition of the panel is:

L. Silverman, HACL, Chairman
W. E. Browning, Jr., ORNL
R. G. Dorman, UKCDEE
W. J. Megaw, UKAEA
A. H. Peters, SRP

The purpose of this panel is to discuss problems of the future as well as those of the present. We will follow the procedure of previous panels and allow the panelists to make brief statements and follow their presentations with questions and answers.

ORNL PANELIST: We have made some theoretical calculations in which we have tried to form an idea of what will happen to materials after they have been released in a reactor accident. We have tried to take especial advantage of certain physical facts; namely, that they do occupy space volumes and there is only a certain amount of meterial depending upon the volume capacity of the particle.

The other physical property is the tendency of particles to agglomerate as a result of their colliding with each other. We tried to set some theoretical limit, if we could, as to the amount of radioactive material which could be contained in gas suspension as the function of time after release.

Mario Fontana, who is the co-author of the paper ORNL-NSIC 1 applied the expressions in Slide 1 to the case in which a reactor is contained in two concentric containments, the outer one of which is ventilated.

If you are talking to members of the Advisory Committee on Reactor Safeguards, who are very skeptical about the reliability of your systems and you have been testing your filters with DOP aerosols, you might find it difficult to convince them that youhave a filter that is good for anything other than the aerosol size for which you have been testing. It turns out that you can forget about particles of any different size than 0.3 micron as long as you catch them when they get to be 0.3 micron. The alternate is the number of curies released. I should mention that we are assuming here that the particles are loaded to their full volume capacity with iodine atoms.

If you are convincing people that you can remove 0.3 micron particles, then the critical time is around 20 seconds; this has a value of approximately 30 seconds. That means you have 30 seconds worth of leakage which will be released during all the time after the reactor accident; if that is satisfactory you do not need to make any more careful analysis. These highly pessimistic assumptions are sufficient.

Applied to the N. S. SAVANNAH case, this means 10^{-5} of the total iodine would escape. While this is just a theoretical treatment, if you want to be really positive, there ought to be some kind of experimental work done. But, it does look to me that the limited volume capacity of particles and the limited concentration that is stable against agglomeration can be used to set a maximum limit as to the amount of material that can be contained in small particles in a gas beyond a certain time.

PANEL CHAIRMAN: There is a subtle implication here as to whether this is a super-efficiency filter, the point being that if you are depending on agglomeration you can, in fact, get higher efficiency from an installed filter. I will have a little more to say after the other panel members have completed their discussion about higher-efficiency filters than what we are using.

The SRP Panelist comes next on the basis of some discussion of roughing filters, demisters, and problems associated with them.

SRP PANELIST: Yesterday, Mr. List described the containment or confinement program at the Savannah River Plant for our production reactors, and he briefly mentioned that we use demisters or moisture entrainment separator systems. I am afraid that I cannot tell you today whether it is economical to use roughing filters or prefilters in any given containment system. In our own case the benefits we get from the demister as a prefilter is only a bonus feature. The demisters are absolutely essential in our own case to protect the particulate filters in the event that we release large quantities of steam in a nuclear action. We have found that dusting filters fail seriously when exposed to unprefiltered mixtures of steam and air containing entrainment, and therefore we have installed or are currently installing moisture entrainment separators. We have found that these units also filter out a certain percentage of atmospheric dust. We have measured in our laboratory program removal of about 30 to 35% of the atmospheric dust by the demisters.

The moisture entrainment separators consist of the conventional stainless steel wire pads, but they differ in that each wire is wrapped with a teflon yarn containing 60 individual filaments of teflon. The individual filaments are 0.8 mil in diameter. Each demister is 2' x 2' x 2" thick. We use 5 demisters upstream of 8 particulate filters. This gives us the required superficial velocity to remove the particles of entrained water in the steam-air mixtures. About three pounds of teflon material are contained in the demister. The density is about 30 pounds per cu. ft.; each demister is rated at 1,600 cfm at a pressure drop of 9.5" of water. I might add that we find the demisters remove approximately 15% of 0.3 micron DOP particles in a standard test.

The units in our own application are expensive in that they are contained in stainless steel cases, and this about doubles the cost. The price is $200 per unit in quantities of 200 or more. The demisters, without the stainless steel case, in such quantities cost about $80 per unit. This is a high initial investment. We use the stainless steel case because we have found that we can clean the demisters simply by vacuuming off the upstream face which collects the cake. There is not an appreciable penetration of the atmospheric dust into the bulk of the fibers, but with time, there will be

penetration. We feel that this dust can be removed by back-flushing the demisters with water.

At the present time, we have an experience of about 13 months in our laboratory facilities. The pressure drop during this period of time has increased from the initial value of about an inch of water to four inches of water. The vacuum cleaning technique produced a pressure drop to within 25% of the initial value.

As far as the production facilities are concerned at the present time, we only have about five months experience, and it is too early to tell whether the demisters have made any beneficial effect in reducing the pressure drop on the downstream particulate filters.

As was mentioned earlier today, we are finding very high pressure drops on the particulate filters after about a year's exposure, approximately four inches of water. This is due to an unusual condition at Savannah River and we attribute it to fly ash from nearby boiler stacks.

A very rough prefilter is in the supply air system. We have a study underway at the present time to determine just what is wrong with these roughing filters, as far as removal of the fly ash, which we have positively identified. We suspect that the filters have not been installed properly; they are of the paper type that you just fold over and insert into a frame.

The work on the demisters is reported in detail in DP-812; the September 1963 issue of Mechanical Engineering covers the work in summary form on the demisters, particulate filters and culminate filters.

UKAEA PANELIST: I was very interested in the ORNL presentation a few minutes ago, because in our reactor containment tests we found out that some iodine does go onto particles; and, as far as we can make out, they all seem to be particles of about 0.5 microns in diameter. However, the iodine is also irrepressibly absorbed onto these particles. You cannot get it off by increasing the pressure or by drawing clean iodine through a Millipore filter containing the particles. We think we are on the scent of something at this stage, and we tried to make iodine attach itself to artificial aerosols. In metallic aerosols the only success we had was with silver. We got some reversible absorption, but not very much irreversible absorption. So it appears that there were some particles in the atmosphere to which iodine absorbs, and the problem is to find out what they are.

The first point I should make is that if this really does occur at 0.5 micron particles, then, if we are going to release iodine from a reactor, we had better make sure that it is attached to the small particles so they don't fall out under gravity at all to any extent. The sedimentation velocity is very slow. They are so big, molecularly speaking, that they don't diffuse out at all rapidly. I think that iodine in this form is in the best form to release into the atmosphere. The deposition risk will certainly be greatly reduced, and the inhalation risk will be reduced somewhat. Chamberlain some seven or eight years ago did some work, which showed that the deposition of thorium-B on the tracheae and bronchi was reduced by a factor of several hundred when the thorium was attached to these condensation nuclei. The sort of particles that are in the atmosphere in the sub-micron range, we have looked at from time to time.

I think particles similar to those shown in three slides may be of some use in filter testing. I know that the DOP test was chosen because of the size 0.3 microns, with expected maximum penetration; it is also a reproducible aerosol. One criticism of this method might be that we do not have a great deal of notion

about the size of the particles, unless we go to the trouble and expense of taking samples for electron microscopy. On the other hand, we have shown that we can get a fair idea of the size by using diffusion techniques. An even simpler way is to measure the fraction of the particles which is not charged. The theory of it is a bit dicey. Somebody asked Professor Shredding a few years back before he died if there was any basic theory in it and he answered there was no earthly reason why the theory should be true, but if it seemed to work, there was no harm in using it.

This method has been pioneered by a number of people in Ireland and in America. It works on the application of Boltzmann's distribution law. It can be written as an expression for the number of particles carrying two electronic charges. This agrees very well in our experience with the size that you get out of a diffusion battery measurement. We have checked this to a size of about 0.5 microns, and there we had some difficulty, but we think it was due to our difficulty in getting a good aerosol. We took it up again at 0.5 microns and worked it up to just above 1 micron. There, the series changes so slowly that the measurements don't really mean very much. But for measurements, say between 0.01 and 1 micron, this measurement of the fraction of an aerosol charged gives a very good idea of the size of the particles, an average size. It must be brought to charge equilibrium, because if you generate these aerosols by spraying or by heating, you may have some particles with very high charges. But if you store the aerosol, natural radioactivity, cosmic ray and ionization soon brings the aerosol to a state in which there is no subsequent change of charge pattern with time. During a study of dynamic charge equilibrium, this process can be accelerated by passing the aerosol past a radioactive source.

I would now like to talk a bit about polystyrene spheres. We get these gratis from the Dow Chemical Company at Midland, Michigan which is an advantage, although the requests have been so great that there has been some delay in sending them out. But they are beautiful, uniform spheres. They are uniformly within very near limits, indeed. We would like to dilute these so that in theory one droplet can only contain one polystyrene sphere. But in fact, we do get clumps of spheres. After we filtered it through an atomizer we picked out the big clumps in a cascade impactor, then dilute the stream quickly so we don't get much coagulation, pass it into a 100 liter vessel to allow some drying. One drawback is that no matter how pure the dilution water is there are a tremendous number of very, very small particles, less than 0.01 micron, sprayed up from the solution. We take these out by passing them through a very coarse filter packed with copper knit mesh. This takes out all the small particles, but it also takes out about 50% of the polystyrene spheres; but the aerosol obtained at the end contains less 1% by number of the very small particles.

These things, I think, will be quite useful in filter testing. You can get them in sizes up to a micron, or thereabouts. Above 0.3 micron it is rather difficult to get an aerosol that is sufficiently concentrated to be useful; but, in this range, certainly 0.188 is a very amenable size to use. You know the size of particles that can be tested and the concentrations can be measured quite easily with nuclei counters, which were described this morning. I would like to suggest this to the meeting as a useful means of testing filters.

These must be brought to charge equilibrium because, as you spray them up, you get particles with very, very high charges. For instance, if you measure the size in a diffusion battery before you reduce them to charge equilibrium, you get answers which are a factor of 3 off, or so.

PANEL CHAIRMAN: I just want to warn you that almost ten years ago they were using polystyrene latex spheres here for test suspension with a P-32 source to discharge it. But it is good technique and a lot of other people in this

country have been using this aerosol.

Our final panelist is from probably the heart of the early British aerosol work, the U. K. Chemical Defense EE Center at Portron. Many of you are familiar with Portron; I cannot make a comparison with Edgewood Arsenal, but it is the same kind of facility basically. He has some interesting information, and what he reports on will be the next standard test method in England.

UKCDEE PANELIST: In the time available I can only give you a short outline of the sodium flame particulate test. Slide 1 is a schematic diagram. We generate an aerosol of carbon salt in spray bottles. There are four bottles per 1000 cfm; the salt is 2% solution. It passes down the trunking, which is about a foot in diameter and some 30 to 40 feet long by a baffle, so that it gets adequate mixing before the aerosol reaches the filter, and the length of this trunking is sufficient to cause all the water to evaporate from the particles. We hope we end up at the filter case here with dry particles of carbon salt. This does only happen if the humidity in the trunking is below 60%. If it is above that drying is improper and we end up with a rather spongy aerosol. Some correction factors can be made if the humidity is known and we know the penetration has got to be reduced by a certain amount.

Now having passed through the filter, the aerosol goes out into a room. But before we sample the aerosol, we mix it by means of an orifice plate and a baffle. This means that it takes care of any pinhole leaks or any gasket troubles. We can sample anywhere in the duct and get the same takeup of salt.

The particles are pretty well all micron in size. They range from about 0.01, which is the limit of our electron microscope up to just a little over a micron. We get an odd one; one in every million or so goes up to 2 microns, or something of that order, but these are insignificant in mass and number.

We may sample anywhere across the ducting. We sample roughly isometrically, anything between a quarter and four times is good enough for tiny particles. We lead the aerosol through to a part of the circuit which is greatly enlarged. There is about a cubic foot per minute passing; anything between ten liters and 100 liters is quite satisfactory.

In a vertical tube is a small ceramic burner, burning hydrogen, and this is only looked at so that we see the 5890 sodium line. It is a free-burning flame, and a design of this size is sufficient. The flame doesn't flare at all. It burns just enough air to keep it burning freely. That means it sucks the salt laden air up, and the flame is colored yellow.

The multiplier is connected to a sensitive galvanometer and the increased deflection, because there is a standing deflection due to the clean flame, the increased deflection is directly proportional to the mass of salt which is burned in the flame. This is independent of particle size. It does not matter what the sizes are within our test limits. I wouldn't say that if we burned a 100 micron one, you would get the same thing as with lots of little ones; but, when they are all a micron and below, the deflection is proportionate to mass, depending upon particle size.

The calibration of this setup is by taking known volumes of the unfiltered cloud and diluting with clean air, and mixing, and then passing through flame. One gets a straight line of the concentration against deflection.

Slide 2 is an enlarged diagram of the photo-multiplier housing and flame tube with a tube leading the hydrogen up. The glass chimney has a silvering on the inside. This silvering is cut away, so that the multiplier sees the flame.

The tip of that burner is about a millimeter below the hole so that the burner itself is not seen, only the flame, a bats-wing flame.

If the humidity in the ducting is not low enough, the salt particles will not dry and we end up with a larger aerosol than anticipated. If the particles are too large because of this increased humidity, they do not penetrate so easily. We have bought a drying apparatus because we are performing these tests at regular intervals, and we wait until the air is dry enough. A drying apparatus is not too expensive and it adds something to the cost; we can test whatever the weather is. I suppose this is perhaps more important in England than it is in the States.

Perhaps the thing that is of more interest to you is the comparison of results between the sodium chloride tests and the DOP tests. We are building a DOP rig. We had one some 20 years ago and dismantled it. However, we now think perhaps we ought to do some correlation.

For the purpose of this comparison, I have taken some results on small sheets of paper from our Canadian and United States friends. I cannot vouch for them. I can't blame them if they haven't given us the right answer, but we fully expect they have given us the right answer. I think we are getting the sort of comparison we should expect.

We found in one series of tests on 4 square centimeters of glass fiber paper at 13 centimeters per second that something on the order of 2.05% penetration, but the sodium chloride cloud was more penetrating by a factor just over 2. This is at a distance of 13 centimeters. But when we go down with similar sorts of paper about 2.5 centimeters per second, which is the velocity per 1,000 cfm filter, I think, the DOP penetration is about two to three times bigger than the sodium chloride. This is most unfortunate, but we can still measure the penetration by salt down to .201 at 1,000 cfm, with something like $\pm$ .302 or .303 possible error. But it is a less penetrating cloud velocity, and I think this is what one would expect. The lower the velocity, the more highly penetrating would be the DOP compared with the sodium chloride. These, of course, were on small sheets of paper; they were not on large filters.

Slide 3 is a photographs of our rig. Here is the spray box. We blow air down here, right down the trunking, with a bend in it at its base. Here is a filter under test showing the monitors. We measure flow and various things by putting these across an orifice plate. This is a flame tube. There is the end window multiplier. This inclined gauge measures the flow going along this tube. It is a rather crude method, but we save money whenever we can. The power unit is a discharge stabilizer with fixed voltage.

Slide 4 is a close-up view of the spray box end. These are gauges for the spray. I don't think I mentioned it, but we spray at 100 pounds per square inch; and, with four atomizers which you need for testing at 1,000 cfm, this involves using 12 cu. ft. per minute of free air.

Slide 5 shows a blower and filter here. We keep these going all the time, so that when we switch off the air from down this trunking, our little flame in the decanter over here is burning clean air, so it doesn't get contamination on the burner.

We can measure penetrations at 1,000 cfm of about .001. This is perhaps pushing it a little, but we would claim this if we were forced into that position.

Now finally, as with the DOP apparatus, if we can't find the signs of any leaks, we disconnect the trunking behind the filter and we put a searching

tube across the face of the filter. We can find exactly where the leak is in the filter.

I might say we've found quite a lot of leaks in the commercial filters we have tested.

PANEL CHAIRMAN: I think the ORNL Panelist had a little concern about super-efficiency; I consider him as one of the advocates of the need for super-efficiency filters. If you can get away with the containment vessel as a replacement, I am all for it. I would like to say though that we do have some situations where filters of an efficiency more than .02 or .01% penetration on small particles may be needed, and I would rather let these instances come up with the hope that we have a solution for them. In fact, we have been asked for a solution on previous occasions. We are using bag filters in which an asbestos float is atomized or aerosolized, if you will, into the air stream. Deposits on the surface of the filter produces an additional filter layer, or a "schmutzdecke," as the Germans would call it. This will then give you a very high efficiency filter.

In the work we did at the Harvard Air Cleaning Laboratory several years ago we found that we could correlate the thickness of the deposit with the improvement in efficiency. So those of you who feel that the absolute filter isn't absolute enough, that would like to get higher efficiency, if you will aerosolize asbestos floats into your duct system, you will get an improvement in performance, and you can show this with DOP or salt, or oil smoke, as we did. I think that in the operations at the beryllium plants, this has made the difference between a very expensive filter installation, where the filters would have to be thrown away, and one where you can use a bag filter and replace the surface after you shake it down into the bin. The so-called ultra air cleaner, which is sometimes used for pre-cleaning atmospheric air as well as the operations of an after-filter after all other filters, using asbestos floats is one technique.

The ORNL Panelist has suggested another technique; that is the setup of super-fine aerosol which will also build up a cake that will be highly efficient. I would like to know though, in terms of super-efficiency problems from our audience, if there are specific applications or questions in this area.

The next item is the question of high temperature. I think you all know the problems of the fire in an absolute filter system. The Dow people had one that was of significant magnitude, and the question of whether or not we need filters to operate continuously at high temperature, not just fire-resistant, has been a major problem.

I think I indicated yesterday with regard to the diffusion board, that it is in fact a high temperature ceramic type filter. There are others that have been demonstrated and used at the ANP project and other places, and if there is still some interest in this area, we would like to hear from the audience.

Another point is on the matter of roughing filters. The SRP Panelist has indicated the Savannah River experience, and I asked him if he knew anything about the comparison of life on absolute filters with and without prefilters, and Savannah River seems to be at some odds in this area, as compared to Hanford. Hanford didn't put roughing filters on their fire confinement system. I am not certain that the Savannah River had ever planned this, but in their metallurgical operations they always precede absolute filters with a dust stop or a similar filter. Most of the statistics we could gather in our survey indicated that this probably doubled the life of the filters. We had other

applications where this was apparent. So one has to get down to the question of absolute economics, which was mentioned yesterday, in that the prefilters might cost as much as the absolute filters; and the question arises, "Well, what is the point in doing it?" Or if one looks at a dust stop, which is a 50-cent or dollar filter, and get twice as much life out of the absolute, I think the economics are clearly apparent.

The other deals with NaK and Na, and special problems associated with them. I think this is one of our future concerns. We are concerned with the fast reactors; we are concerned with the SRE type, the sodium graphite reactor. We have had NaK fires in laboratories, and we have tried various solutions for this.

In our case, when we heard about this, we tried to develop a vinyl filter which could be washed, but this was not intended to be an absolute type filter. We have since seen that we could get paper made from Dynel fibers, or thermoplastic fibers, like polystyrene; there is not enough demand for us to have any filter manufacturer make it in absolute size or in quantity.

With the coming need for these type filters, especially if we go to fast reactors and must use sodium as a coolant, we will have problems where a filter must use sodium oxide or sodium potassium oxide, and we may need a much better filtration system than we have at the present time.

COMMENT: My comment isn't exactly relevant to your discussion, but I want to get it on the program somehow, and I think this is a propitious time.

Mr. Collins previously indicated that some significant portion of the iodine that is released will go into methyl iodide, which goes right back through the filter and is released; and, he indicated that the amount of methyl iodide that is formed seems to be related to the amount of organic material that may be in the atmosphere. So here is some kind of a correlation between a serious penetration problem, both with filters and with carbon beds, and an organic constituent in the atmosphere.

Mr. Brion indicated yesterday that some aerosols will decrease the filter efficiency; at least, in paper and cellulose filters. In our private discussion afterwards, we were speculating that because of the surface tension effect on the fibers, it might also depreciate the performance of other types of filters with other types of fibers. He indicated also in his private discussion that burdening a carbon bed with organic vapors, and he mentioned specifically paint solvents, would really interfere with the performance of a carbon bed filter.

Now I pose two situations where a burden of organic constituents could interfere with either a particular type filter or a carbon bed type filter. I am concerned whether anyone has looked at this problem to see what order of organic contaminants in this type of atmosphere would have what types of effects on the penetration of these types of filters.

PANEL CHAIRMAN: There is a difference of opinion as to the effect of tars on filters. Some of the work we did with incinerator effluents with tarring aerosols has indicated a serious plugging problem to the point where flow was practically decreased to zero, rather than a penetration problem. So I think you can get more than one effect.

UKAEA COMMENT: I think that having regard to the observations made by ourselves and at Harwell on the formation of methyl iodides where iodine is released into the atmosphere in various conditions, we ourselves have no doubt

that it can under certain circumstances represent a real problem, with which carbon filters are unable to deal. Undoubtedly, the ability of carbon filters to deal with methyl iodide, even up to the loadings which we find that they can effectively retain, may possibly be decreased by loading the charcoal bed with organic contaminants, which is obviously a problem perhaps of more concern to chemical processing operations than to reactors. But here we must not forget the work that is being done on organic reactors, where this may well be a quite severe problem.

COMMENT: At Hanford, I have looked at the effects of vapors on charcoal filters, and I find that the hexaclone does not interfere with the molecular iodine. I have also looked at the effects of oil droplets from aerosols, and there I find that this leads to increased penetration of the bed. I do not know whether it is because of the iodine going onto the droplets, or formation of iodine compounds.

AEC COMMENT: I have data to offer Mr. Dorman. On November 15, 1961, we checked a 1,000 cfm panel from Great Britain, which had been exposed to methylene blue with a cutoff rating of 0.01, sodium chloride 0.0035 penetration, and the DOP at Edgewood indicated 0.008, which was roughly twice the sodium chloride consistent with the particle size. I won't ask him to vouch for the makeup of the sodium chloride machine on which it was checked.

Dr. First, I think, had a question over here.

HACL COMMENT: I was going to accept your invitation to comment on fireproof filters by pointing out that the fire retardent resistance is largely a matter of construction, using fire retardent plywoods, rubber base cements, and so on. The upper limit is about 300°F, not that the filter will burn up at that temperature, but the organic materials begin to degrade.

On the other hand, using metal framed filters with glass fiber packing instead of cements and gas vapor made by asbestos or aluminum separators, the effective temperature limit is somewhere between 900° and 1,000°F., depending upon the resistance of the particular paper. All that will happen at high temperature is that the organic binders in the paper will burn off with a small amount of smoke, and the filter will degrade. For higher temperatures than this it is necessary to go to a ceramic material. It is possible to build a filter with ceramic fibers which will withstand temperatures to 2300°F. for an indefinite period. These were the filters that the Panel Chairman was referring to at the reactor test site, I believe. The primary objection to filters that withstand 2300°F. is their enormous cost, but there is a complete range of materials available where the need exists.

PANEL CHAIRMAN: Has there been any experience with mechanical failure of ceramic filters because they are brittle and cannot take much in the way of vibration or shock?

HACL COMMENT: Yes. I saw two installations at Merck Chemical Company about a year ago, in which ceramic filters were installed in a filter frame; I believe there were 16 of these units costing almost $1,000 apiece. No provision had been made for thermal expansion, and, when I saw them, each one of them was completely cracked and useless after about one day's operation.

COMMENT: What is the best means of testing carbon filters for iodine removal efficiency in-place? I don't know whether it is appropriate to this panel, but it doesn't seem to have come to an easy solution previously.

ORNL PANELIST: We have run a number of in-place tests for the SAVANNAH to

determine whether the charcoal absorbers are intact and functioning. In these tests mostly elemental iodine is injected into the ventillation stream about the place where the gas leaves the reactor compartment, and samples of this gas are taken before and after. The samples of gas are passed through charcoal absorbers and filters, and these collectors are radio-assayed to determine the efficiency. We have obtained consistently high efficiencies in these tests.

Sometimes it is inconvenient to perform radio-assay tests because of the possibility of contamination hazards. We have limited these tests to times when the ship is in a place where we can stand an accidental spill or at sea or berthed where there is enough confinement around the ship to prevent accidental exposure of the population.

For this reason, we have developed a method of testing which is similar to the radio-assay technique, except that we use larger amounts of normal iodine, without any radio-iodine, measuring by activation analysis. In the activation analysis we can detect a microgram of iodine readily, although background amounts of normal iodine limit our actual sensitivity to about 5 micrograms. This background iodine comes from the charcoal and possibly from the atmosphere.

COMMENT: I want to give a report from the stranded ship SAVANNAH. The methods just described for iodine checks work quite well when we are in port and we have every expectation of being out of port eventually. In the program, we have been working on instrumental methods of checking the filters, using stable iodine having cross-checked the instrument both with the Bureau of Standards and correlated it with the developments of some work that Mr. Adams has been doing at ORNL. It is not as sensitive a detector as is activation analysis. However, we can, on a go-or-no-go basis, determine the filter removal efficiency up to 99.8%. Since we are limited by hazardous evaluation to operate as long as the filters are above 99.0%, we feel it is good enough.

PANEL CHAIRMAN: Earlier this morning in the first panel, somebody had a question for this panel, and I haven't heard it repeated. I would like to have it now.

QUESTION: The question was with regard to testing in-place by means of stack monitoring devices. The sources suggested were possibly radon decay daughters and normal fallout that might be present, or possibly a known and controllable process stream being fed through the filters.

LRL COMMENT: The system using radon daughters and atmospheric dust as a test method to check filters was developed and has been used once since. There is no organized use of it in checking filters at this time.

QUESTION: The question I have relates to the use of pre-filters. Mr. Peters mentioned 15% DOP for the Demister. He also mentioned a 30% deficiency. He didn't mention what basis was used on that. If one were to specify a pre-filter to have a 50% DOP, is this a good way? Or should one use, say an NBS, either atmospheric or the dust? I am interested in the British use of pre-filters, what they have found in this regard as to recommended efficiencies and added life which you might expect toward the high efficiency filter.

UKCDEE COMMENT: I have some figures for pre-filters, which are glass fibers - rough glass fiber, 50% penetration initially to a standard dispersed cloud with a mass mean diameter of about a half micron. With this backed by what you might term an absolute filter against this particular cloud, the resistance area is about four or five inches, and the penetration of the filter had dropped 50% to 0.1%. Carrying out these experiments, we can use such a pre-filter. We can use about eight different pre-filters before the backing filter has risen

appreciably in resistance.

The use of pre-filters obviously must depend to a large extent on what the particle size is. Hard and fast rules cannot be made. We must know what particles are in the air before we can decide whether it is economically worth while to use a pre-filter. But it is surprising how a very, very poor pre-filter soon clogs up and becomes a good filter because of the deposition of particles on it. 50% from 1% is quite a large range in increased efficiency.

SRP PANELIST: We generally agree with Mr. Dorman. The 30 to 35 per cent I quoted on the Demister was for rural atmospheric dust at the works in the pilot plant area, with a particle distribution of about 1 to 40 microns, and a mass mean diameter of 3 to 4 microns.

I think the application of pre-filters has to be considered for each application. In our own case, I mention the fly ash problem, the mass mean diameter of the particles getting out of the stack and into the filter was about 3 to 4 microns. We feel there, that the Demisters are going to do a very good job as a dust cake is built up on the upstream face, and eventually extend the life of our absolute filters, which at the present time is very low - one year where we were hoping for three years. The Demisters we have a stainless steel case. We hope these have a life in excess of five years, since we have demonstrated they can be cleaned.

PANEL CHAIRMAN: Mr. Cheever's question as to whether or not DOP is a good test method for the other types of filters makes a good comparison if such equipment is available. But as to the correlation with NBS and any other test codes, there could be some doubt because of the size of those aerosols. They have a fairly wide size distribution, whereas DOP has a narrow spectrum, and complete correlation may not be obtained.

In screening materials a test like DOP has an advantage, in that some comparison is possible, but there is quite a shock when looking at something like the pre-filters of HB-2, and so on. When you run a DOP test and get zero for efficiency, these are oil coated filters and they don't respond at all to this particle size.

UKAEA COMMENT: To add to that comment on pre-filters, when used in buildings where the air is already pre-cleaned and the atmosphere inside consists of dust particles which are still below the 1 micron range, we are working on a pre-filter for use in conjunction with high efficiency filters, which would be of the superfine class fiber type.

SRP PANELIST: Our tests of Demisters, particularly filters and activated carbon units, in which we entrained moisture in the system, we found that the entrained water was saturated with iodine. So it is a matter of what that concentration is and what the entrained moisture is in your system. In some of our simulated tests, none of the iodine got beyond the Demister where we had a clogged condition.

QUESTION: In some of the other installations, the pads of Corning 115 glass fiber have been used for hot streams, where high reliability is required and more life is desired. I understand now that Corning is going to discontinue the manufacture of that fiber. That being the case, I wonder if there is a suitable substitute available for that service?

COMMENT: Owens Corning furnished some pre-filters made with 115-K which we used fairly widely in the program, and the fiber they have proposed to substitute for this, which is 135-C. The 135-C is rather a straight fiber. The

filters were placed in a single bank at Hanford for 18 months or so, and the dust removal was about 75 to 50, the lower ratio being the 135-C. Corning would like to discontinue the operation of the machine making the 115-K, because it is run only two weeks out of the year. Notwithstanding these results, they would like us to forecast needs and try to find a substitute, so that they can set about doing this. They do not have a definite date, and they will not give us a date for shutting-off that fiber manufacture.

QUESTION: I would like to ask Mr. Megaw in connection with his iodine releases in containment vessels, whether he has attempted to fractionate the particulate activity in the air to determine to which fraction of the particles the iodine seems to be sticking?

UKAEA PANELIST: The answer is yes. The first series, the ones we did in the containment vessels, was in May 1960. On this we measured the fraction of the iodine which would attach to particles, and we tried to get some idea of the size distribution. But it didn't work out very well. In fact, we didn't get any results that we could believe in, due to the fact that it was the first time we had done this and the equipment wasn't all that it might have been. But the results indicated that the disappearance of the particulate iodine from the atmosphere was a little bit faster than that of the nuclei in the atmosphere. I do not really know what this means. It could mean they are either smaller or larger. Certainly, the results could have been explained. We felt the results could have been explained if the iodine was attached to particles in the 1, 2 and 3 micron range.

We recently had the opportunity of doing several other runs last May. We had a sampling line which contained a four stage cascade impactor, plus a filter which we thought would take out most things above 1 micron. We then followed this with a diffusion battery on which we got some idea of the size of the inactive nuclei in the atmosphere; that is, the ones that didn't have iodine attached to them, and also the particles which did have iodine attached to them. These results came out fairly consistently, from memory, at 0.05 micron diameter.

PANEL CHAIRMAN: I am going to take advantage of the chairman's position here and say that unless some real stimulating question comes forth, we will consider that the panel has discharged its obligation right now. We are indebted to the panel members here, both from the U. K. and the U. S., for providing a very stimulating discussion.

PANEL D - ROUND TABLE SESSION
Thursday Afternoon, 24 October 1963

MISCELLANEOUS PROBLEMS TO BE CONSIDERED

a. Fume Hood
b. Plastic Materials
c. White Rooms
d. Particle Size
e. Rapid Determination of Activity
f. Iodine Sampling
g. Incineration

PANEL CHAIRMAN: Good morning, gentlemen. Panel D, Miscellaneous Problems To Be Considered, has the following panel members:

R. Dennis, HACL, Chairman
M. W. First, HACL
D. P. O'Neil, ANL
L. Gemmell, BNL
R. E. Adams, ORNL

You have probably observed in our list of subjects for this last panel we have material which cannot be attributed to any one category. We have had one paper on special type of materials used in fume hoods, but that subject has not come up to any great consequence in any of our discussions so far. Plastic materials have been touched on and we intend to cover that somewhat during our discussion. White rooms merit comment. Particle size has been treated to a great extent in many of our discussions. In rapid determination of activity we have had several general methods indicated, and our BNL Panelist has mentioned he would like to treat the subject specifically from the point of view of iodine monitoring. In view of the very enthusiastic response and interest in problems relating to iodine this is a worthwhile part of our agenda. If time permits, I would myself like to take the liberty of making a few comments on incineration problems.

The only instructions to the panel members is that we are pressed for time. If we can hold our comments down, as individuals, each to five to seven minutes, it would be quite helpful. At this time I would like to turn the discussion over to the BNL Panelist.

BNL PANELIST: My only reason for being on the program, I presume, is that we depend very heavily on monitoring. We have no ultra-filters in our reactor setup, and anything that goes along, we have to depend strictly on our monitoring methods.

The reactor* itself is a cube of graphite in which we move approximately 270,000 cfm of air through it for cooling. There are approximately 615 horizontal holes and about 4,900 highly enriched fuel elements. The flow comes up to the

*See "The Use of Activated Charcoal Iodine Monitors During and Following a Release of Fission Product Iodines," by Charles F. Foelix and L. Gemmell, p. 629.

center gap and flows bilaterally. It is monitored by moving tape particulate monitors. Inlet air filters are ordinary glass-wool to filter out the large "sticks and stones."

Other filters in the duct are filters that have been in there for 12 years. The filter efficiency is not high; it is only about 80%. After 12 years of gathering dust, we are looking forward to in-place filter testing very soon.

Slide No. 2 is a typical charcoal trap. The filter in the trap is normally changed at two- or three-day intervals, and the quantity of iodine-131 on the filters is determined by counting in a calibrated gamma spectrometer after sufficient time has elapsed to permit the decay of the short-lived iodides. After all necessary decay and samplings are made, the total stack release of iodine-131 is computed. The system is used primarily as an inventory monitor to measure accurately the total release of iodine-131 and it is not necessarily intended to pick up accidental releases.

During a two-day period about a year ago there were three distinct short-term releases of activity which were the result of a partial cladding failure in one of the fuel elements. Although these releases were not of serious proportions, they did provide valuable experience in the area of reactor effluent monitoring under emergency conditions. The three releases were characterized as follows.

On the operational monitors the north duct particulate monitor showed a peak and the presumption is that some material in the cooling air had been activated. The classic example is that a vehicle, an automobile or a stationary engine, operating near the air intake with the exhaust fumes being sucked into the reactor. When only one duct monitor shows a peak, it indicates that the activity has been released in that half of the reactor.

The Kanne chamber monitor responded promptly to full-scale reading and returned to a normal, which indicated a short, concentrated release of gaseous activity. The particulate monitor in the base of the stack showed a peak of modest proportions which would not in itself be cause for alarm.

The first release occurred at about 2100 hours on September 10, 1962. The next morning the charcoal trap was taken from the sample line and placed in the gamma spectrometer within ten minutes after removal. It was immediately apparent from the display of the gamma spectrum on the scope of the analyzer that a release of fission product iodines had occurred. The 0.365 mev photoelectric peak of iodine-131 was prominent, and almost as large as the 0.53 mev peak of iodine-133. Normally the iodine-131 peak is almost entirely masked out, and much smaller than the iodine-133 peak. Under normal conditions the reactor will release about 8 mc of iodine-131 a day. It was calculated that the first release totalled something in the neighborhood of 70 mc. The second and third releases contained 180 and 300 mc of iodine-131 respectively.

The problem of locating the fuel element is one of the things that would be of interest to you.

Needless to say a great deal of effort was being expended to find the source of the releases, but finding one or two damaged fuel elements out of 4,900 elements is a difficult and time-consuming task. Between the second and third release the reactor was shut down, and the elements in several suspected channels were inspected. These channels were suspected because of higher temperature readings on the thermocouples in the channels. The elements appeared normal, so the reactor was brought up to reduced power level, and shortly thereafter the third release occurred.

It was decided to reduce power level and take air samples from each fuel channel. The samples were taken to the charcoal traps and the traps were monitored with a survey instrument. One fuel element was found to be much higher than the rest. The reactor was shut down and elements in the channel were removed and inspected. Two of the four elements appeared to be damaged. One had a spotted appearance, and the other was badly blistered. Subsequent hot-cell inspection and testing of the elements proved that they were the source of release.

The reactor was again brought up to power. No further distinct releases occurred, but the stack samples showed that the iodine-131 being released was much higher than normal, initially about ten times higher and slowly tapering off to normal in about 20 days. It was theorized that some of the iodine from the elements had condensed or adsorbed on the duct work and exit air filters and was slowly subliming or exchanging out into the air stream. The analysis of the additional air samples taken on charcoal at the north and south duct monitors and at the base of the stack, supported this theory.

On September 15, about three days after the last release, a set of 24-hour samples were started, with samples taken at the north and south duct monitor locations, and at the stack. When these samples were analyzed, the following information was obtained: The ratio of iodine-133 to iodine-131 in the south duct was 8. The north duct was 1.4. And in the stack, 1.2.

The rate of release and the ratio found in the south duct was normal. The ratio in the north duct and the stack samples was not as low as one would expect for three- or four-day old equilibrium fission products. However, if the sample results were corrected by subtracting the normal amount of iodine-131 and iodine-133, the remaining activity shows a ratio of about 0.1, which corresponds to several-day old equilibrium fission products. Also, it was found that the amount of iodine-131 being released from the stack was almost twice the amount found in the duct samples, indicating that about 50% of the iodine-131 being released was coming off the filters.

These samples, then, supported the theory that the iodine released from the fuel elements had adsorbed or confined on the duct work and filters and was slowly subliming or exchanging off into the air stream. Subsequent experiments showed that the adsorption-exchange mechanism was the dominant one. In the course of trying to develop a new operational iodine monitor, stable iodine-127 was released into the reactor to produce iodine-128 to check the response of the new monitor. Each time this was done the stack charcoal iodine monitor showed a sufficient increase in the amount of iodine-131 present. The fact that iodine-127 is put in, and iodine-131 comes out indicates that even under normal operating conditions there is iodine adsorbed in the reactor structure which exchanges off into the air stream. This knowledge of the behavior of iodine suggests a method of decontaminating reactors or other structures.

The system of iodine monitoring in use at BNL has proved to be a satisfactory means of measuring the release of iodine-131 to the environment under emergency conditions. Although the cooling air effluent is monitored by other means, which indicated that something had been released, only the system using activated charcoal traps and gamma spectrum analysis could reliably indicate that a release of equilibrium fission product iodine had occurred and accurately measure the amount released. Other media tested by BNL and others do not have as consistently high collection of fission release as the charcoal traps. The system was also used for locating the defective fuel elements, and explaining the behavior of iodine within the reactor structure.

ANL PANELIST: What I would like to discuss is the change in philosophy in some areas of Argonne National Laboratory that have taken place as a result of corrosion problems we have run into in our analytical problems; we have introduced about 200 plastic hoods in the last two years. This was necessary because the chemists encountered corrosion products in some analyses in spite of using plastic sheeting, tape, and other coatings.

In some of the other hoods in which we have used approximately 6,000 liters of concentrated acid during the past ten years, we are still working with the same hoods. These hoods, which were cleaned regularly, were not satisfactory for the chemists. A testing program was started in 1959 for corrosion, heat resistance, decontaminability and fire resistance. Some of the materials tested were Hetron 92-55, a polyester with 5% antimony trichloride, 5% styrene laminate, a fiberglass reinforced material. PVC, vinyl, and some others were also tested.

As a result of these early investigations there were some heat tests; materials were placed on top of heating elements. The decontamination tests consisted of putting a Pu solution in various concentrations on these materials, and then cleaning them off. One decontamination experience which tended to direct them toward Hetron-92 was the fact that we had a Hetron hood from some previous work and the Pu was readily removed. Some of the other plastics in that hood could not be cleaned. As a result some large hoods were fabricated, 26" deep, 42" wide and 42" high. In-place fire tests were run on the hoods and the ducts, which were fabricated of the same material. A typical laboratory hood loading was used: Four $\frac{1}{2}$-gallon cardboard containers; two 1-quart cardboard containers; 18 empty 250 PV wash bottles; 48 sheets of Kleenex; twelve feet of $\frac{1}{2}$" inside diameter rubber tube; 10 feet of 20 mm polyvinyl sheet; 10 feet of absorbent paper; 1 pound of acetone; and some other items. I choose to think this was a collection of materials from various hoods, and that no one hood ever contained so much rubbish!

Five tests were performed. On the first test, using the Hetron 92-55 hood, in starting a fire in the acetone, the prefilter plugged at 37 seconds, and 30 or 40 people were driven from the building. The same test was run with a stainless hood, and it plugged in 100 seconds, or in about three times it took with the Hetron 92.

It was promptly concluded that whatever hood is used, a fire resulting in the plugging of a prefilter would result in the contamination of the laboratory. It was determined that a sealed extinguishing system was needed; it was tested in the stainless and worked. Tested in the Hetron hood, it worked equally well. When the extinguisher was activated at 11 seconds, in 60 seconds it was too far gone, and it was plugging.

The fire-extinguishing system then became an integral part of the hood. It consisted of a cylinder of CO_2, with discharge head, which could be manually or automatically actuated; a sealed nozzle to protect it from corrosion; two outlets in the hood; four in a double box, one in a glove box and two in a large hood; a heat detector located in the top rear of the hood; a switch that will actuate an alarm in the hood and cause an alarm to indicate at the fire board so that the fireman can respond on a single corridor, checking the laboratory for the noise and red button.

The hood costs about $1,000 for an order of 127. The stand on which the hood is placed, including the rheostats, the service controls, and electrical outlets costs about $156. The fire-extinguishing system for the 93 installed hoods costs $300, for a total of $1,456 for one hood.

The hoods are easily decontaminated. They have a safety glass front at 7-½°. The chemists seem more than satisfied. One small fire has left a small spot in one hood. A considerable amount of acid has been used without any detectable damage to the hood. Where the fire-extinguishing systems are to be used in our hot chemistry laboratories these hoods will be employed. There are none now being used in the wet chemistry laboratories. That concludes my comments.

HACL PANELIST: I would like to extend the remarks of the ANL Panelist about plastic structures. This came to mind from Mr. Boise's talk when he described a PVC blower which failed in a matter of a few weeks. This is perhaps unusual for this type of equipment, because plastic materials are coming into widespread use industrially and in general their service and performance is excellent.

I am familiar with one PVC installation which is working on fumes from aqua regia pots dissolving platinum metals which has been in operation for approximately ten years. I am familiar with many glass-reinforced polyester installations in pickling and etching service of a very severe nature, including hydrogen chloride, oxides of nitrogen, and hydroflouric acid.

One of the principal problems with rigid PVC construction is its inability to withstand vibration, and I wonder whether the blower which was described by Mr. Boise might not have become out of balance because of the deposition of particulate matter on the blades.

There are many advantages to the use of plastic materials. One is the specific gravity of glass-reinforced polyester, about 1.5, as compared to a specific gravity of 8 for steel, or perhaps 9 or more for alloy steels, which the plastic structure would be replacing. Even though the wall thickness for a plastic structure would tend to be larger, perhaps 3/4" wall thickness for a plastic structure as against 1/4" for a steel or alloy structure, there is still a net gain of about 1/2 in weight for the plastic structure. This, of course, makes it a lot easier to handle; smaller supports are required.

I have in mind one structure constructed of glass-reinforced polyester which was supposed to be the largest plastic structure ever built. It was a scrubbing tower of 10-1/2 feet in diameter and some 56 feet in height. It was shipped on a flatcar and erected in place with a crane; the structure is self-supporting. The point I am trying to make is that these materials are very useful and are solving many problems.

I was recently at a factory making this type of structure, and I was surprised to see they were making axial flow blowers of quite large size; perhaps four or five feet in diameter of glass-reinforced polyester; this is a real achievement in terms of strength and durability because the speeds of this type of centrifugal machines tend to become quite high.

Turning to the use of fibers, I think you have already heard something about the use of teflon fibers in the Demisters which have been discussed the last few days; of somewhat older service are saran fibers which we investigated at the Harvard Air Cleaning Laboratory back in 1950, and which have been in service for corrosive conditions in many installations since then. I believe there is an installation here at Oak Ridge that was installed within the last couple of years and is in continuous service.

In addition to saran, orlon and Dynel fibers are available for deep-bed filtration and for gas adsorption in scrubbing; all of these fibers have been woven into cloth or felted for use with industrial, cleanable bag filters.

One limitation of plastic materials is temperature. Polyester materials, polypropylene materials now are available with a temperature limit of 350°F. Teflon, of course, will go up to 450 or 500°F, at least for some limited period. Each year, when the reviews of plastic materials appear, the temperature limit seems to go up ten, or perhaps twenty degrees; we are continually finding improved materials of a plastic nature.

I would like to now turn to the White Room topic. A new Technical Order of the Air Force has recently appeared; it is a revision of Work Standards for Clean Rooms and Clean Benches. There is quite a voluminous report and I certainly have no time to review it in anything like its entirety. I would like to bring up the matter of a leak test or an in-place test for the filters for clean work stations, as they are called in this technical order. The test consists of a cigarette smoke aerosol generated by a hand-squeeze bulb from an ordinary cigarette; the detection mechanism is listed as some type of a smoke photometer. The smoke photometer probe is followed around the edges of the filter and across the face; if there is any leakage, the filter is improperly installed. No standard is given as to what constitutes a leak; that is to say, no percentage increase or ratio. We are pretty much left with the same sort of thing we were discussing this morning; namely, there are no standards except each person will have to decide himself what his particular standard is.

The thing in the TO that puzzles me is that if the group assembled here, with all the experience and know-how on absolute filters, cannot agree on what a proper in-place standard test would be, where are we going to go to find this information? Who are we going to ask? Most of the know-how is sitting right here in the room. I would like to suggest, as a final word, that perhaps we are talking about two different kinds of tests. On the one hand, the standard DOP test which is made by the manufacturer is an index of performance. It has no meaning in the sense that it corresponds to any actual situation in practice. I don't know anyone who is interested in filtering 0.3 micron DOP smoke in any plant in the AEC, or otherwise, and yet this test, or any other of the tests that have been suggested, provide a very handy index of filter quality.

Another type of test is the one made on site for the particular conditions that exist at an installation. This type of test can be focused on the particle sizes, the temperatures, the loadings, and so on, that apply specifically to that situation, and this is quite a different test, in my opinion, and I think the two should not be thought of as a single test. We need the specific tests for a specific installation. But I think we also need a test which gives us an index of performance to evaluate quality.

PANEL CHAIRMAN: To continue our discussion, I would like the ORNL Panelist to discuss the uncovered points in the iodine area.

ORNL PANELIST: To point up the iodine problem, it is interesting to note that approximately 50% of the papers presented at this meeting are concerned in varying degrees with iodine. This is to be compared with approximately 20% at the 7th Air Cleaning Conference. It appears that the iodine problem is larger than some had originally proposed. Over the past several years many methods have been studied and applied to the problem of iodine removal. We have scrubbers, high-temperature silver reactors, the low-temperature or room-temperature silver reactors, porous-solid materials such as silica gel, molecular sieves, and activated charcoal to name but a few.

Then we have the special methods of development, including the foam and diffusion board studies. I believe we will agree that at the present time the activated charcoal seems to be the best available solution to the iodine-control problem.

One field that we are just getting into now is the question of the other forms of iodine. This appears to be a different matter altogether. We can control, I feel, the molecular iodine releases. The other forms of iodine are different matters. The magnitude of this problem is still being defined. The lowered efficiency of charcoal for iodine present in off-gases from chemical processing plants is an excellent example. Additional studies appear to be necessary to identify and characterize the behavior of these other forms of iodine.

Another area deserving more attention is this area of in-place testing of iodine-control systems. What we need in the iodine field is a testing procedure such as the in-place DOP tests, but I probably shouldn't say that now, considering some of the remarks made here!

The use of freon adsorption in testing full-scale charcoal units is under study at Savannah River. Our English colleagues have tested the behavior of gas-cleaning systems, using iodine released within reactor containment vessels. In-place testing procedures are being studied at ORNL in support of the Nuclear Ship SAVANNAH project.

Those of us in the iodine field are still looking for a quick, simple test method. If any of you can suggest such a method, we would be most happy to receive it. That concludes my remarks.

PANEL CHAIRMAN: Taking advantage of my position as Chairman, I would like to make a few statements on the general subject under consideration. The first point I would like to cover is our impression and that of the AEC, particularly the Division of Reactor Development, with regard to a recent publication by the Bureau of Mines. The publication came into print after the 7th Air Cleaning Conference.

The Bureau of Mines has issued a publication ROI-6083 which suggests that there is available a working incinerator for the disposal of low-level radioactive wastes. My first reaction was that perhaps we had fallen by the wayside and had missed some more recent experimental data, but upon examining the report we found out that the Bureau of Mines had come to perhaps an entirely different impression of the serviceability equipment in contrast to the opinions that we had expressed at the previous AEC seminars.

We did receive communications from the field asking what our impression of the unit was, and until we received the final Bureau of Mines publications we could not answer. We discovered that the information presented was precisely what had been presented before, that no new experimental work had been done, and our conclusions of 1957, were that there was considerable experimental work to do before considering the BOMAEC 30 unit a functioning incinerator. One of the big problems at that time was the design of a gas-cleaning system which would handle any type of effluent produced with the typical laboratory-type wastes that one expects to burn.

Many of you recall we had unsuccessful experiences with the BOMAEC 30, perhaps partially due to modifications. The net result was that we could not produce an effluent that could be filtered with glass fiber bags, and evolving from that was the incineration package which Mr. Bloore discussed earlier.

As far as the Nuclear Defense Laboratory unit is concerned, I think that Mr. Bloore covered this quite well. We want to emphasize again that it is strictly an experimental unit, and there is considerable flexibility in the design of this package to permit a variation in the mode of admitting air, both as to quantity, velocity and direction.

We accept criticisms on the present grate design. We expect the Navy to follow through with some burning material, and in the experimental unit intend to use lightweight, cheap metal gratings of dimensions sufficient to prevent the actual fall-through of material, that is, a fixed grate. But we could see no point, in the experimental unit, of putting in any involved, rotating device which would require elaborate mechanical shields. What has been presented as a grate design we recognize as only a temporary device until we have time to iron out some of the burning features, and the same applies to the charging hopper which is also subject to many criticisms. This was just one simple way of getting the material into the unit while the fire was under way, then permitting drying.

A loading fork is used, and the sensible question has been put, "What if you forget and leave the loading fork?" I dare say, if you were loading it with stainless, it would melt in no time at all! During the experimental work we know that Mr. Bloore will be alert and see that the fork doesn't stay in the fire!

Our experience was, in the laboratory studies, that one minute would be required to take a charge containing 90% moisture; one minute's exposure to a hot gas had dried it sufficiently so it could be dumped on the grate without interfering with the burning.

I have had a chance to discuss incineration problems with a few people here. One question was brought up as to the matter of charging intermittently; our philosophy has been that if an incinerator is charged intermittently we would experience the whole process of heating up through any refractory materials. During this period combustion products will be high inorganics, and constitute rather a difficult filtering load.

The matter of using fabric bags has again been brought up. We did find that glass fiber bags did do a fair filtration job with the BOMAEC unit, provided that the unit was burning properly, but whenever difficulties were encountered there was a strong tendency to plug the fabric, and consequently a rapid rise in resistance; because of the nature of the fabrics themselves and exposure to acid materials there was a tendency to rupture along the seams.

Plastic media, or vegetable fibers, do not seem to be a safe way of handling filtering problems when considering the fire problems. Even if water sprays are used to precool the stream, the eventuality must be faced that water power may be lost and the filter bags burned.

As far as the wet collection is concerned, it sounds easy, and if the facility is to handle the liquid-waste problem, a wet-collecting system might handle the effluent. However, there has been a rather sad experience in some locations in the field due to corrosion.

The net result? I do not think there is any incinerator yet on the market which will solve anyone's waste-disposal problems. I hope, as a result of Mr. Bloore's test at Edgewood, that we can eventually come up with something more fruitful.

With regard to iodine, which has been sort of a pet peeve for several years, I would like to mention that with carbon tetrachloride and iodine-131, salted with iodine-137, we did find in the high concentration range that there was no effect whatsoever in the efficiency of Columbia-type activated charcoal. However, it is not a realistic type of test aerosol, and we certainly would prefer to use some other type of material. You might even feel that the carbon tetrachloride might be an adjunctive selection. In this case, it is a pretty

darn good solvent for iodine.

A few questions might be posed on the degree of fixing iodine to charcoal beds; what type of creep might or might not be expected; what type of interchange we might get if we are testing iodine filters with normal iodine, with loadings of many orders of magnitude higher than anything we would expect as a radioactive form? We are also interested in the N. S. SAVANNAH program.

COMMENT: We got into the instrument problem because of the problem of the N. S. SAVANNAH being a mobile reactor, and the requirement to test the filters for iodine retention. We cannot depend upon the use of iodine-131 when we are away from certain places in the United States; there is no source of iodine-128 aboard the ship, and we use 25-minute life material when we are away from the coast. It takes several weeks to get activation analysis results from iodine-127 tests. We had to have a ship-board means for testing the iodine penetration of the filters.

Contrary to the situation at National Laboratories or shore-based plants, we cannot afford to keep a chemist aboard the ship for wet chemistry work and we have the problem of training a technician to interpret a routine chemical analytical technique.

Having checked various methods we selected the electrical conductivity meter, which is based on a small flow of potassium iodide solution over an electrode. The sample air stream also passes over the electrode and the difference in conductivity is read on a recorder. A strip-chart record is available. If we all work on a simple system perhaps we can develop some way to cut our filter checking costs. We will have a report published on this very soon.

UKAEA COMMENT: I thought that following Mr. Dorman's description of the method, that you might like to see photographs we have taken, in order to analyze the effect of particle size and penetration. The left-hand side of Figure 1 is of the unfiltered cloud of sodium chloride, and that on the right-hand side is of the same cloud after passing through a 99% efficient filter, a fiberglass filter, of the aerosol type; and this seems to show not only an absence of the larger particles, but a pronounced absence of the smallest particles, as well. Figure 2 shows the sheet with three curves obtained at three different velocities in the filter, indicating very clearly the maximum particle size penetration and the peak penetrations in each case. As I said earlier they are two or three times the average penetration for the whole cloud.

As a matter of further interest, this is based on the use of sodium chloride which is a cubic material we are hoping to extend to plutonium, which is also cubic, and because of the fact the shape factor is eliminated we would expect that we could show an effect directly due to the density variable.

PANEL CHAIRMAN: Is there any significance to the apparent shift toward a slightly smaller diameter with the velocity, or is that the way the curves came out?

UKAEA COMMENT: We think there is just a technical effect due to velocity which gives a shift to a smaller particle size.

PANEL CHAIRMAN: Thank you. Having already gotten out of sequence, I would like to try to get into sequence again and entertain comments or questions from the floor directed toward Mr. O'Neil, and possibly Dr. First, as a bit of overlap in the experience, there; and as far as fume hoods and plastic materials are concerned, I think you can direct your questions either way.

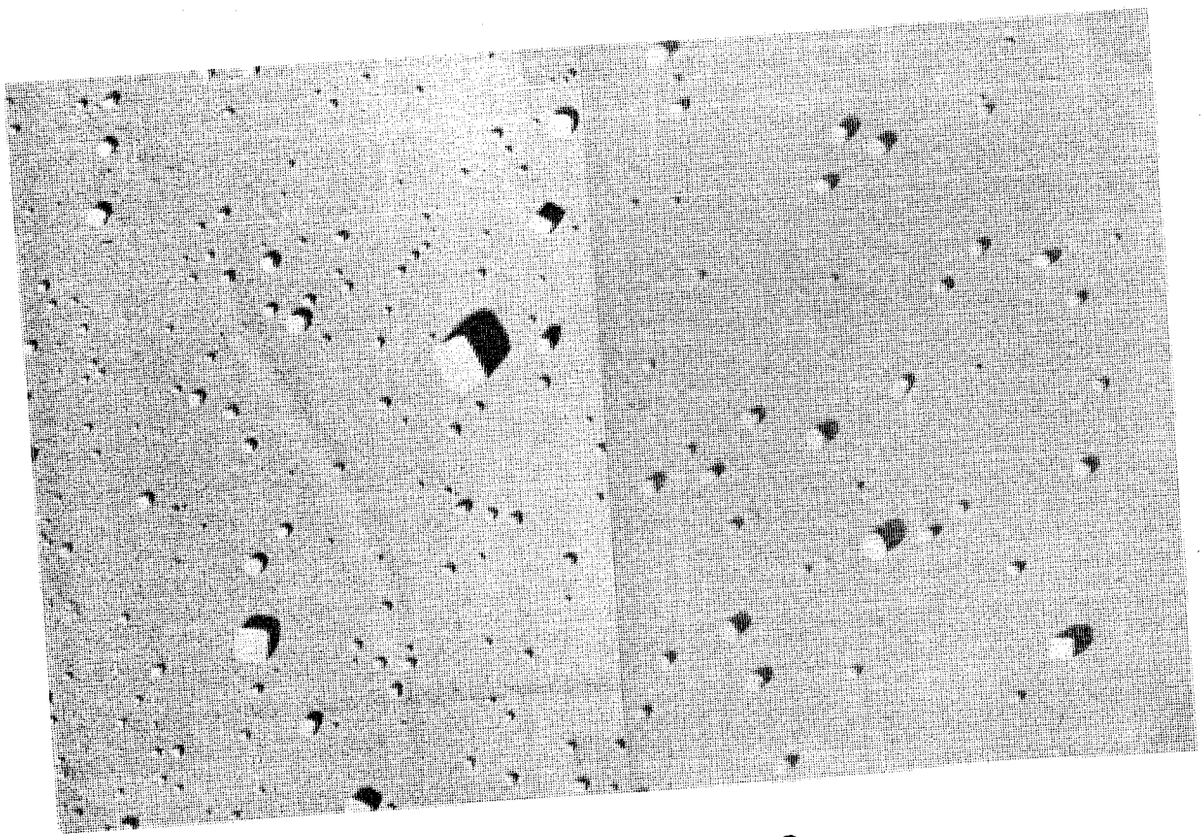


FIG 1 ELECTRON MICROGRAPHS OF SODIUM CHLORIDE

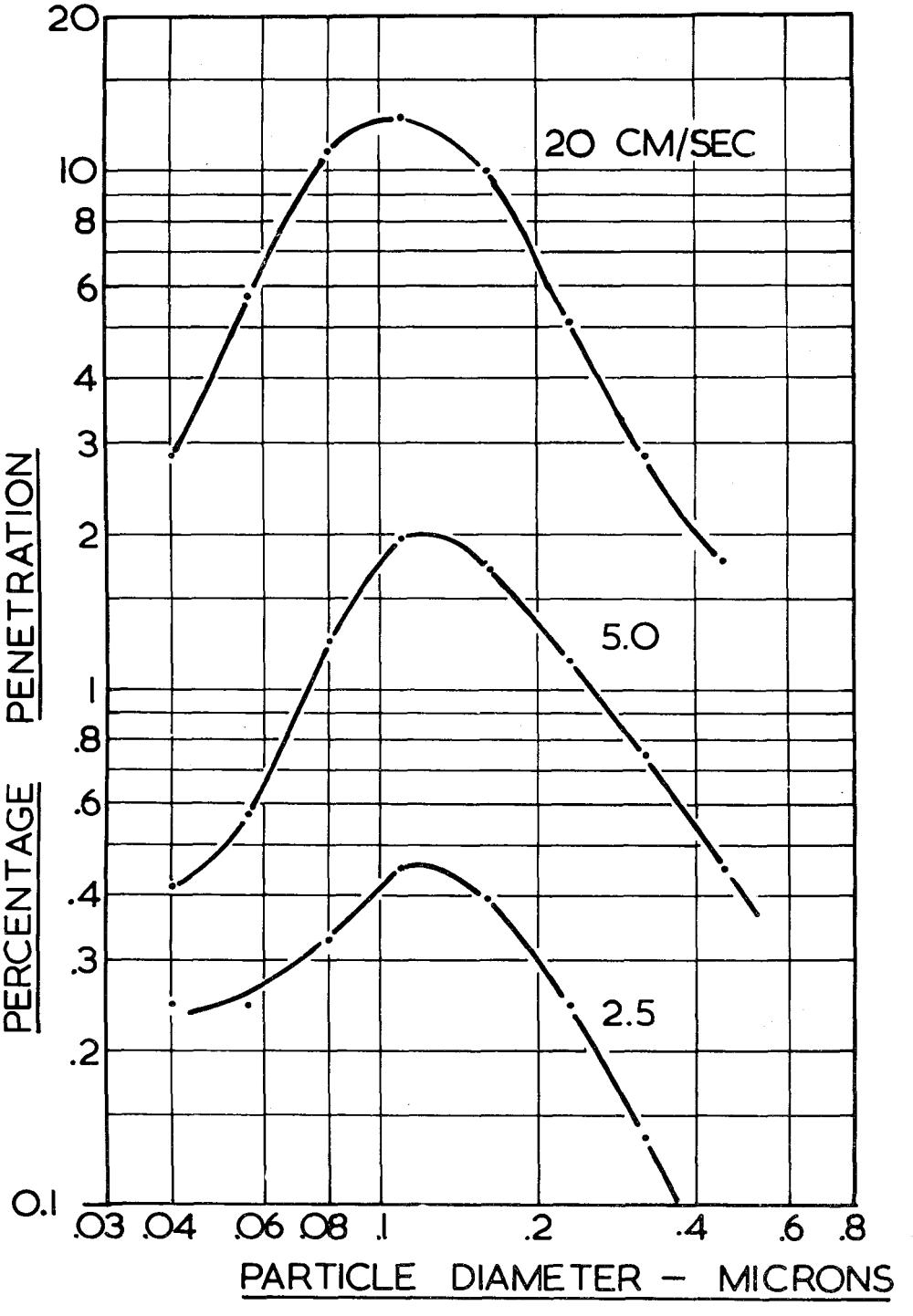


FIG 2. PENETRATION v PARTICLE SIZE FOR SODIUM CHLORIDE.

NLO COMMENT: I would like to clear up the HACL Panelist's assumptions, and perhaps apologize to him for misleading him in the assumption that we did not like PVC. Actually, we have carried on quite an expensive program in testing plastics, and we find that PVC is a very good material. We are in the process of doing some design work for hoods in PVC, and with duct work. The scrubber blowers were PVC. They were direct-driven, and were furnished as an integral part of the scrubbers. We found, on examination, that there was very little erosion but no deposition. Erosion of the PVC itself was a mis-engineered proposition due to the fact that the manufacturer used a greater peripheral speed than the PVC could stand, and they actually flew apart.

I would like to also ask the ANL Panelist if he has any data regarding the concentrations of the acids, and the types of acids that he used in Hetron polyester hoods, and if he knows what the face velocity of air intakes were across your hood faces?

ANL PANELIST: About 135 foot per minute. I do not know the acid concentrations.

The tests that we ran on the materials, but not in a fabricated hood, included immersing these sheets in concentrated HF, HCl, nitric, and sulfuric for periods up to months both concentrated and dilute. It consisted of exposing panels in hoods where this type of work was going on for months. We did have one early hood (or glove box) used for all our Pu operations, before Pu became so common at the Laboratory. Acids were used extensively. I cannot tell you how much, what kinds, or when, but I know they were used with no problem of corrosion or deterioration of the surface.

NLO COMMENT: We had some tests run on several similar plastics and rather than running them immersed in the concentrated acid solution, we suspended them above a flue system in heated vapors at about 100° up to 150° and found quite a bit of degradation with the percholoric, and also with concentrated nitric acid.

PANEL CHAIRMAN: After all that acid left the multiple-eductor units on the roof, did you experience any difficulty with automobile paint or painted structures? It appeared to me there was a little bit of rust on some of the assemblies on the roof that was intimately associated with the eductor unit itself.

NLO COMMENT: The particular tests that we ran were closed. In our general operations we had no concentrations up to that amount. The rusted units you saw were the results of a concentrated nitric acid atmosphere from another stack. These, incidentally, are on the roof of the building approximately 50 feet high.

QUESTION: Relative to the use of plastic materials, the AEC design criteria makes use of the NFPA Code. How do you justify the use of plastic materials? The Code mentions metal duct work.

ANL PANELIST: We have received approval for the installation of these hoods, not only the hoods, but the lateral duct work, vertical duct work, glove box, holders right on through the entire new hot chemistry laboratory attached to the Chemistry Building.

QUESTION: Were concessions made such as having additional sprinkler protection?

ANL PANELIST: No. We do not have additional sprinkler protection there. We do have the fire protection systems integral with 93 of the 127 hoods. I know of no other concession we have made.

QUESTION: I am somewhat surprised on the use of CO_2 for two reasons. One, the great turbulence that you get in the hood, which does cause, if you have any contamination associated, a great spread of contamination will result with the use of CO_2 in the hood or particularly in the glove box. Secondly, was consideration given to use of the dry chemical compounds in preference to CO_2, because of much greater fire-kill capabilities?

ANL PANELIST: Yes, dry chemicals were considered. A number of tests were run with the CO_2, in which CO_2 was discharged through .04" diameter orifice, I believe. The pressure never went positive in the hood, and the fire was extinguished on about a half square foot surface of kerosene and alcohol in a matter of 20 some seconds.

The tests in an open-faced hood did result in small amounts of the CO_2 coming out into the room, and that is the risk that they were willing to take; the contamination of the room, as opposed to more extensive contamination if no extinguishment was used at all; or in effect, the ruination of the experiment if dry chemicals were employed with possibly plugging of the filter.

QUESTION: Might we infer from the possibility of plugging of filters that efforts at fire-resistant filters may be not as important as arranging quick detection and termination of exhaust ventilation, if we must realize we are going to plug up and contaminate our work area anyway?

ANL PANELIST: We tested the speed of response to our sensing element, and we found that 500°, it would respond within 6 seconds. At 160°, that temperature was required, I think, for a little over a minute.

QUESTION: Are any precautions taken against accumulations of perchloric acid in the plastic, duct work, or in the filters perhaps?

ANL PANELIST: We have done our utmost to discourage the use of perchloric. There is a small perchloric scrubber in use at the present time which will confine, I think it's 90%, of the perchloric to the scrubber itself.

In addition, in open-faced hoods we use a perchloric scrubber that was developed by Dr. Silverman at Harvard, or modifications, in three or four of our laboratory hoods.

We have had so far no untoward incidents as a result of the frequent replacement of duct work which we have had to do.

PANEL CHAIRMAN: I would like to thank all the panelists for improvising considerably and abbreviating their discussions. And at this time we will turn the meeting over to Mr. Belter and Dr. Silverman.

FUTURE BUSINESS AND CONCLUSION OF CONFERENCE

MR. BELTER: I would like to get some kind of general reaction to the type of session that we have had today. Would anybody care to make any comments concerning this informal, round table type of discussion. I have had one comment that perhaps we should intersperse these types of panel discussions with the formal type of presentations that we had the first two days. In other words, maybe have something like five to six formal papers in the morning, and then maybe have the informal type of round table discussion this afternoon.

I am sure that all participants have been well aware of the wide variety and different aspects that we have attempted to cover in a period of three days. The first day was devoted pretty much towards fission product release studies, and followed up by some of these experiences in the second day on containment and confinement studies, especially at production sites like Hanford and Savannah River. The work that has been covered by Dr. Silverman, and the newer type of containment approaches, like diffusion board, and the foam encapsulation studies was also presented. Then we covered a wide range of subject material in today's four panel sessions; in one afternoon four papers were presented that had to do with the meteorlogic aspects of air cleaning. I am wondering, in view of this wide variety of subjects, do you think that we have really covered the field? What have we missed in this 3-day session that we should perhaps plan for maybe when we have the next meeting?

Are there comments or suggestions on other types of subject matter that we should attempt to cover, even in view of what we have tried to do here for three days? It has been mentioned that one person feels that we should bring out the need to consider fuel reprocessing problems. In this respect maybe we need more emphasis on the krypton-85 and tritium problems. This is one area that we did not cover at all. While we certainly didn't have any papers on rare-gas recovery methods, we had one paper on rare gas or noble gas detection methods. This is an area that we should attempt to cover in any future meetings. Is there anything else that we should consider as a possibility for future agendas?

DR. FIRST: This is an extension of the remarks I made a few moments ago. I wonder what the reaction would be to perhaps forming a committee to propose standards for in-place testing, or these other subjects which have come up and been of somewhat controversial view.

MR. BELTER: Certainly that is a good point. I agree with your previous statement that perhaps there are more people in this room right here that have the very basic background experience for developing standards in this area.

MR. BLOORE: A quick look has been taken to see if the ASA was interested in this type of standard. It is to be discussed at the next meeting.

MR. BELTER: This is a point that we probably can bring to somebody's attention at the next ASA meeting.

MR. SHAVER: It will be of interest to us in our new low-level radiochemistry building at Hanford to have specification considerations with regard to requirements that might be associated with Clean Rooms, and any other

experience that might be outstanding to date.

MR. LIEBERMAN: In the last several years there has been a new organization, the American Association for Contamination Control, which has been devoted essentially to Clean Room operations, and it has a good background of experience in Clean Room operation and design, which is available from the members of this group. I think that this might be a reasonable organization to give you assistance.

In addition to that the ASTM has a committee which also has connections with Clean Room problems.

MR. HUMPHREY GILBERT: The GSA will issue a Federal Standard on Clean Rooms. The work was done by Sandia and the Albuquerque Office; it has been reviewed and there have been hearings on it and there will be three orders of Clean Rooms.

MR. BELTER: At the beginning of the meeting I mentioned that perhaps everyone should give some thought to whether it would be desirable to have a laboratory training session like the one we held six years ago at Harvard. I recall it lasted for two days and was held prior to the regular meeting; it certainly involves a lot of work for Dr. Silverman and his group.

If there is enough of a need or demand for this type of training session we in Reactor Development would certainly seriously consider sponsoring or supporting this type of work in conjunction with our next meeting.

DR. SILVERMAN: These sessions consist of general orientation as to what you can expect from various types of air cleaners. There is a session on checking performance of a typical air cleaner, and a session on particle sizing, measurement, and there is one on behavior of sampling instruments. We cannot dignify them by saying they are laboratory sessions. They are more on the order of demonstrations for familiarizing people with the general concepts of air cleaning principles and practice. We would welcome enthusiastic interest on the part of no more than 40!

MR. BELTER: Perhaps maybe we could just have a show of hands right now of the people here who would think that either they themselves, or somebody in their immediate organizations, would find this to be quite useful. It looks to me approximately like somewhere between 15 and 20 hands. For the others, if you think this would be desirable, drop us a line after you discuss it a little more at your sites and let us know what you would feel would be useful in this area. Depending on the response we get, we could determine whether it would be a good thing to do for the next meeting.

Of course, that leads right into the next point, i.e., where the location of the next air cleaning conference should be. If we have the training session, or orientation meeting, this would almost of necessity cause it to be held at Harvard. If we do not have that type of session, however, we then could think in terms of some of the other sites. I have had several suggestions that it would be nice to have a meeting like this over at Harwell or Paris. About the only major sites that have not hosted the Air Cleaning meetings are Hanford and Savannah River, the two large production division installations.

MR. KEIGHER: I don't know who at Hanford ought to be offering an invitation, although there are many of us here. Our new Federal Building, the framework of which is partially up at the present time, will have a very handsome auditorium that will hold 300 people and will undoubtedly be finished by 1965. It will not be finished next year. I am not extending an invitation,

but we may have the best facilities that Hanford has ever had for technical meetings ready within 24 months.

MR. BELTER: Fine. Actually, we weren't looking for definite or specific places, unless somebody had a pretty strong feeling about it. I think we will let that point go and wait and see what response we have for a training session thing, and then decide where the next meeting would be held.

Perhaps Dr. Silverman would like to make a closing comment or two, and I have a couple of other things I would like to mention after that.

DR. SILVERMAN: On behalf of the non-Oak Ridge, non-AEC official delegates, I would like to take this opportunity to thank the Oak Ridge National Laboratory, and Union Carbide Nuclear Corporation, for being the host and for giving us what I think is an excellent session room.

All things considered this has been, in my opinion, an excellent meeting, and on behalf of all of you I am sure you would have the same feeling; we should thank the help we have had here, which has been outstanding.

MR. BELTER: Thank you, Dr. Silverman, and certainly on behalf of the AEC I want to express our appreciation, too, for the excellent facilities that we have had here. One other thing I would like to do at this time, too, is to express our appreciation to the Division of Reactor Development, appreciation to Dr. Silverman and his group for the invaluable assistance that they have given us in developing this meeting, and as usual, in helping to run the meeting.

We are certainly pleased to have the number of foreign participants that we have had here, and they have made a very valuable contribution to the overall program. We are always pleased to have representatives here from our friends in the UK, from France and Canada, and whatever other countries can make it to these types of meetings. We are very pleased to have you with us, and we hope that your subsequent stay here in the States, and your visits to some of our sites, will be useful and rewarding.

For those who do have to leave at this time, we are sorry that you do have to go. However, I still think we have time, here, for some of the questions that were not raised at the time of the first and second panel meetings this morning, and if those panel members are still here, and you would like to continue, we certainly would be prepared to go on. So we will bid a pleasant adieu to those who must leave right now, and certainly would like to keep the rest of the meeting going as long as the group desires.

There were a number of questions not answered during the sessions.

I was wondering if the NRL Panelist could perhaps go into a more detail in describing or elaborating on shock-testing method used for filters, and also what type of environment is this shock-testing method being used for in the Navy? Of course, what I am thinking of principally is thinking in terms of the application to our own nuclear-powered ships.

NRL PANELIST: These are standard Navy specifications for shock and vibration. They have been established over the years, mainly to insure that any piece of equipment that goes aboard a ship will be predictively capable of withstanding the environment one expects.

Of course, ships vibrate particularly when you back down after going at flank speed! This is a standard check which every ship must be able to perform on their trials.

The vibration tests subject the equipment to increasing frequency and amplitude on a vibrating table. The equipment must be capable of performing to the specifications after such environmental tests equally as well as before.

The shock test depends upon the size and mass, and actually there are three different size shock machines. The filters were actually subjected on the medium sized shock machine, the hammer is about the size of my body, and weighs several hundred pounds. The filter is mounted in such a fashion that the three dimensions will achieve a certain predicted level of shock. It is a very dramatic test to witness, to see how the filter attempts to jump out of its housing, when the shock is applied. The filters we have tested were able to withstand, I believe, to the third or fourth level of shock intensity. The hammer is lifted up to different heights before it strikes the table on which the filter is mounted; each filter failed at about the third or fourth level. We did not use a new filter each time, because the equipment is actually supposed to withstand each of nine blows. Each of eight filters passed the vibration test. None of them passed the shock test which follows a standard specification derived through the years. Of course we don't expect each piece of equipment to have to be constantly in that environment, but it has to be capable of withstanding that environment.

COMMENT: I was going to comment on the validity of specifications to the environment. Merchant ships do not have guns on them. We went over the standards with the David Taylor Model Basin personnel, and their calculations of what the vibrations would be on the SAVANNAH, which we had checked out with vibrometer studies during the few times it had been to sea, and we decided as for the standards we were not going to have any part of it. It was just useless.

NRL PANELIST: There were three types of damage that were noticeable. In one type under shock the separators came through the paper, actually punctured through the paper. In another type of damage it was a cross-cutting. The corrugated edges would actually shear the paper like scissors. A third type was simply a complete rupture of the seal. An unusual type was the filter with the pressure glass mat surrounding the core, between the frame and the paper core. In this type the separation occurred so that the glass paper actually came out of the filter; it was actually a matter of differential forces involved.

QUESTION: Relative to the problem of charcoal I would like to know what effect DOP smoke would have on charcoal as far as depleting its efficiency?

HASL PANELIST: DOP goes through a charcoal bed without very much trouble, 95% or more. As far as DOP vapor is concerned, this vapor pressure is pretty low. I wouldn't anticipate too much trouble. You should cut the DOP test as short as you can conveniently, because you are going to do some damage to the carbon bed, but I think it is going to be pretty small.

QUESTION: I wonder if someone here could comment on the Dynel supply air filter performance and economy, compared to other filters of this type?

COMMENT: At the Naval Research Laboratory, as part of our submarine habitability program, we looked at Dynel as a prefilter. We ran it at standard flow conditions and found an appreciable penetration. It is about equivalent to the Navy Standard metal mesh filter. I think the Farr units are comparable to the Standard Navy ones. It has a further disadvantage that ruled it out as far as our application in the ship as it decomposes rather readily under high temperature conditions. It has a defibering quality that will allow the fibers, which are not tightly bound in the mat, to go on into our electronic instruments and they collected in some of the areas that were very vital for us.

We are now looking at some of these micropore polyurethane materials that seem to have some of the advantages; they decompose into only oxides of nitrogen under fire conditions, and they do not have any fibrous blow-off. They have approximately the same filtration performance as Dynel but they have slightly higher pressure drops.

COMMENT: This is not a technical question, but is a point of view that I believe requires open discussion.

What are we achieving by our expenditures for experimentation, theoretical studies, and development work unless this can be translated into acceptable engineering safeguards as far as site criteria for power reactors go? If we cannot achieve an economic benefit by obtaining sites closer to centers of resident or trade population, why are we spending on containment and filter work? This is a philosophical, a non-technical question.

QUESTION: I would like to ask you if you think you could get the SAVANNAH into a port if you did not have some filter systems on it that were backed up by large masses of data taken from the laboratory?

COMMENT: We have large masses of data; lots of it. Don't forget those filters have been sitting in that ship running continuously since last January.

But the problem is, when you get into a political or social situation how close can you bring a reactor into a large city? The immediate question is: "Well, maybe your filters aren't as good as they are supposed to be. Let's cut the filter efficiency down." In that way you will keep the circle the same as it was before you made any other equivalent improvements in the ship.

So what we have got is the fixed distance established by 10 CFR 100, and engineering safeguards are not being given full credit.

Therefore, why spend money without an economic return?

I agree with what you asked. We have reams of technical data.

MR. BELTER: I think, though, we actually do not have data of what would happen under accident conditions. We have never had an MCA, so we have never had to test out the efficiencies of these various cleanup systems. These certainly will be tested in these various types of engineering demonstrations, and tests that are being planned starting off with the Nuclear Safety Pilot Plant work at Oak Ridge, and later scale-up. We hope, in what is called the Containment Test Facility and also perhaps in the large-scale installation which is now in the planning stages out in Idaho that these types of cleanup systems, everything from sprays to the different types of high efficiency filters, and charcoal beds, and whatever other type of cleanup systems which might also be developed in the next two or three years, will be tested in these facilities.

Of course, the basic question arises then when we do get that data, how much of it will be accepted as engineering safeguards, or in lieu of distance, as far as reactor siting is concerned? Right now I do not think this is a question that perhaps can be answered, but we certainly pose a very perplexing type of question. It is not entirely a technical question involved; there are many other political-social aspects that are involved. If you are sitting in a position of having to review these reports from a licensing standpoint there certainly are a lot of other pressures that are brought to bear.

PANEL A CHAIRMAN: As we stand today, the greatest engineering advance that could be made in contamination control would be to investigate and approve the efficiency of high-efficiency systems. I think this is the greatest need now; from there we can go on to new developments in filters and filtration. But in the case of systems today, they need work. I am not worried about the Laboratory today: the systems have been tested, and we know what the efficiency of each system is; we know what it handles. But, we haven't provided this service around the country to other installations. Many think that when a high-efficiency filter is installed in a system, there is a high efficiency system. We have found, on the first test, efficiency order of magnitude 2% on up. Thank you.

MR. BELTER: Are there any other questions or statements that anyone would like to make at this time? We have arrived at pretty much the elastic limit of our open or formal type of questions.

COMMENT: We have been sitting here for three days and we have heard some interesting things about filters. We have heard, for example, how many hundred pounds of steam have been passed through a filter at seven times the rate of flow. They have been heated to 700°F. We attack them with DOP, and others attack them by hitting them with hammers that weigh about 300 pounds. All of this testing is to evaluate filters; actually we have to admit that we have got a pretty good product that we are hitting, pounding, steaming, and burning!

MR. BELTER: That's a very good comment. Does anyone else have anything they want to say at this time? If not, I think we will formally adjourn this part of the 3-day meeting, and as was announced be prepared to start on the Tours at ten minutes before 8:00 tomorrow morning.

TOURS - Friday Morning, 25 October 1963

8:00-10:30	Tour A. Oak Ridge Test Facility, ORGDP (US Citizens Only)
8:00-10:30	Tour B. In-Place Filter Testing Facilities, ORNL (For Persons Not Attending Tour A)
10:30 -12:00	Tour C. Central Off-Gas Treatment Facility and Nuclear Safety Pilot Plant (All Attendees)

Friday Afternoon, 25 October 1963

1:00-3:30	Tour D. General Plant Visit Around ORNL
1:00-2:15	Tour E. In-Place Filter Testing Facilities, ORNL (For Persons Who Did Not Attend Tour B)

SUPPLEMENTARY PAPERS

IN-PLACE TESTING OF HIGH-EFFICIENCY FILTERS AT ORNL

E. C. Parrish and R. W. Schneider

Oak Ridge National Laboratory

ABSTRACT

In most exhaust systems the high-efficiency filter is the primary means of minimizing atmospheric contamination during normal operation or during the accidental release of radioactive particulate material. Any effective contamination-control program must include a routine test for measuring the filtration efficiency of each system with its operational filters in place. The program of testing filter systems in situ at this Laboratory has clearly demonstrated the importance of this contamination-control technique.

INTRODUCTION

During the last three years the Oak Ridge National Laboratory (ORNL) has been actively engaged in the inspection and testing of high-efficiency filters. Since March 1961, over 1500 new filters have been checked for stores stock. Since November 1962, more than 1000 in-place tests have been made to determine the filtration efficiency of actual operating filter systems.

It is obvious that one cannot have an efficient system unless sound filters are used. It is also obvious that the use of sound filters alone does not ensure an adequate system efficiency. It is for this reason that ORNL has emphasized the importance of testing installations in situ at a prescribed frequency, after every filter change, and when there are reasons to suspect that filtration efficiency has deteriorated.

Stack monitoring is also an important contamination-control technique. In some instances, however, systems may contain very little activity

except in the case of an accidental release. In these cases stack monitors will only announce the release of activity to the atmosphere if the filtration efficiency of the system is unsatisfactory.

The method ORNL uses for testing filter systems is basically the same as that employed by the AEC Quality Assurance Stations for testing individual filters, except for the method of generating the aerosol. The thermal generators used by the AEC stations produce an aerosol of dioctyl-phthalate (DOP) with an average particle size of 0.3 μ. Since thermal generators are not suitable for field work, ORNL employs air-operated generators, which also produce an aerosol of dioctyl-phthalate, but with a slightly larger average particle. The difference in particle size is not considered important. Tests on single filters which were previously checked by AEC Quality Assurance Stations show excellent agreement.

IN-PLACE TESTING PROCEDURE

The testing of filter systems in situ is not difficult. The procedure used by ORNL consists in discharging a polydisperse aerosol of dioctyl-phthalate, produced by atomization of the liquid with compressed air, into any convenient air intake ahead of the filter bank. The concentration of the unfiltered smoke is measured by drawing a sample from the duct ahead of the filter bank and passing it through a forward-light-scattering photometer. The concentration of the filtered aerosol is then measured from a sample withdrawn downstream of the filters. The filtration efficiency of the system is calculated from the two concentration values.

In general, the in-place test is conducted according to the procedure described above. In a few instances it has been necessary to modify the basic technique to circumvent physical limitations imposed by the particular installation. For additional information, see Report ORNL-3442, Tests of High-Efficiency Filters and Filter Installations at ORNL.

Figure 1 illustrates one type of photometer used by this Laboratory. The air-operated generator (Fig. 2) was developed by the Naval Research Laboratory particularly for field applications. Figures 3 and 4 show the removal of an upstream and downstream sample, respectively, during an in-place test.

When an in situ test shows that the efficiency of the system is unsatisfactory, the source of the leakage can be found by probing the downstream side of the filter bank. One method of performing this operation is shown in Fig. 5, except that the door to the filter house was left open for photographic purposes. Leaks are indicated by the erratic behavior of the needle on the amplifier when the probe picks up unfiltered aerosol particles.

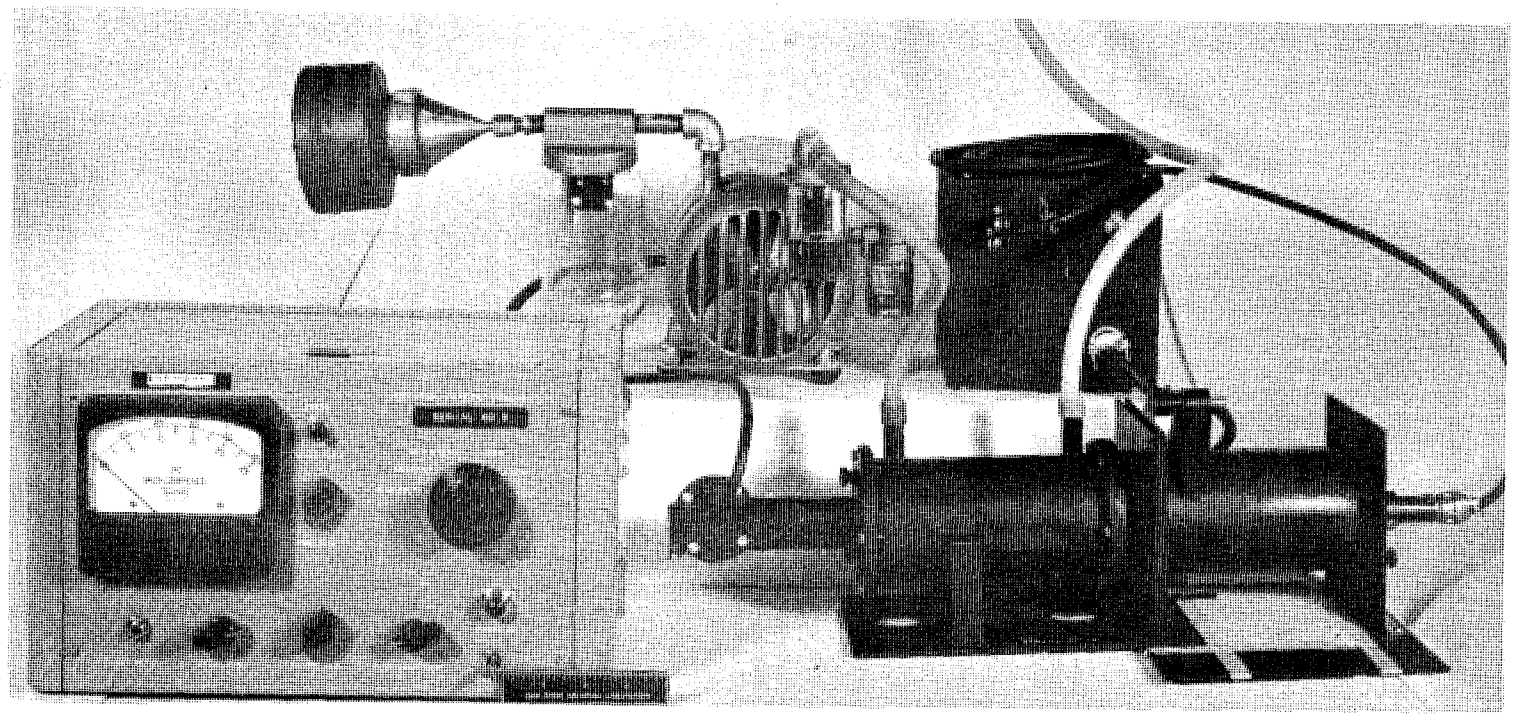


Fig. 1. A Forward-Light-Scattering Photometer.

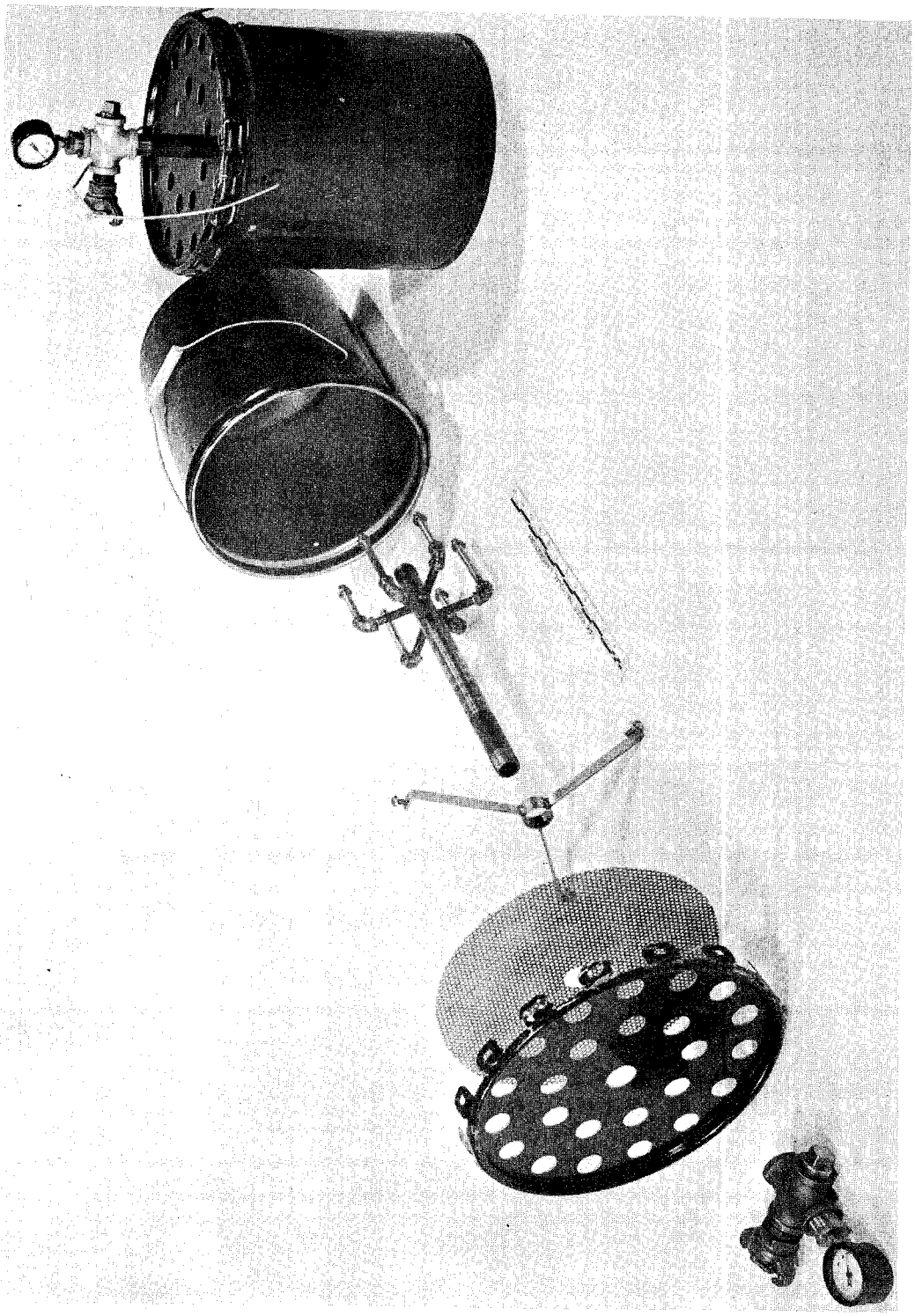


Fig. 2. High-Capacity Aerosol Generator.

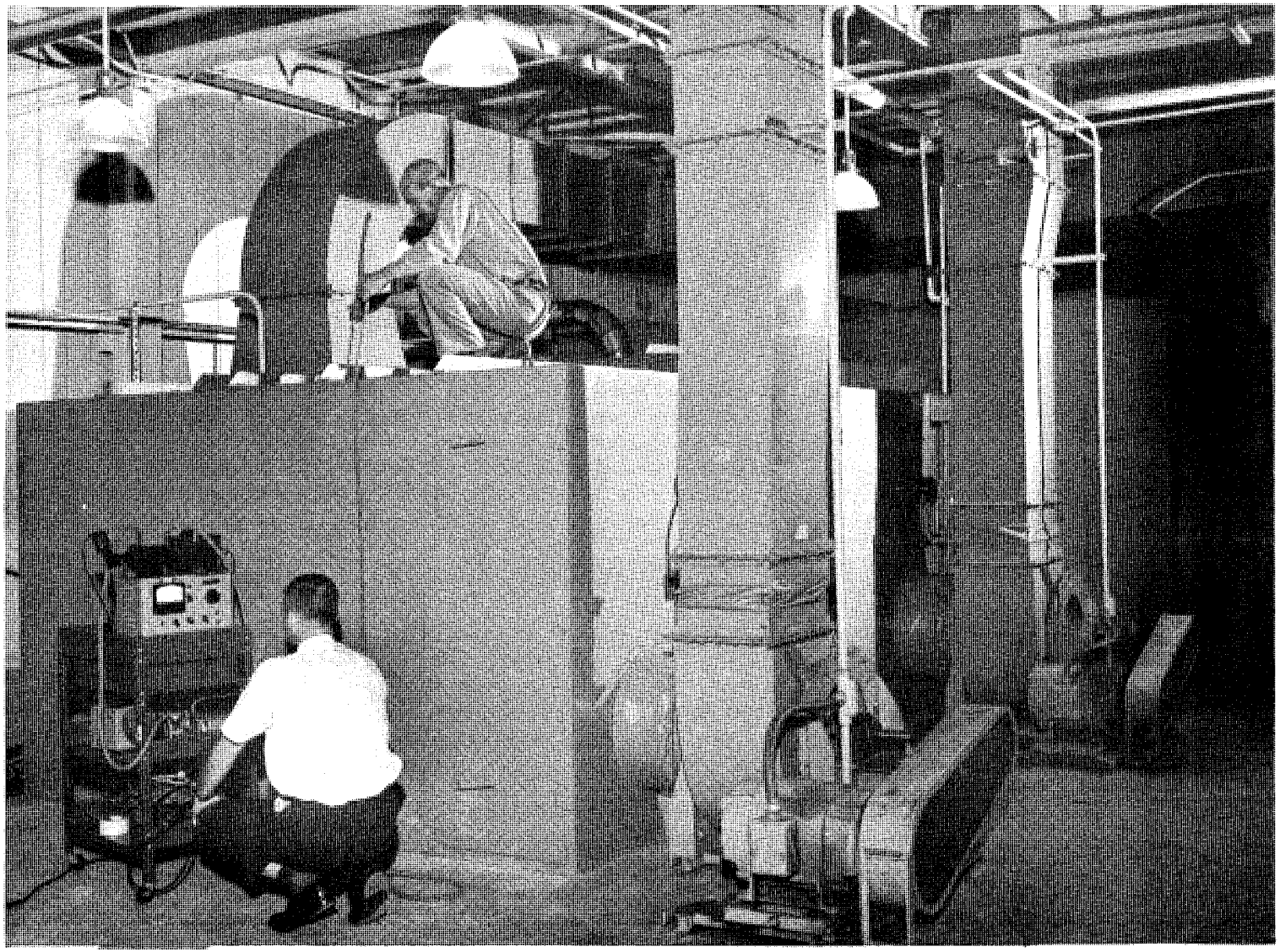


Fig. 3. Removal of an Unfiltered Sample for a Concentration Determination.

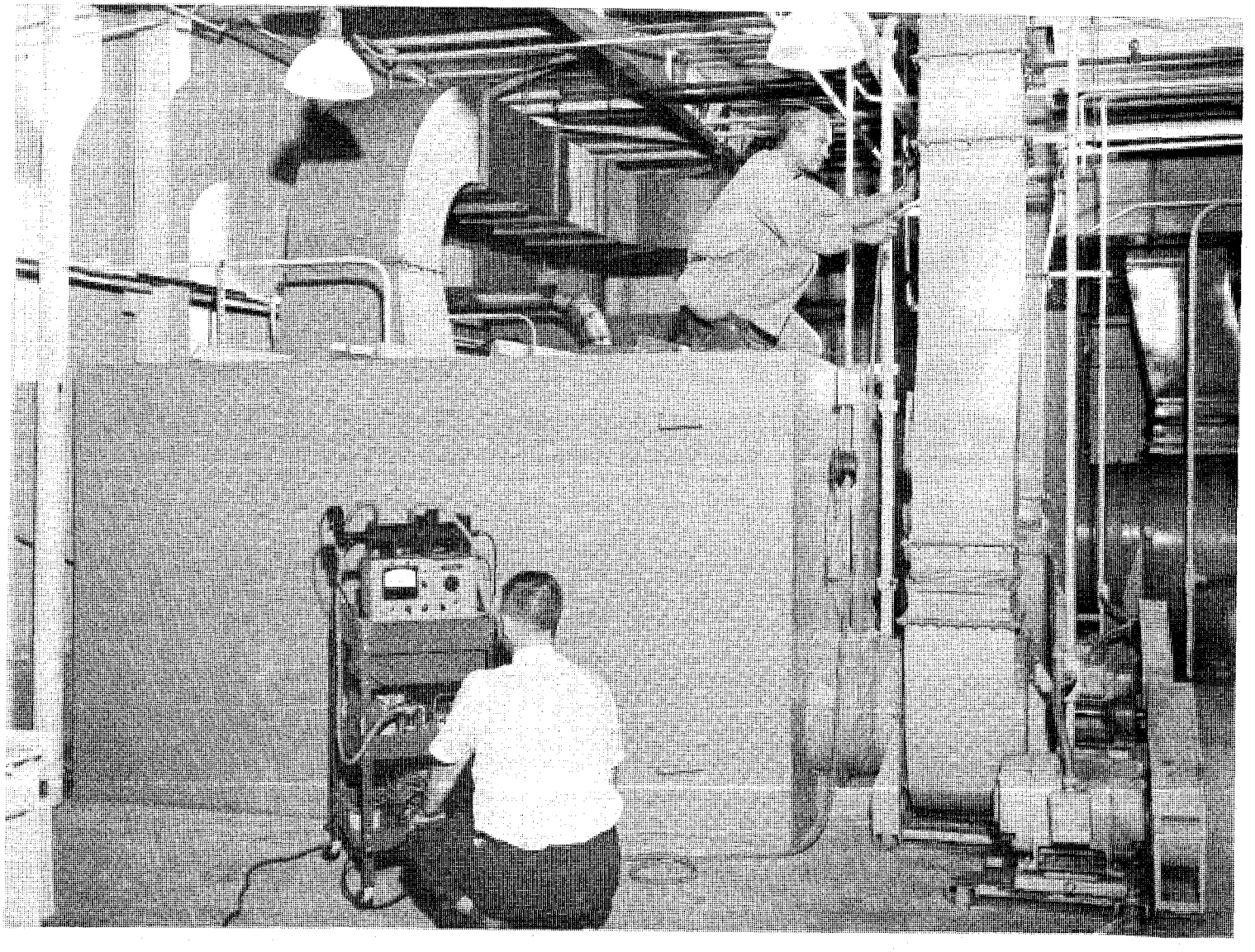


Fig. 4. Removal of a Filtered Sample for a Concentration Determination.

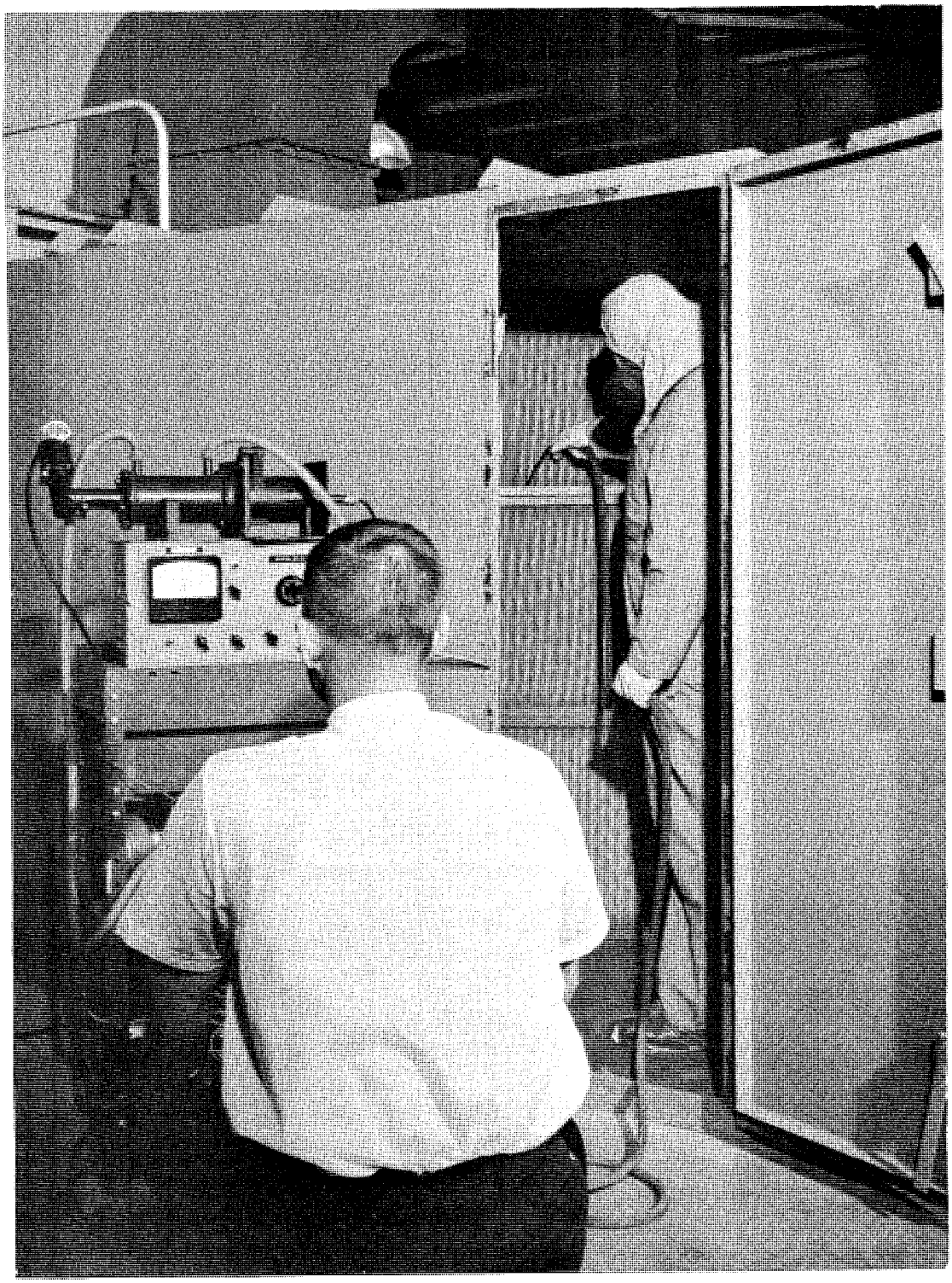


Fig. 5. Probing the Downstream Side of a Filter Bank.

RESULTS OF IN SITU TESTS

There are many ways available to present the results of the tests to illustrate differences which may exist between different types of systems. It appeared that, on the average, small systems containing one or two high-efficiency filters should give a higher "first test" efficiency than systems with a greater number of filters. Also, it seemed reasonable to expect that filters serving chemical laboratory exhaust hoods might have lower "first test" efficiencies because of the presence of corrosive vapors than systems handling air essentially free of chemical vapors. The term "first test" is intended to mean the first in situ test of a particular system and bears no relation to the age of the installation or the length of time the filters were in service prior to the test.

Table I presents the results of the first in situ test of 486 different systems. Two categories were selected for the reasons indicated above: (1) Chemical Laboratory Hood Exhaust Systems and (2) Cell Ventilation and Normal Building Exhaust Systems. Category 2 has been subdivided to show filter banks of one or two filters and banks containing three filters or more. Only installations containing one or two filters are tabulated in Category 1 since very few systems serving laboratory hoods contain more than two filters.

On the basis of the data in Table 1 and experience in general, the following conclusions may be drawn:

1. It is relatively easy to achieve a system efficiency of 99.97% or higher in small single- and double-filter installations. No significant difference is apparent between Categories 1 and 2.

2. Relatively few existing large multifilter installations had a satisfactory efficiency at the time of the first test. Only 31% of the systems containing three filters or more had an efficiency of 99.97% or better on the first test as compared with about 78% for the one- and two-filter installations.

3. One system was found to have an efficiency of only 2% owing to deterioration of the filter media. In a few other instances low efficiencies were found to be the result of corrosive attack of the media. In general, however, efficiencies less than 99.97% were attributed to (1) faulty installation of the filters, (2) damage to the filter media during installation, (3) gasket leakage due to inadequate compression, and (4) inadequacies in the filter housing and filter mounting frames.

4. New systems of all sizes have a reasonably good chance of passing a preoperational in situ test if close attention is given to details of design and construction and if the filters are properly installed.

Table 1. Results of the First In Situ Test of Two Different Types of Systems Employing High-Efficiency Filters

Range of Efficiency (%)	Category 1 Chemical Laboratory Hood Exhaust Systems (1 or 2 Filters per Bank)		Category 2 Cell Ventilation and Normal Building Exhaust Systems (1 or 2 Filters per Bank)		(3 or more Filters per Bank)	
	Number	Percent of total	Number	Percent of total	Number	Percent of total
100.00-99.97	263	76.0	72	79.0	15	30.6
99.97-99.95	5	1.4	3	3.3	3	6.1
99.95-99.90	15	4.3	2	2.2	4	8.1
99.90-99.0	25	7.2	5	5.5	20	41.0
99.0 -95.0	22	6.4	7	7.7	4	8.1
95.0 -90.0	7	2.0	0	0	1	2.0
90.0 -80	4	1.2	0	0	0	0
80 -0	5	1.4	2	2.2	2	4.1
Total	346		91		49	

Two new systems (30,000 and 80,000 cfm) showed efficiencies of better than 99.97% on the first test. Each system subsequently checked out better than 99.97% on two consecutive filter changes without the need of remedial measures.

CONCLUSIONS

Most existing systems can be tested in situ. The task is usually easier and more economical, however, when new installations are designed or existing systems are modified to facilitate such a contamination-control procedure.

In-place testing is a powerful tool for verifying the adequacy of a system or for locating the source of leakage, yet the cost represents a very small fraction of the cost of the filters.

THE EFFECT OF HOLES ON THE PERFORMANCE CHARACTERISTICS OF HIGH-EFFICIENCY FILTERS

by

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The development of high-efficiency fibrous filters has been a major advance in the science of industrial air cleaning. Stringent requirements set forth by the U. S. Atomic Energy Commission concerning the removal of radioactive particulates from plant waste gases was a prime mover in the commercial production of these filters. The Commission's contractors, as well as other industries, now routinely use high-efficiency fibrous filters where dependable, high quality air cleaning is required.

This paper describes how damage to high-efficiency filters alters their efficiency in a characteristic manner. Incorrect seating of gaskets in the filter mounting frame, gasket damage, or mechanical damage to the filter medium itself--any of these types of damage can easily occur during handling and installation.(1) In many instances, such defects are not apparent from visual inspection.

Performance Characteristics

Commercial, high-efficiency filters conform to rather uniform overall design and construction. They normally consist of a square wood or metal frame containing a core of filter paper folded into pleats. Figure I shows a typical high-efficiency filter unit.

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(1) TID - 7023 High Efficiency Particulate Air Filter Units by Humphrey Gilbert & James H. Palmer, U. S. Atomic Energy Commission, August, 1961.

This work was performed under contract No. AT(45-1)-1350 between the U. S. Atomic Energy Commission and the General Electric Company.

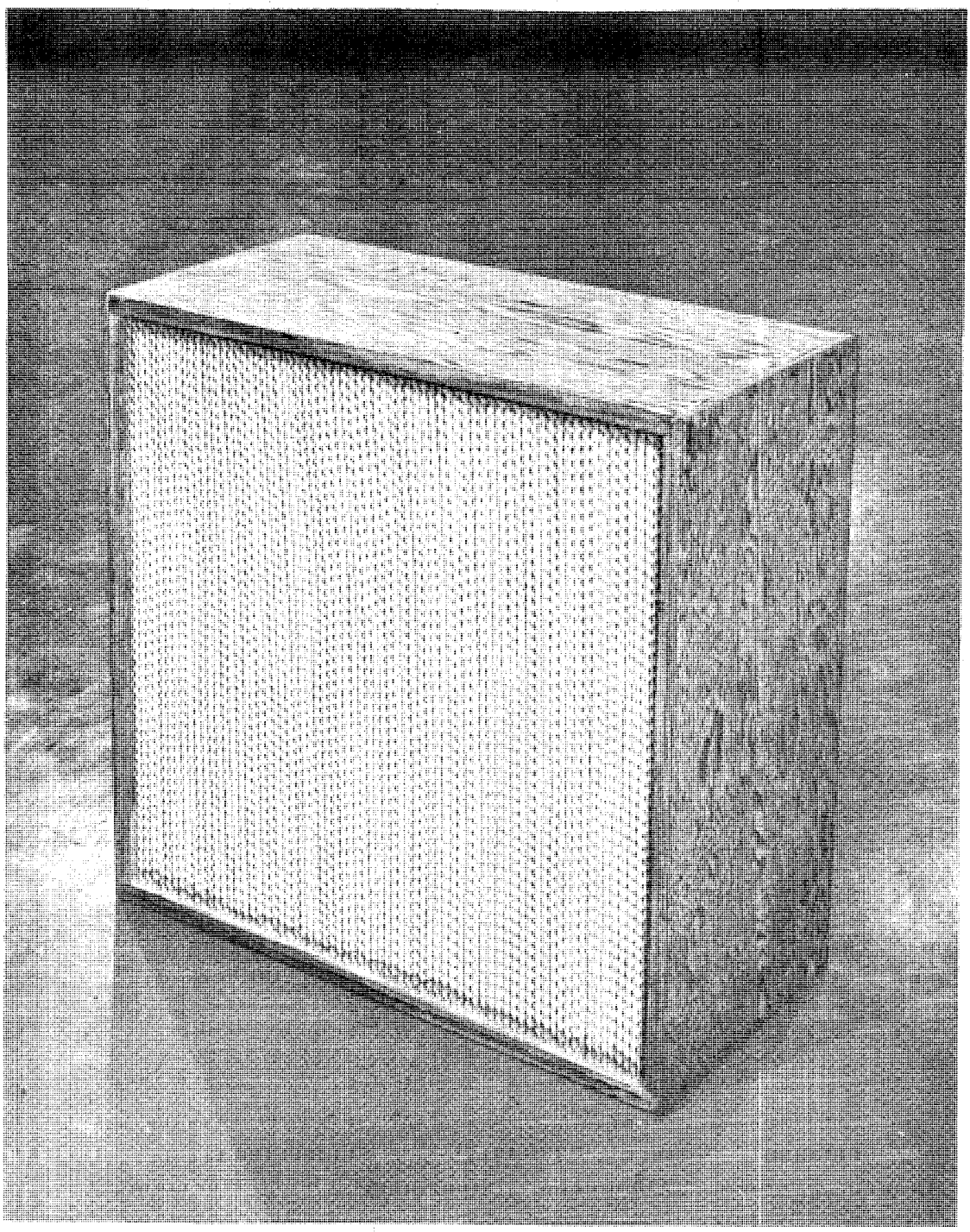


Figure I

Standard filters of this type are available with flow capacities ranging from 25 cfm to over 1000 cfm. The components of a typical filter as shown in Figure I include: the frame, the filter paper medium, the separators between filter pleats, the gasket around the frame, and an adhesive which bonds or seals the filter core to the frame. Such a filter unit will normally have a penetration of less than 0.05% at its rated airflow.

The standard efficiency test used by filter manufacturers and by the Atomic Energy Commission's two testing stations[2] is a DOP test. The DOP test uses a dioctyl phthalate smoke of 0.3 micron diameter as the test aerosol according to Military Standard MIL-STD-282, May 28, 1956. Penetrations in excess of 0.05% are considered to be indicative of a defective filter. High penetration levels are usually the result of defects, some of which are evident by visual inspection and others which are not. High penetration can be attributed to a number of causes. Breaks may be present externally or internally due to factors such as punctures or rough handling. Also, if the core is inadequately sealed to the frame, leakage may occur and, in addition, the frame joints or the gaskets may permit the passage of unfiltered air.

The filter media commonly consist of a bed or paper of fine fibers of glass, or ceramic, or combinations of either one with asbestos or cellulose. Particle removal is accomplished primarily by direct interception, inertial impaction and diffusion. Diffusion is a prominent force in the removal of submicron particles with such paper. The equation for diffusion as indicated below, shows that the efficiency of removal is inversely proportional to the velocity of filtration.

$$D = \frac{1}{v\, d_f} \quad \frac{(C\, k\, T)}{3\, n\, d_p}$$

where
- D = diffusion parameter
- C = Cunningham correction factor
- d_f = fiber diameter
- d_p = aerosol particle diameter
- k = Boltzmann constant
- n = viscosity of gas (poise)
- T = gas temperature (degrees absolute)
- v = filtration velocity

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(2) Occupational Hygiene Operation, Hanford and Oak Ridge Filter Test Facility, Oak Ridge.

Effect of Hole in Filter

The effect of velocity on penetration in high-efficiency filter paper containing holes has been previously established.[3],[4] It was shown that with DOP smoke of about 0.3 micron diameter a reduction in velocity was accompanied by an increase in penetration. A simple laboratory arrangement was set up to demonstrate the relationship with air cleaning filter paper to provide a basis for extending the understanding of this action to high-efficiency space filters similar to that in Figure I.

Specimens of filter paper, 2-3/8 in diameter, of the type used in commercial filters were mounted, as shown in Figure II, so that holes could be added without dismantling the holder.

In initial tests, flow through the specimen was reduced from approximately 7.8 fpm to 0.62 fpm. The tests were performed on an "as manufactured" paper specimen. A 0.012 in.-diameter hole was added and a remeasurement of flow rates at various pressure drops was made. The results are shown in Figure III.

The flow through the hole, as presented by Curve C, was estimated by difference between Curves B and A. Calculated flow through the hole, assumed similar to a thin-plate orifice,[5] was obtained by the formula below and is shown in Curve D.

$$Q = 21.8\ Kd^2\ \sqrt{h} \quad , \tag{1}$$

where
Q = volume rate of airflow in cubic feet per minute
K = coefficient of airflow
d = orifice diameter in inches
h = pressure drop across orifice in inches of water.

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(3) NRL Report P-2642, Development of Smoke Penetration Meters by H. W. Knudson and Locke White, U. S. Naval Research Laboratory, Wash. D. C., Sept. 14, 1945.

(4) Performance Characteristics by Dry Fibrous Air Filter Media, Earl Stafford and Walter J. Smith, Arthur D. Little, Inc., Cambridge, Mass., Dec. 28, 1950.

(5) Industrial Health Engineering by Allen D. Brandt, 1947, John Wiley & Sons, Inc., New York.

FILTER PAPER TEST ARRANGEMENT

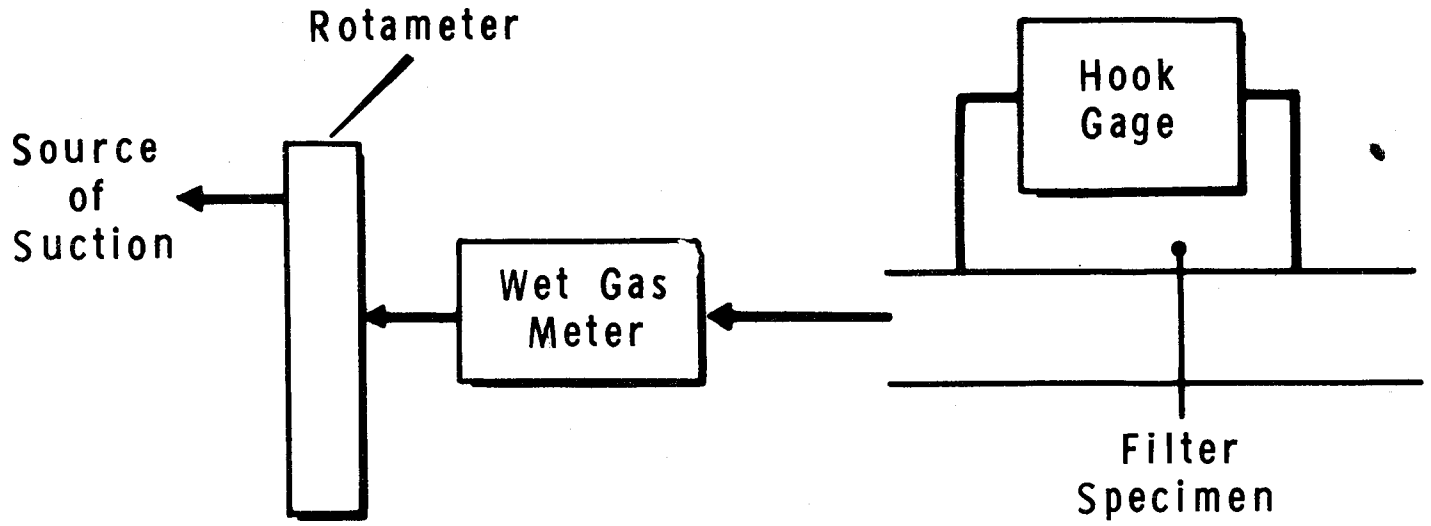


Figure II

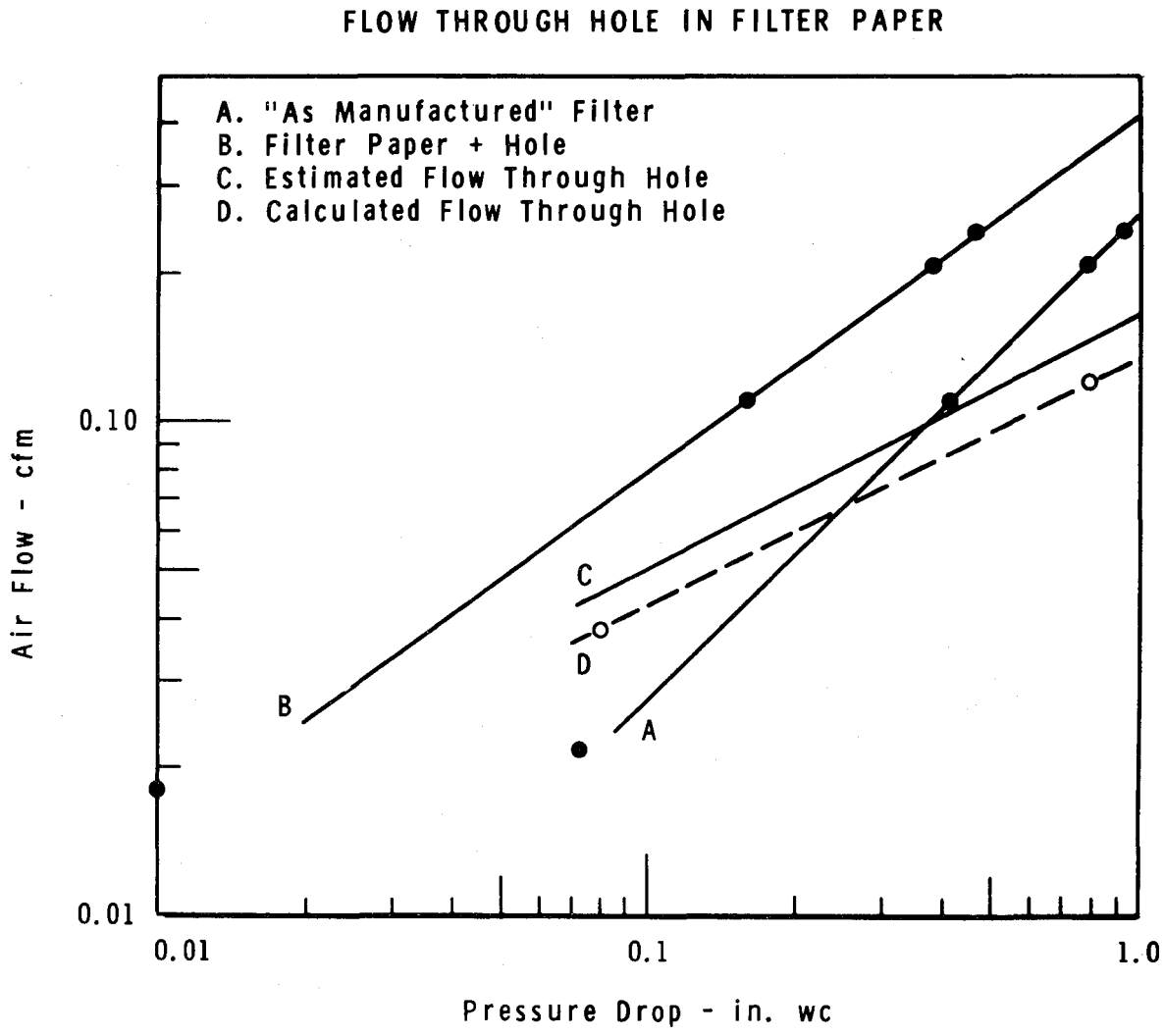

FLOW THROUGH HOLE IN FILTER PAPER
A. "As Manufactured" Filter
B. Filter Paper + Hole
C. Estimated Flow Through Hole
D. Calculated Flow Through Hole
Air Flow - cfm
0.10
0.01
0.01
0.1
1.0
Pressure Drop - in. wc
A
B
C
D

Figure III

The change in airflow-pressure drop relationship caused by a hole in the filter medium arises because airflow through a fibrous filter bed at the velocities studied are essentially streamline, whereas the flow through a hole is turbulent. It has been shown by Silverman[6] that the flow characteristic through a fiber filter may be expressed as:

$$R_1 = K_o V \quad , \tag{2}$$

where R_1 = resistance in inches of water
V = filtering velocity in feet per minute (face area)
K_o = resistance coefficient (clean cloth).

In turbulent flow as indicated in Equation (1) the capacity varies as $h^{\frac{1}{2}}$. A unit reduction in pressure drop will, therefore, result in a less rapid drop in flow through a defective filter medium than through an intact medium due to the influence of the hole, the flow through which falls off less rapidly than that of the medium. This is evident in Figure III where the flow through the filter decreased 85% when the pressure differential was reduced from 0.90 in. to 0.10 in.; whereas, the flow through the hole diminished by only 67%.

From the preceding review, it can be concluded that a characteristic difference is demonstrable in the pressure drop-airflow relationship between good filter paper and that having defects.

SPACE FILTER PERFORMANCE

Experimental Defects

In view of the difference in the pressure drop-airflow relationship in good and defective filter papers, tests were made to determine the changes in the airflow-penetration relationship which occur in a commercial space filter. A typical 1000 cfm filter of the type shown in Figure I was tested before and after the consecutive addition of two 1/8 in.-diameter holes in the medium. A series of penetration measurements were made during the reduction in flow from

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(6) Filtration Through Porous Materials, Leslie Silverman, Amer. Ind. Hyg. Quarterly, 11:1, March, 1950.

1100 cfm to 450 cfm. The results are presented in Figure IV.

The filter unit (Figure IV) had a known penetration value of 0.01% as determined by standard DOP test. The penetration varied directly as the airflow (Curve A).

After addition of a 1/8 in. hole to the crown of one of the filter pleats, measurements were repeated. Penetration varied inversely with airflow (Curve B). Data in Curve B were obtained with the hole in the upstream position. When the hole was positioned downstream, an increased penetration resulted (Curve C). The addition of a second 1/8 in. hole on the same face as the first hole allowed the penetration shown in Curves D and E with the holes oriented in the upstream and downstream positions, respectively.

Due to the compact pleating of the filter, the discharge gas stream from the holes when on the upstream side was restricted and disturbed by the proximity of the separators and sides of the filter pleats. When the holes were on the downstream side the unrestricted discharge gas stream resulted in a greater airflow and penetration.

"As Found" Defects

The demonstration of a characteristic airflow-penetration relationship in a space filter by a controlled defect in the form of a hole in the filter medium prompted the testing of 19 high-efficiency space filters. Twelve contained no visible defects, and 7 had defects of various types. Tests were performed by a series of penetration measurements as the airflow was reduced from the rated capacity. The results are presented in Figure V.

The filters having a penetration of about 0.01% and lower at rated airflow showed a reduction in penetration as the airflow was reduced. Those filters with penetration values of greater than 0.01% at rated flow as demonstrated by Curves D through S, showed an increase in penetration as the flowrate was reduced. This appears to indicate that there was some factor involved which permitted a portion of the air to pass through the units unfiltered. In some instances, as will be discussed later, defects were evident in some filters

CHANGES IN PENETRATION CAUSED BY THE ADDITION OF HOLES

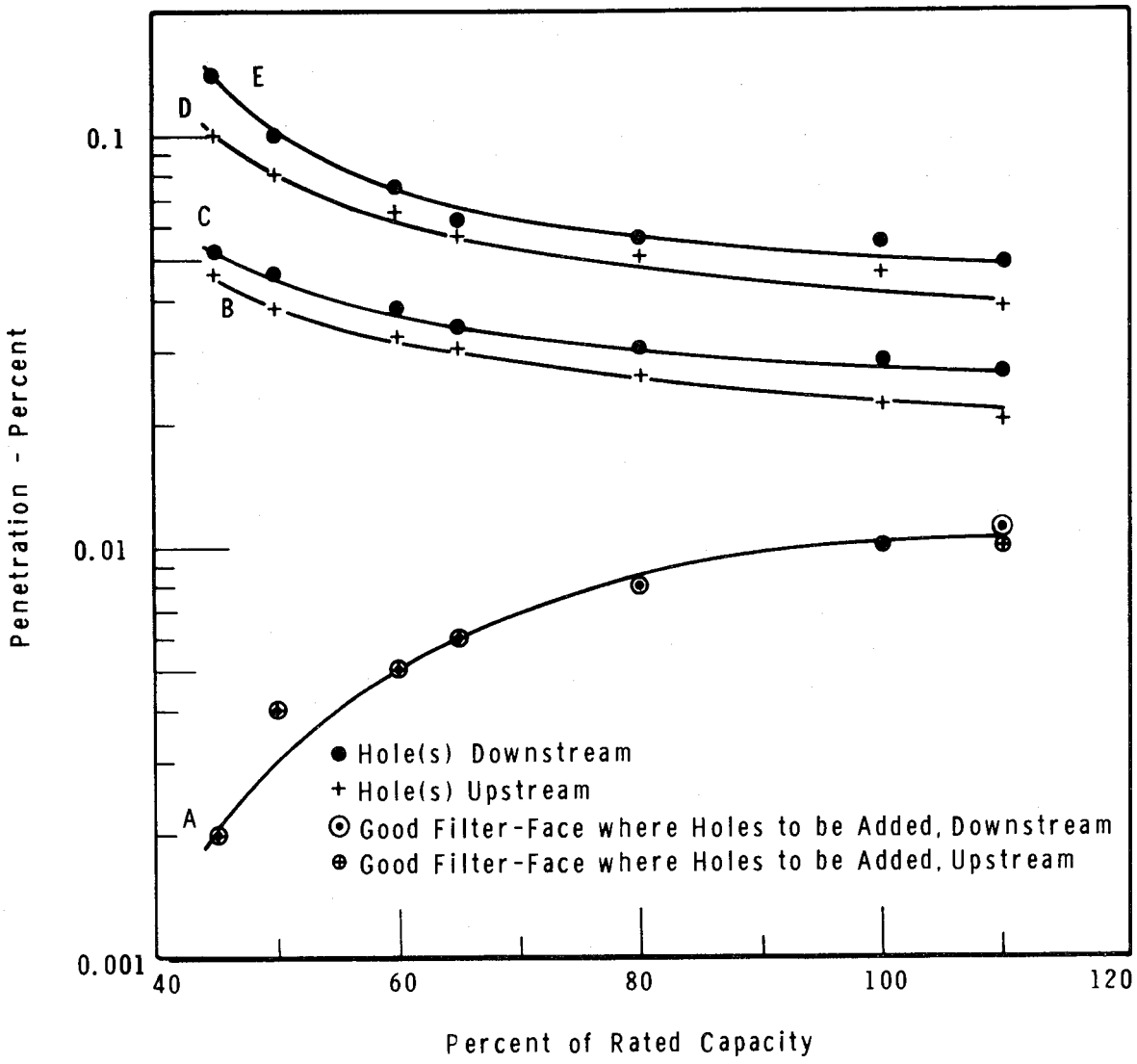


Figure IV

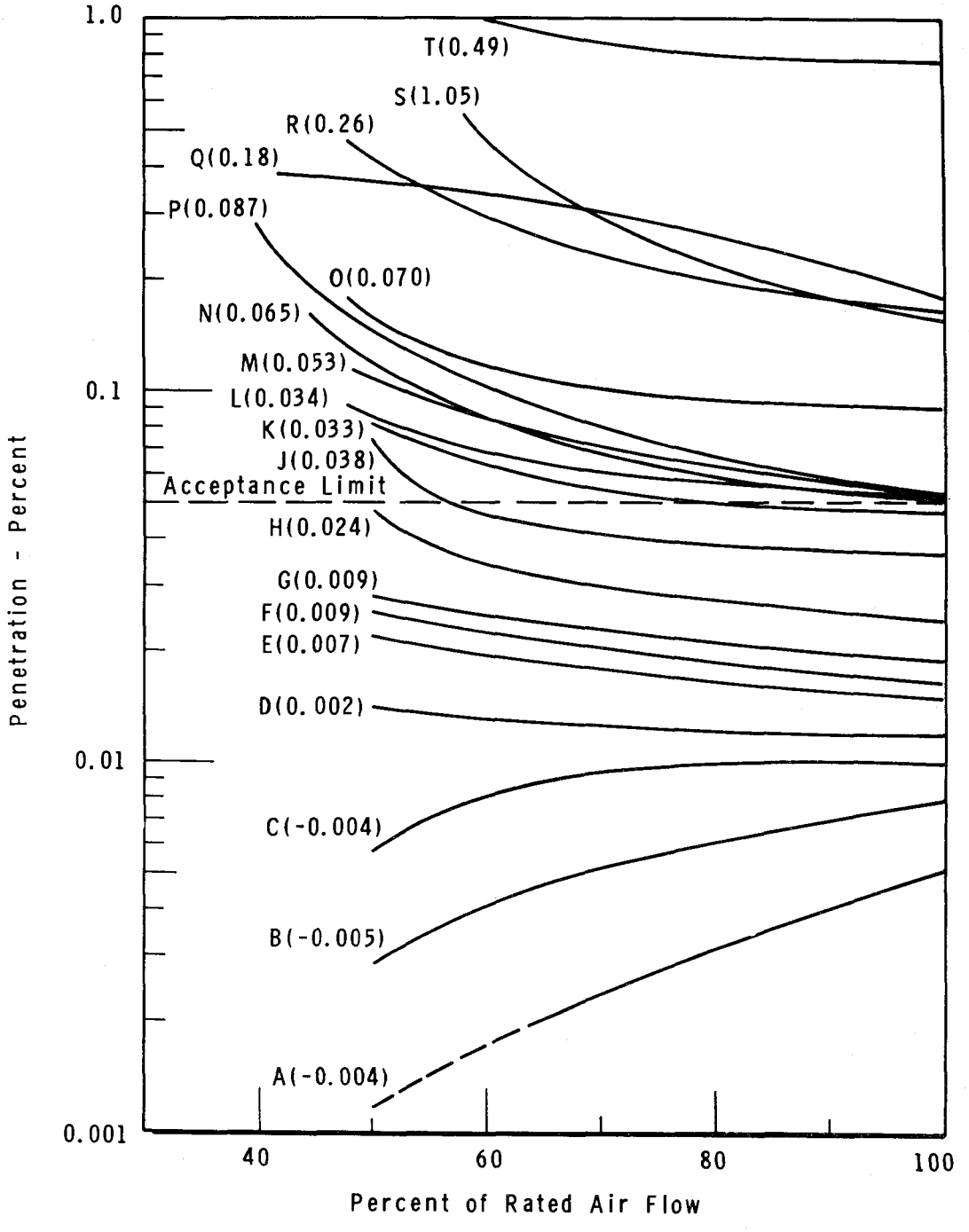

1.0
0.1
0.01
0.001
Penetration - Percent
T(0.49)
S(1.05)
R(0.26)
Q(0.18)
P(0.087)
O(0.070)
N(0.065)
M(0.053)
L(0.034)
K(0.033)
J(0.038)
Acceptance Limit
H(0.024)
G(0.009)
F(0.009)
E(0.007)
D(0.002)
C(-0.004)
B(-0.005)
A(-0.004)
40
60
80
100
Percent of Rated Air Flow

Figure V

with elevated penetration values; whereas, in others, defects were not evident. The changes in percent penetration, for each filter, resulting from a reduction in airflow from 100% to 50% of rated capacity are also shown (Figure V).

An empirical determination of the size of the various defects on the passage of unfiltered air through such filter units was made. Assuming that the intact filter as plotted in Curve A in Figure IV was essentially free of defects, the change in penetration when the airflow was reduced from 100% to 50% of rated capacity was noted. Similar changes were also determined for the filter with one and two 1/8 in. holes as shown in Curves B and D. These values were plotted in Figure VI.

By applying the "penetration change" values from Figure V to the data plotted in Figure VI, it is possible to estimate the approximate equivalent size of a hole which would permit unfiltered air to pass through and cause the filter performance shown. Since the filter defects that may be encountered are of various types (punched holes, incomplete sealing of the adhesive, shear breaks across filter pleats, or cuts which created flap-like breaks) the equivalent hole area must be considered an approximation. A correlation of the filter performance data shown in Figure V with equivalent hole area, from Figure VI, is presented in Table I.

CONCLUSIONS

It is possible to appraise the integrity of a high-efficiency air filter by measuring the change in penetration as influenced by a change in airflow. The tests demonstrated that penetration varied directly as the airflow for filters of good integrity and inversely for filters containing defects.

The difference in airflow through a hole and a filter medium resulting from a given change in pressure drop was demonstrated to account for characteristic performance in good filters and those containing defects. By these performance characteristics it is possible to estimate whether a significant proportion of unfiltered air may be passing through a filter.

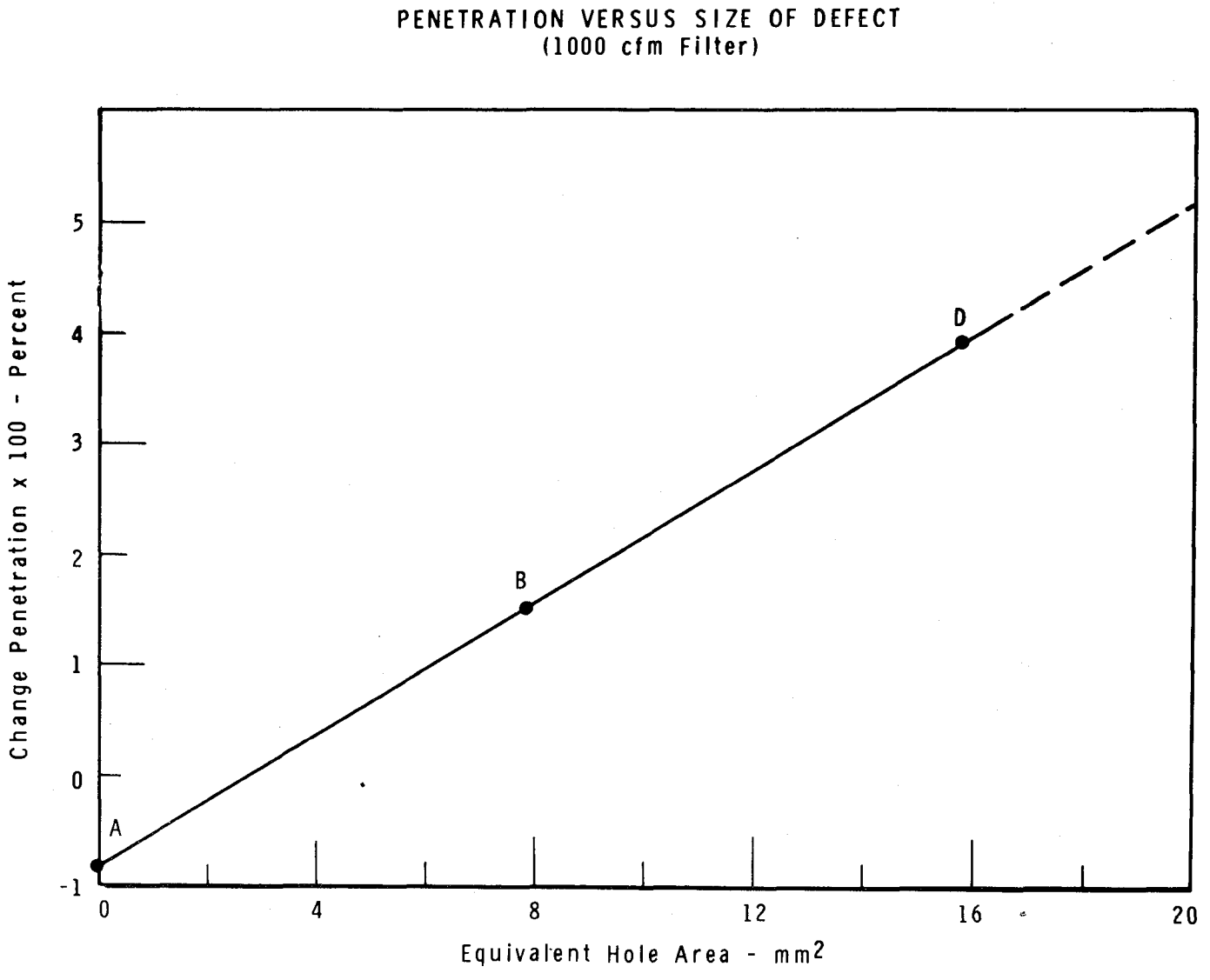

PENETRATION VERSUS SIZE OF DEFECT
(1000 cfm Filter)
Change Penetration x 100 - Percent
5
4
3
2
1
0
-1
A
B
D
0
4
8
12
16
20
Equivalent Hole Area - mm2

Figure VI

Table I

EQUIVALENT HOLE AREA

Filter	Rated Capacity, cfm	DOP Penetration,* Percent	Remarks	Change In Penetration,** Percent	Equivalent Hole Area, mm^2
A	1000	0.005	No Visible Defects	-0.004	1.5
B	1000	0.007	No Visible Defects	-0.005	1.0
C	1000	0.010	No Visible Defects	-0.004	1.5
D	1000	0.012	No Visible Defects	0.002	3.
E	1000	0.015	No Visible Defects	0.007	5.
F	1000	0.016	No Visible Defects	0.009	6.
G	1000	0.019	No Visible Defects	0.009	6.
H	1000	0.024	No Visible Defects	0.024	11.
J	1000	0.036	No Visible Defects	0.038	16.
K	1000	0.047	No Visible Defects	0.033	14.
L	1000	0.053	Shear Break Across Pleats	0.034	14.
M	1000	0.054	Hole in Medium, Punched by Separators	0.053	20.
N	1000	0.052	Two Approximatedly 1/8 in. Puncture Holes in Medium	0.065	24.
O	1250	0.053	Shear Break; Metal Frame, Dry Pack	0.087	(1)
P	1000	0.090	No Visible Defects	0.070	26.
Q	1250	0.180	Shear Break, Core Shifted; Metal Frame, Dry Pack	0.180	(1)
R	1000	0.160	Ends of Filter Pleats Unsealed; Pack Shifted	0.260	88.
S	50, Spec.	0.150	No Visible Defects	0.050	(1)
T	1000	0.760	Shear Break Across Several Pleats	0.490	164.

*At Rated Airflow

**Due to Reduction of Flow from 100% to 50% of Rated Capacity

(1) Data Derived from Figure VI is Applicable for Filter Capacity of 1000 cfm Only.

Due to the disturbance of the air discharging internally from filter holes into pleats or separators, the penetration through a filter is less when the face containing the defect is placed upstream. If the defect is internal or within the filter core this condition would not necessarily hold true. Additionally, this observation would exclude defects which form a flap which might change its configuration depending on the direction of airflow.

It is possible for high-efficiency filters having a penetration as low as about 0.01% at rated airflow to contain defects which permit unfiltered air to pass through the filter. It was shown that there is a semi-quantitative relationship between the penetration level of a filter and the size of any breaks or defects which permit the passage of unfiltered air.

Performance changes in high-efficiency filters as related to variation in airflow suggest the use of this phenomenon as a method for demonstrating the integrity of installed filters, singly or in multiple filter banks. Such tests could demonstrate the presence of defects such as damaged filter media, inadequate seating of filter gaskets on the mounting panel and defects in the mounting panel.

ORNL-NSIC-1
Nuclear Safety – Special

EFFECT OF PARTICLE AGGLOMERATION ON THE PENETRATION OF FILTERS UTILIZED WITH DOUBLE CONTAINMENT SYSTEMS

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W. E. Browning, Jr.

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Oak Ridge, Tennessee

Foreword

This is the first report prepared under the auspices of the Nuclear Safety Information Center which was established in March 1963 at the Oak Ridge National Laboratory under the sponsorship of the U.S. Atomic Energy Commission. The Center is intended to serve as a focal point for the collection, storage, evaluation, and dissemination of information in the following areas:

1) containment of nuclear facilities;
2) fission-product release, transport, and removal;
3) nuclear instrumentation, control, and safety system;
4) radioactive effluent control monitoring, movement, and dosage;
5) reactor transients, kinetics, and stability; and
6) meteorological considerations.

The present study was requested of the Center by Merson Booth of DRD because of concern which existed regarding the removal of radionuclides by filters following a reactor accident where the radionuclides may be associated with particles significantly smaller than 0.3 μ diam. Inquiries concerning the capabilities and operation of the Center may be addressed to:

Wm. B. Cottrell, Director
Nuclear Safety Information Center
Oak Ridge National Laboratory
P. O. Box Y
Oak Ridge, Tennessee

Abstract

The penetration of filter systems in dual containment systems by fission products adsorbed on particulate matter was studied theoretically. A simplified model was analyzed in which the particulate matter was assumed to be pure iodine, and all particulates having diameters less than 0.3 μ were assumed to penetrate the filters. It was shown that agglomeration would occur rapidly enough so that the particles, even though initially much smaller, would reach a 0.3-μ size in a short time (< 20 min for typical water-reactor systems). This time is directly proportional to the containment volume and inversely proportional to the power level. Assuming that the filter efficiency of the secondary containment sweep gas filtration system is zero for particles less than 0.3 μ, the fraction of the core activity released to the atmosphere during that time was calculated for some conditions of interest. For one reactor system treated, less than 10^{-5} of the iodine available would be released. It was shown that conditions existing during a reactor accident could not be as pessimistic as those of this model.

Introduction

The penetration of filters by fission products adsorbed on submicron particulate matter has been of some concern to those responsible for the performance of nuclear reactor containment systems employing filtration as a means of limiting activity release. The efficiency of absolute particulate filters is known to be > 99.95% for particles of 0.3 μ, but the filtration efficiency is not known, with comparable certainty, for particles of substantially smaller size, e.g., in the range 20-40 Å. It is known, however, that particulate matter of a high particle-count density per unit volume as would exist after a reactor accident would agglomerate at a rapid rate to a smaller number of larger particles.

This memorandum summarizes the results of a simplified analysis of the effects of particle agglomeration on the activity release from a containment system that depends on particulate filtration for its effectiveness. The case treated here is that of a dispersion of activity into a primary volume, such as the first containment, and its leakage into a secondary volume in which a sweep air flow is maintained and filtered before it is exhausted into the surroundings. The secondary barrier is thus made effective in that all leakage from the surroundings flows into it and all activity that is released is filtered. Some examples of this kind of containment are the N.S. SAVANNAH and the Hallam reactor.

Method of Analysis and Assumptions

A calculation of particulate agglomeration was performed on a simplified model which is shown to be conservative. Since iodine is of major concern in filtration problems, it was chosen to illustrate the particle behavior. Only the particulate form of iodine is treated. It is assumed that iodine remaining in vapor form is removed by adsorbers. The analysis was performed in the following manner: 1) It was assumed that all the iodine isotopes existing in the reactor core after full-power full-life operation were released at the time of the accident and evenly dispersed within the primary containment vessel as an infinite number of small particles. 2) The iodine agglomerated as a monodisperse pseudoaerosol of pure iodine yielding particle sizes as a function of time. 3) All of the pseudoaerosol (i.e.,

the material with particle size < 0.3 μ) that leaked out of the primary containment penetrated the secondary containment filtration system. 4) The amount of iodine being released during this time period of zero filter efficiency was calculated and presented.

The agglomeration calculations were performed using the relationship:[1]

$$\frac{1}{n} = \frac{1}{n_o} + Kt \qquad (1)$$

where

n = number of particles/cm^3 at time t (cm^{-3}),
n_o = number of particles/cm^3 initially (cm^{-3}),
t = time (sec), and
K = agglomeration coefficient (cm^3/sec) taken as 5×10^{-10} (ref. 1).

The value n was related to the concentration of matter in air by the equation:

$$\frac{m}{V_1} = \rho \frac{\pi}{6} d^3 n \qquad (2)$$

where

m = total mass of material making the particles (gm),
V_1 = total free volume of the primary containment (cm^3),
ρ = density of the particle (gm/cm^3), and
d = diameter of particle (cm).

Substituting Eq. 2 into Eq. 1 yields the time required to reach a given diameter.

$$t = \frac{d^3 \pi \rho}{6 \frac{m}{V_1} K} - \frac{1}{n_o K} \qquad (3)$$

Since n_o is large, the last term is negligible.

The diluting effect of the sweep gas in the secondary containment was considered because the filters were located in this system. The ratio of the rate of activity released from the secondary containment to the activity release rate from the primary containment is shown in Appendix A to be:

$$\frac{C_2 Q_{23}}{C_1 Q_{12}} = 1 - e^{-(Q_{23}/V_2)t} \qquad (4)$$

where

C_2 = concentration of material of interest in the secondary containment (curies/cm^3),

Q_{23} = sweep gas volumetric flow rate (cm^3/sec),

C_1 = concentration of activity in primary containment (curies/cm^3),

Q_{12} = volumetric leak rate from the primary containment (cm^3/sec), and

V_2 = volume of secondary containment (cm^3).

The integrated release from the secondary containment up to time, t, compared to the rate of release from the primary containment can easily be shown as:

$$\frac{A_{23}}{IR} = t - \frac{V_2}{Q_{23}} [1 - e^{-(Q_{23}/V_2)t}] \qquad (5)$$

where

A_{23} = total integrated activity released to time t (curies),

I = total activity inventory in the primary containment available for release (curies), and

R = primary containment release rate (%/sec).

Results

Figure 1 is based on Eq. 3 and shows the particle size as a function of time for seven values of (m_1/V_1) and a particle density of 4.93 g/cm^3, corresponding to elemental iodine. Curve E shows the values for the N.S. SAVANNAH, this being an example of the containment system studied herein.

Figure 2 shows the performance of the secondary containment sweep gas system, relating the total activity released up to time t, for three values of the volume change times (V_2/Q_{23}). Curve E of Fig. 1 is superimposed on Fig. 2 to show the procedure for finding the worst case operation of the system, assuming that all activity, I, is in particulate form and all that is released from the primary containment prior to the time that the critical particle size is attained passes through the

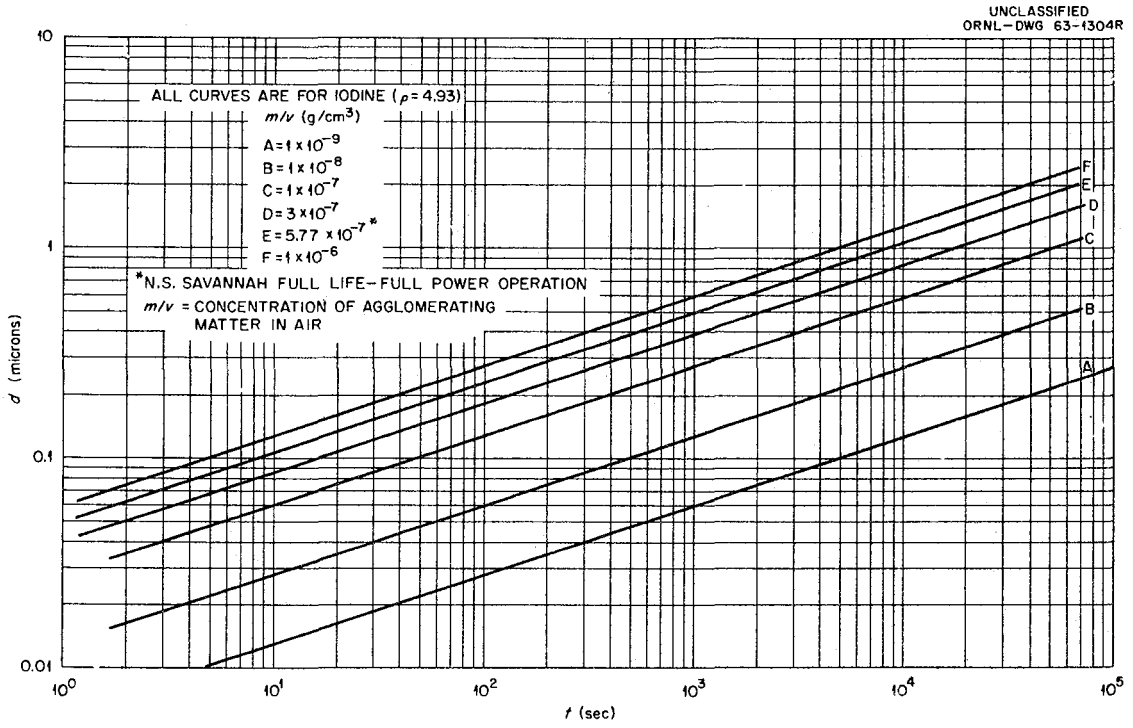


Fig. 1. Particle Size vs Time as Controlled by Agglomeration.

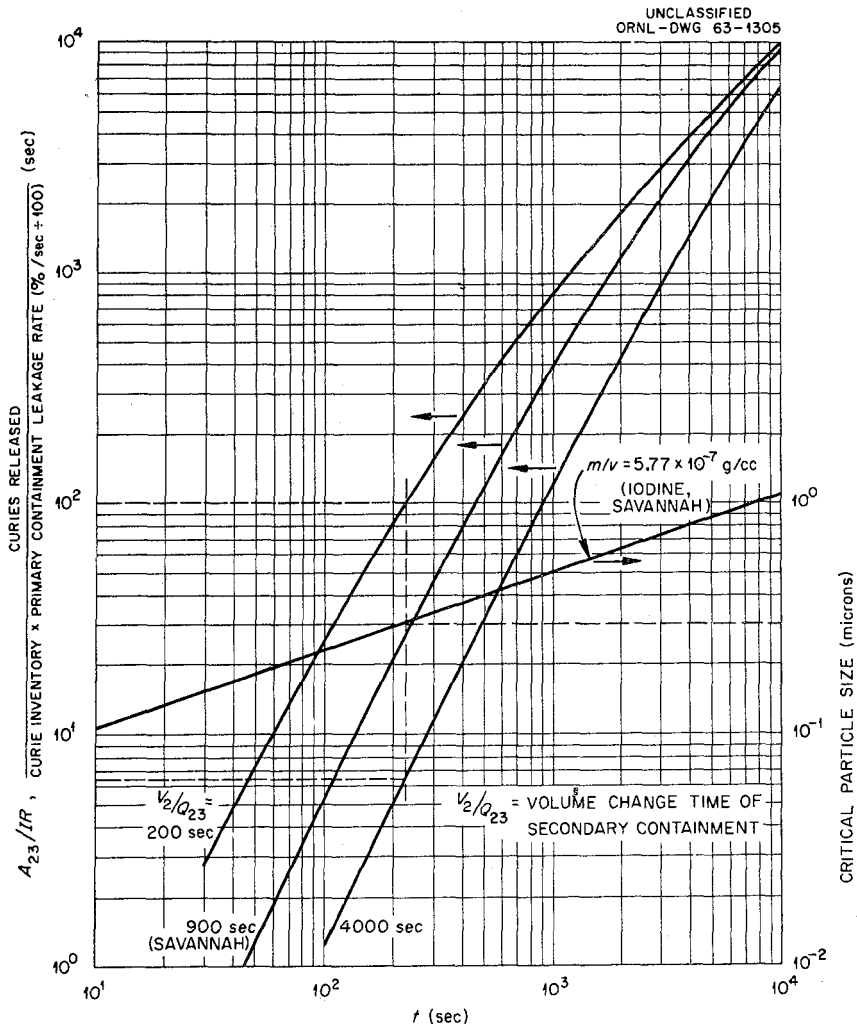


Fig. 2. Total Activity Released During Period of Zero Filter Efficiency per Release Rate vs Time.

filtering system in the secondary containment. For example, if 0.3 μ is chosen as the critical particle diameter, it can be seen that if the core inventory of iodine is the only material available to make particles, this size will be reached in 235 sec. The N.S. SAVANNAH has a secondary containment volume change time of 900 sec, and this curve shows that the total release to the atmosphere is $A_{23}/I = 26$ (R). Since the N.S. SAVANNAH primary containment has a maximum leakage rate of 3%/day.

$$R = \frac{0.03}{8.65 \times 10^{4}} \text{ sec}^{-1} = 3.47 \times 10^{-7} \text{ sec}^{-1}$$

The ratio of total activity released to that available is

$$\frac{A_{23}}{I} = 26 \, (3.47 \times 10^{-7}) = 9.02 \times 10^{-6}$$

Table I shows the core inventory and amounts released to the surroundings for the N.S. SAVANNAH for the case of 0.3 μ critical aerosol diameter.

TABLE I

Activity Release for the N.S. SAVANNAH Conditions

Nuclide	Core Inventory (curies) (600 day at 69 Mw)	Amounts Released (curies)
8.05 d I^{131}	2.29×10^{6}	20.6
20.8 h I^{133}	2.05×10^{6}	18.5
6.68 h I^{135}	2.01×10^{7}	181

Discussion

A. Validity of the Agglomeration Equation. Equation 1 has been shown to hold ever since reliable methods of counting the particles in smoke clouds have been available.[1] Theoretical expressions for coagulation of monodisperse particles can be shown to be:

$$\frac{1}{n} - \frac{1}{n_o} = \frac{4 R T}{3 \eta N}\left(1 + \frac{A\ell}{r}\right)t \qquad (1\text{-a})$$

where

R = gas constant,

T = absolute temperature,

η = viscosity of the medium, and

N = Avagadro's number.

The term $[1 + (A\ell/r)]$ is the Cunningham correction factor for non-Stokes behavior of very small particles where

A = a constant (~ 0.9),

ℓ = mean free path of the molecule, and

r = radius of particle.

From Eq. 1-a it can be seen that the coagulation coefficient

$$K = \frac{4\ R\ T}{3\ \eta\ N}\left(1 + \frac{A\ell}{r}\right)$$

would decrease as the radius increases. Experimentally determined graphs of t vs 1/n are straight lines within the limits of experimental error except for the case of very small particles for which there is an indication of curvature. The use of this theoretical expression for K for air at standard conditions and a standard stearic acid cloud yields $K = 5.1 \times 10^{-10}$ cm^3/sec. The use of $K = 5.00 \times 10^{-10}$ cm^3/sec in this analysis in Eq. 1 appears justified on a conservative basis.

B. Effect of the Assumption of Particulates Made of Pure Material. The artifice of assuming that all of the iodine coagulates into particulates of pure iodine is a useful concept that can be shown to be conservative. Actually, in the case of a real accident, some of the iodine would remain in the vapor form and some would deposit on particulates caused by debris and smoke concurrent with fuel meltdown. Taking the case of all the iodine depositing on particulates of other matter, then the m of Eq. 3 must include the iodine plus the other debris and must be larger than the case of pure iodine; e.g.,

$$m_t = m_o + m_I \qquad (6)$$

where

m_t = total mass (g),

m_o = mass of foreign matter (g), and

m_I = mass of iodine (g).

It can be seen from Eq. 3, however, that the time required to reach a critical, filterable diameter is directly proportional to ρ_t/m_t. Since $\rho_t/m_t = 1/V_p$, where V_p is the volume taken up by the particle, substitution into Eq. 3 shows that:

$$t = \frac{d^3\pi}{6K\,(V_p/V_1)} \tag{3a}$$

That is, the time to reach a given diameter is inversely proportional to the ratio of the volume taken up by the particles to the total free volume of the containment vessel. (Note, however, that V_p/V_1 must be very small for Eq. 1 to hold.)

Equation 3a shows that if foreign matter is added to the iodine, the time at which filtration is effective will be shorter.

C. The Case Where Less than the Total Inventory of Iodine is Available to Make Particulates. In a real accident, much of the iodine will be immobilized shortly after a meltdown by deposition on surfaces or otherwise or will remain in elemental form and will be effectively scavenged by the charcoal adsorption system and therefore will not contribute to the effects under scrutiny in this study.

The amount of activity released from the primary containment vessel is:

$$A_{12} = IRt \tag{7}$$

where

A_{12} = total activity released from the primary to the secondary containment.

Substituting Eq. 3 for t:

$$A_{12} = \frac{IR\,\pi d^3}{6\,(m_1/V_1)\,K} \tag{7a}$$

Since the core activity inventory, I, refers to that available for release, I is associated with m_1, the mass available to make particulates, so that I/m_1 is a constant for a given accident condition. Therefore, the activity released from the primary containment to the secondary

containment that would be eventually released from the secondary containment, assuming that further agglomeration does not occur in the secondary containment, is independent of the amount available for release. It is obvious that minimizing I/m reduces the total activity released. Thus, the presence in the smokes of foreign matter of low specific activity, such as structural materials, unfissioned uranium, etc., would decrease the release of important activity associated with it.

D. Effect of Polydispersity. The usual effect of a size distribution in a cloud of particulates is to promote agglomeration at a faster rate than would occur in a cloud of equal-sized particles.[1] Experiments at ORNL[2] have shown that the amount of 20-40 A iodine-bearing particulates after aging is relatively independent of the initial concentration of iodine in the source of the experiment. This can be interpreted to mean that agglomeration and settling accounts for the major amount of iodine leaving a small residue of small particulates that would agglomerate at a slower rate because of depleted particulate population.

Although not proved, it appears that the assumption that all particles of a size below 0.3 μ penetrate the filter and the faster agglomeration rate of the polydisperse particles introduce a greater degree of conservatism to this worst case analysis than could be disputed by neglecting the trace amount of small particulates that has not undergone agglomeration up to the time of filtration.

E. Effect of Different Materials. The agglomeration coefficient, K, is relatively independent of the material. Green and Lane[1] quote values for nine different aerosols which range from 4.9×10^{-10} cm^3/sec to 8.3×10^{-10} cm^3/sec. A value of 5×10^{-10} was used in this calculation because it lay in the low range of quoted values and would be conservative as seen from Eq. 3.

F. Effect of Electrical Charge. Green and Lane[1] state that the effect of monopolar electrical charge is not great. In fact, where large and small particles coexist, or where there are differences in charge magnitude, coagulation is increased by the mechanism of induced charges. Although this is a complex phenomenon to describe, it is not expected to have too great an effect for the case in question.

G. Limiting Size of Agglomerated Particles. Agglomeration according to Eq. 1 may be expected to take place with the particles coagulating to a size large enough to settle due to gravity. When it is considered that a particle of 1 μ diameter of specific density = 4.93 would settle at a rate of 0.0172 cm/sec in air, it can be seen that settling would not be an important depletion mechanism in the 0.3-μ size range.

Conclusions

From the results of this simplified analysis, it appears that fission-product penetration of filtration units by transport of particulate matter should not be a great problem because, with a high population density, as would exist after a catastrophic reactor accident, the particles would agglomerate in a very short time to a size readily removable by filters.

The amount of activity released from a dual containment system as analyzed herein is dependent on the specific activity of the particulate debris. That is, a given amount of activity dispersed over a large amount of cooler debris would result in less total activity released to the atmosphere than would be the same amount of activity associated with a smaller amount of debris.

Following the above argument, the extreme of conservatism is the case where the debris is pure radionuclide, in this case, iodine. This analysis shows that agglomeration occurs at a rate fast enough to prevent significant penetration of the filtration systems even if all particulates of a size smaller than 0.3 μ were assumed to penetrate the filters. In one example the calculated amount of iodine released would be less than 10^{-5} of that available.

References

1) H. L. Green and W. R. Lane, Particulate Clouds, Dusts, Smokes and Mists, E. & F. N. Spon, Ltd., London, 1957, pp 126 et seq.

2) W. E. Browning, unpublished work, 1962.

APPENDIX A

Derivation of Equations Describing Total Activity Released from a Dual Containment System

The schematic of the system is shown in Fig. A.1.

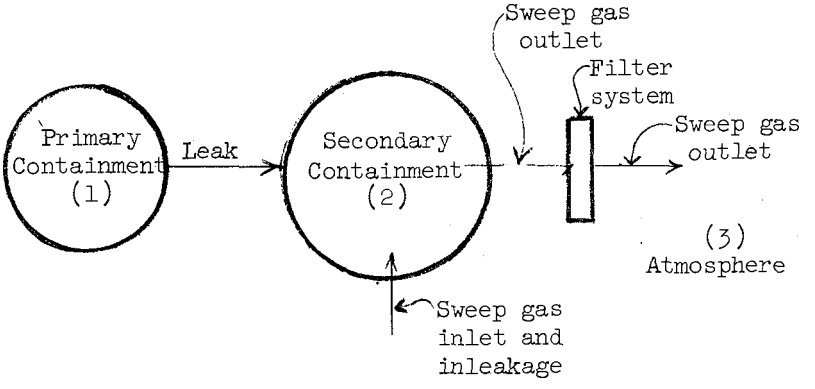


Fig. A.1. Schematic of dual containment system.

The mass balance in the secondary containment is:

$$C_1 Q_{1-2} - C_2 Q_{2-3} = \frac{d}{dt}(C_2 V_2) \qquad \text{(A-1)}$$

where

C_1 = concentration in primary containment (x/cm^3),
C_2 = concentration in secondary containment (x/cm^3),
Q_{12} = volumetric flow rate from primary containment to secondary containment, leakage (cm^3/sec),
Q_{23} = sweep gas flow rate from secondary containment to the atmosphere (cm^3/sec),
V_2 = volume of secondary containment (cm^3), and
t = time (sec).

Rearranging:

$$\frac{dC_2}{dt} + \frac{C_2}{V_2} Q_{23} = \frac{C_1}{V_2} Q_{12} \qquad \text{(A-2)}$$

Solving by integrating factors:

$$C_2 e^{(Q_{23}/V_2)t} = \frac{C_1}{V_2} Q_{12} \frac{V_2}{Q_{23}} e^{(Q_{23}/V_2)t} + a_1 \qquad \text{(A-3)}$$

where a_1 is a constant of integration.

When $t = 0$, $C_2 = 0$. Therefore:

$$a = -\frac{C_1}{V_2} Q_{12} \frac{V_2}{Q_{23}}$$

Substituting into Eq. A-2 and rearranging yields:

$$\frac{C_2 Q_{23}}{C_1 Q_{12}} = 1 - e^{-(Q_{23}/V_2)t} \qquad \text{(A-4)}$$

The total amount released up to time, t, is:

$$A_{23} = \int_0^t C_2 Q_{23} \, dt'$$

Therefore,

$$A_{2-3} = C_1 Q_{12} \int_0^t [1 - e^{-(Q_{23}/V_2)t'}] \, dt'$$

since C_1 and Q_{12} were assumed to be constant. Integrating:

$$\frac{A_{23}}{IR} = t - \frac{V_2}{Q_{23}} [1 - e^{-(Q_{23}/V_2)t}] \qquad \text{(A-5)}$$

since

$$C_1 Q_{12} = IR$$

where

I = inventory of quantity in question in primary containment available for release (curies, lb, etc.), and

R = primary containment leakage rate (%/sec) × 100.

MAINTENANCE PROBLEMS ENCOUNTERED IN THE SERVICING OF FILTER INSTALLATIONS

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Oak Ridge National Laboratory has numerous 100 per cent fresh air systems providing temperature and some degree of humidity control of air supplied to offices, laboratories, and process control rooms. In general, air flow is through offices and corridors into laboratory or processing areas where additional direct air supply maintains the required air volume to be removed through chemical fume hoods by attic exhaust fans. Exhaust from all potentially hazardous operations passes through individual high-efficiency filters ahead of the individual fans. The filtered air is discharged above roof level.

In two areas of the facilities recently constructed, large banks of filters have been incorporated in both intakes and exhausts. From the viewpoint of maintenance requirements, there are a number of deficiencies which should be avoided in future designs. For example, the air intake to one building contains 174 Aerosolve 3A95 units, 24" x 24" x 12" deep, with a face-mounted 2-inch-thick throw-away prefilter. These are arranged 6 units high by 30 units long in a flat bank. Clearance to the intake louvers and dampers is less than $3\frac{1}{2}$ feet. The 12-foot height requires the use of ladders or scaffolding for access to the upper half of the bank. Further complications arise from the location of a single access door at one end of the plenum. Handling of clean and dirty filters must necessarily "cross-over" at the expense of additional labor. A permanently installed, traveling scaffold is contemplated to improve safety and to reduce handling time in this installation.

A similar installation of 90 Type 3D95 Aerosolves, 24-inch deep with prefilters, is also 12 feet high and is further complicated by a front clearance of less than $3\frac{1}{2}$ feet. Both this intake and the one previously described are at grade. Since completion of construction and establishing a stand of grass, the life expectancy of these installations is in the order of 15 months, depending on weather conditions. Where economics permit, it would be desirable to locate intakes as far above grade level as possible.

The exhaust systems associated with the 174-unit intake are 12 in number and contain from 3 to 60 high-efficiency filter units with face-mounted throw-away prefilters. Two banks containing 28 and 16 filter units are stacked four high, making the use of step ladders necessary when servicing the upper row. All other systems are three units high and can readily be serviced from floor level. This building was designed for control of both radioactive and toxic materials. The filters in all exhaust systems operating over the past year and a quarter have been changed out recently. Radioactivity and toxicity levels were below tolerance in all systems indicating the care taken by research personnel to contain such materials within their equipment. In the event of an accident within this facility, the exhaust systems will afford a high degree of

protection to the occupants of adjacent facilities.

These exhaust systems are located in a rooftop penthouse. Fans are located toward the central open area with access doors to the clean side of the filters near the fans. Filters have been designed for changing from the dirty side. Access is hindered by being on the perimeter of the penthouse area and by the adjacent plenums. Thus on the largest banks, dirty filters are bagged up at the plenum door and carried to an open area for boxing and second bagging as conditions warrant. If a high activity level were ever to be accumulated on these filters, the handling and temporary storage prior to removal from the penthouse would constitute a serious exposure problem. Handling of materials into and out of the penthouse requires the use of a motor crane between ground level and the roof and manual labor to hand carry between the penthouse and the roof edge. A study is to be made based on the experience gained in the recent filter change to improve material-handling operations.

A large number of sizes and types of filters are required in servicing the many facilities at the Oak Ridge National Laboratory. These are stocked by the Finance and Materials Division. On large installations of high-efficiency filters, an effort is made to coordinate original delivery direct to the point of use just prior to the need for a filter change, thus minimizing the unnecessary handling of the high-efficiency units. Such action is not usually appropriate where individual hood filters are changed on-the-spot basis. Depending on the nature and level of contamination, filters are destroyed by burning or burying. A simple effective method of reduction of volume is needed for the disposal of high-efficiency filters containing high levels of contamination. At present, burial accomplishes the desired end result at the expense of three to four times the actual solid volume in a filter unit.

Necessity for filter change is based on the pressure drop across the filter bank and the ability of the fan to move the rated air flow which has been reached or slightly exceeded. Since the investment in high-efficiency filters is high, it is imperative that their service life be extended to obtain the maximum value. Improved means of determining the air flows and pressure drops are being provided on all critical exhaust systems.

The physical condition of the filters may deteriorate due to chemical fumes or a mechanical failure or rupture might occur during the service life of an installation. In the existing systems there is no way to determine the condition of the units without shutting the system down and making an inspection of the filters in place. One suggestion has been advanced to install a removable test coupon in the supply air stream. Periodic removal and evaluation of the specimens would provide a basis for evaluating the condition of the main bank. This idea has been developed further in discussions with several others. As now envisioned, a bypass duct would contain both a prefilter and main filter with manometers to measure the individual pressure drops and DOP test connections. Flow would be equivalent to that through the main bank and be representative as of the suspended and entrained materials. This installation could thus provide factual data on the conditions in the main bank as follows:

1. DOP test at intervals of three or four months would indicate trend in dirt accumulation or chemical attack of media.

2. Pressure drop indications would evaluate need for change of prefilter or both prefilter and main unit.

3. Being located in a bypass duct, the filters would be capable of being isolated and removed for sampling and analysing for potential radioactive and toxic hazards.

4. Filter changing would be simplified by having complete hazard data in advance without having to shut down a system, obtain samples for analysis, and start the system back up. At present, such sampling must either be done in advance with full protective measures or at the initiation of filter replacement with full protective measures in force which can be relaxed upon receipt of analytical reports.

5. Direct examination would detect the development of detrimental conditions before failure could occur.

From the viewpoint of the maintenance personnel, many improvements could be made in the initial installation to make our job simpler. It is evident, however, that each such "improvement" incorporated into a design increases the cost. Therefore, each one must be considered on its own merits, installation cost versus improved operational cost, and considerations of safety and health.

In conclusion the following points are suggested for consideration in the design of new installations as applicable:

1. Provide individual lighting in each plenum with external switch and pilot light. Use of submarine-type light fixtures arranged for relamping from exterior of plenum.

2. Provide visual inspection windows on both clean and dirty sides of plenum.

3. On large banks provide bypass arrangement to evaluate conditions in main bank.

4. Limit height of banks to approximately six feet or provide permanent walkways and steps within plenum and make the bank a little over 12 feet high.

5. Clamping and sealing of filters to frames should be simple, positive and made of noncorrodible material.

6. Provide adequate but not excessive clearances for ease of insertion and removal. (36" minimum aisle width, from main area to plenum doors.)

7. Provide adequate working area and storage space to accomplish a filter change. Specifically, space should be available for storage of a complete complement of clean filters plus sufficient area to unbox and inspect sufficient filters to service the largest system in the group.

8. Consider the material-handling problems in respect to filter bank location and means of access.

9. Provide for adequate flow and pressure measurement and excess pressure drop indication and/or alarm.

10. Avoid use of fans having a bearing within the air stream; i.e., select a single inlet fan with cantilever support.

11. Reinforce plenum structure to prevent drumming or pulsations which may affect the filter media.

A DISPOSABLE LIGHT CHAMBER FOR THE NAVAL RESEARCH LABORATORY PERCENT PENETRATION METER

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INTRODUCTION

In situ DOP tests of high-efficiency particulate filters are sometimes complicated by system conditions which result in contamination of test equipment. Obviously, systems which are likely to contaminate test equipment are those most in need of efficiency tests. When equipment becomes contaminated it must be discarded, decontaminated, or handled in such a way that the activity is not spread.

The routine in situ DOP test at ORNL involves withdrawing samples of the aerosol from both sides of the filter bank under test and passing these samples through the light chamber of an NRL Percent Penetration Meter [1]. The instrument arrangement is shown in Fig. 1.

Figure 2 is a cross section of an NRL forward-light-scattering photometer and shows the parts of the instrument which are exposed to the aerosol samples. Included, are parts of the permanent lens system, the hardwood conical liners with their machined connector ring, and the metal shell of the light chamber.

The cost of replacement or decontamination of these parts adds significantly to the cost of in situ testing and, in addition, safe use and storage of contaminated instruments is troublesome and time consuming. One alternative is to replace the light chamber of the NRL photometer with an inexpensive, disposable unit when testing systems which are likely to cause instrument contamination. Figure 3 shows a standard NRL photometer and an NRL photometer with the disposable chamber installed.

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[1] H. W. Knudson and L. White, Development of Smoke Penetration Meters, Report NRL-P2642, (September 14, 1945).

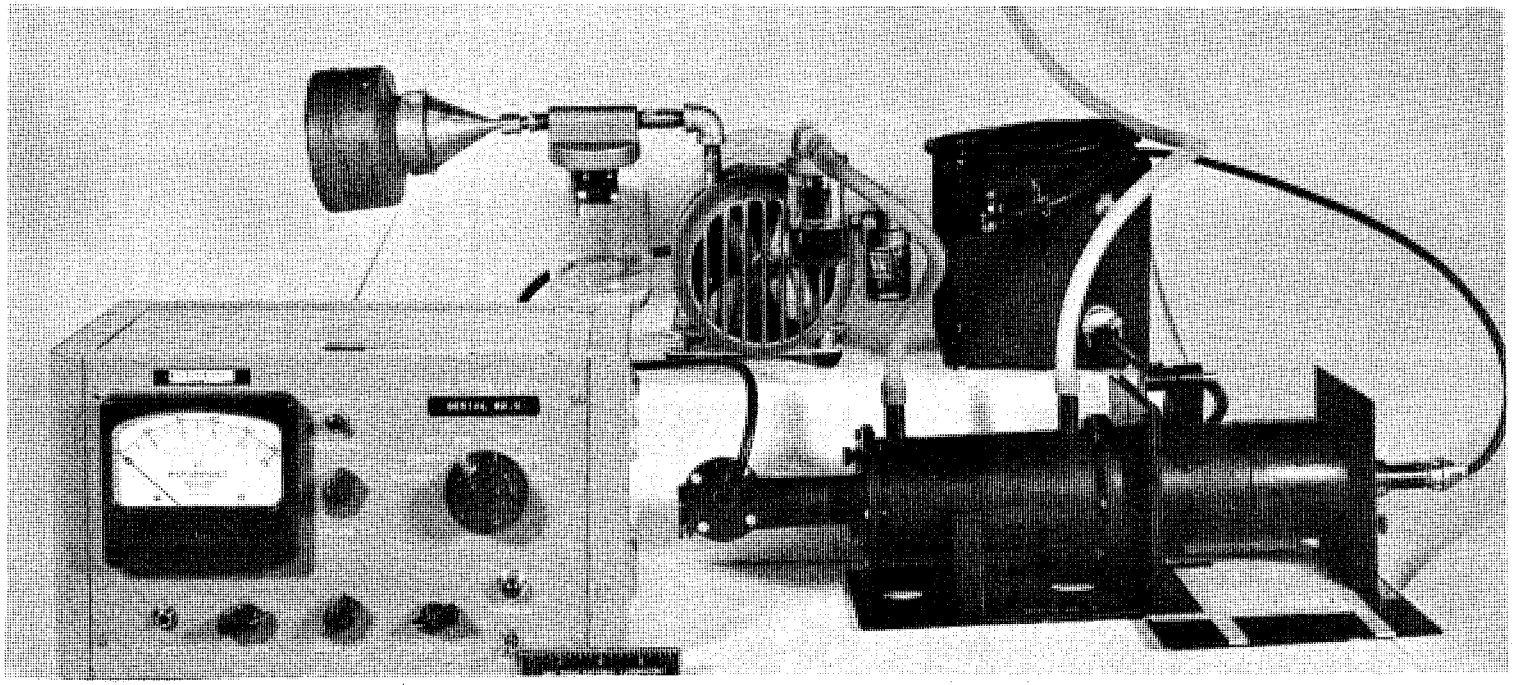


Fig. 1. Naval Research Laboratory Type Photometer, Amplifier, Transformer and Pump.

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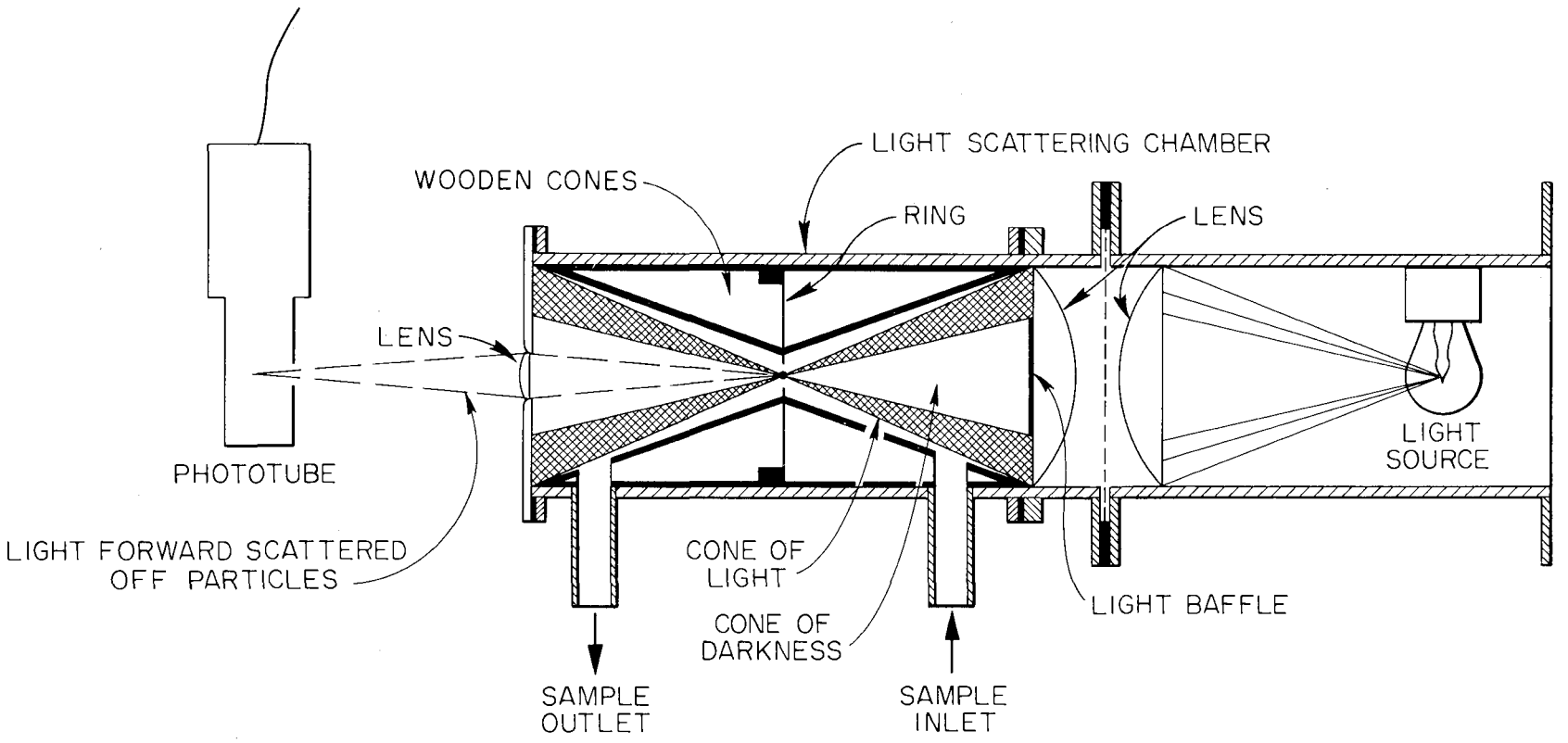


Fig. 2. Cross Section of a Forward-Light-Scattering Photometer.

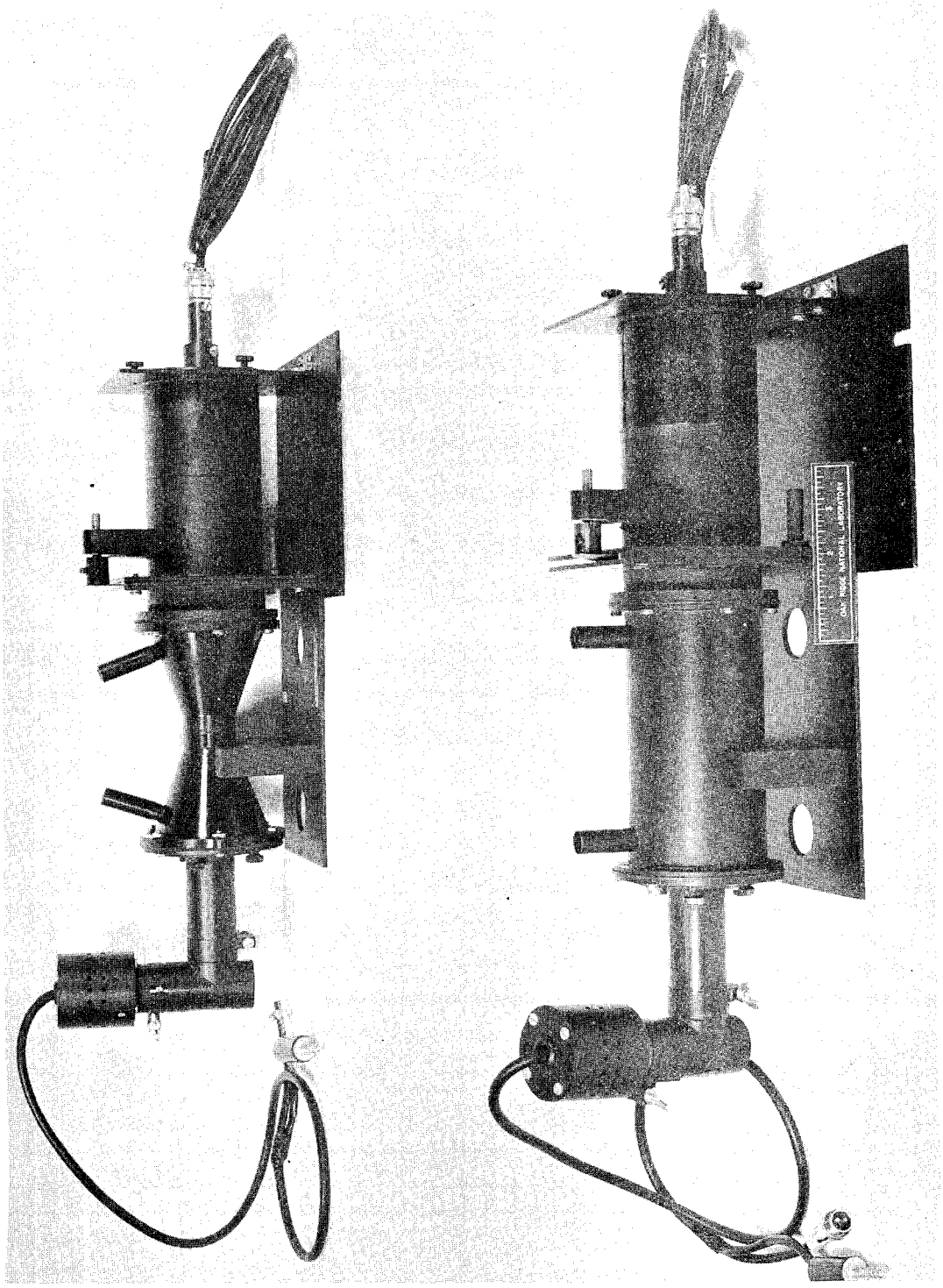


Fig. 3. Upper, NRL Photometer with Disposable Light Chamber.
Lower, NRL Photometer with Commercial Light Chamber.

DESCRIPTION OF DISPOSABLE LIGHT CHAMBER

Figure 4 shows the components and the assembly details of the disposable chamber. The body is made by cementing together two identical epoxy resin castings, the internal dimensions of which duplicate those of the commercial unit. Glass discs cemented in place seal the ends and thus contain contaminants within the disposable unit. The non-transmitting areas of the glass discs are covered with a non-reflective paper to reduce internal scattering of light.

Figure 5 shows the disposable unit connected for use; the gas mask canister filter in the exit sample line prevents radioactive particulate matter from reaching the vacuum pump. The canister, disposable light chamber and the sample line tubing are discarded after the in situ test as shown in Fig. 6.

PERFORMANCE TESTS

The effect of the added glass in the optical system was investigated by checking the linearity of the instrument at high and low concentrations and by a correlation check between two, NRL Percent Penetration Meters; one equipped with a commercial light chamber, and the other equipped with the disposable unit.

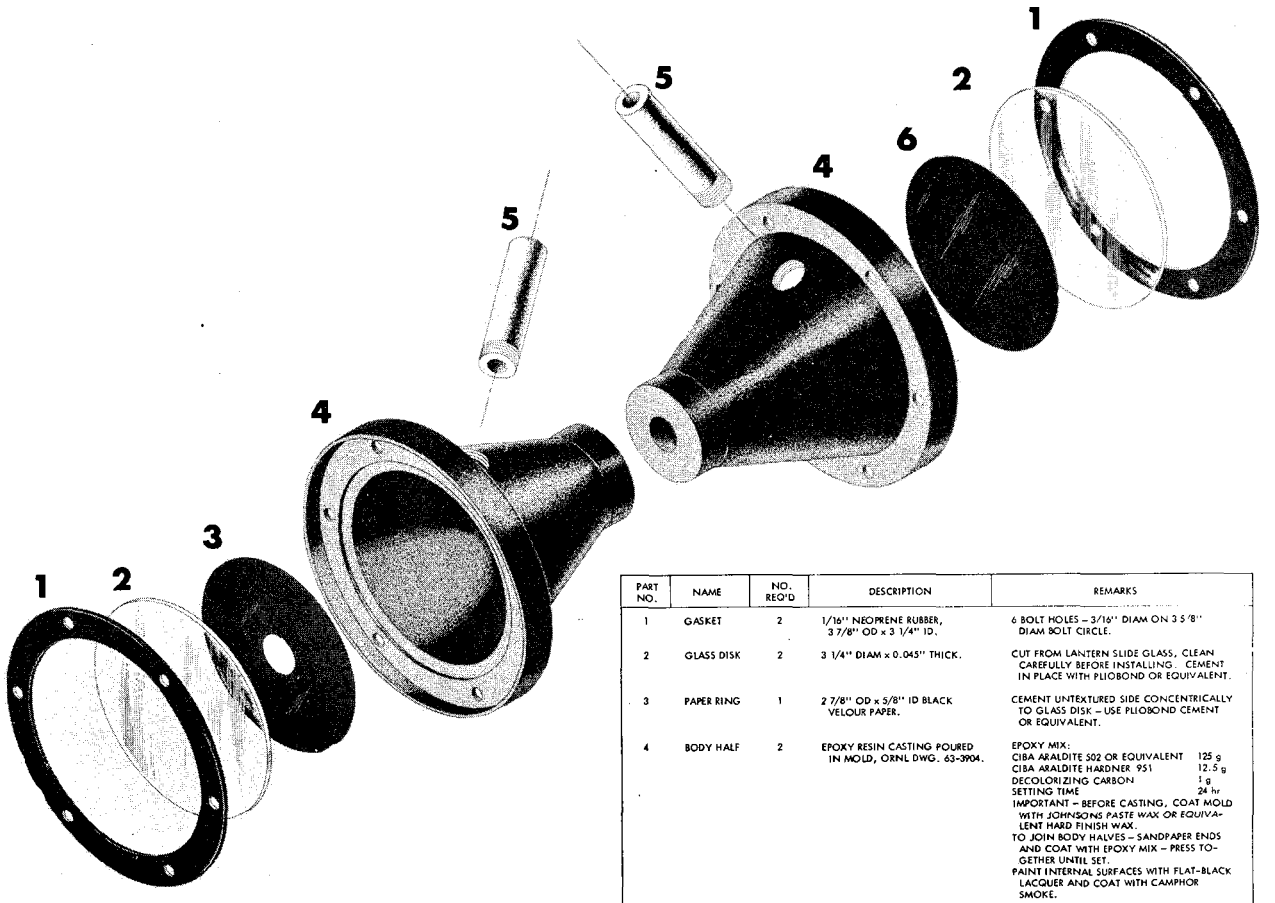
The linearity in the high concentration range was checked as follows: an aerosol generator was arranged to produce a constant amount of smoke, and concentration was measured as the air flow in the test rig was varied between 390 cfm and 1370 cfm.

If the measured concentration is inversely proportional to the air flow, the instrument may be assumed to be linear over the range of concentrations used. The inverse proportionality criterion was applied to the concentration measured at 800 cfm, since reasonable precision in the measurement of both flow and concentration may be expected near the mid-point of the curve. The data are shown in Fig. 7. The agreement between the experimental curve and the predicted curve is satisfactory and closely parallels the results of a similar test made on the commercial NRL photometer [2].

Next, a filter with a metered bypass was installed in the test rig as shown in Fig. 8. The output of the aerosol generator was held constant, and the downstream concentration was measured over the range of bypass flows indicated by the curves of Fig. 8. Curve A indicates that the photometer with a disposable chamber is linear in the low concentration range.

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[2] E. C. Parrish and R. W. Schneider, Tests of High-Efficiency Filters and Filter Installations at ORNL, Report ORNL-3442, (May 17, 1963).



PART NO.	NAME	NO. REQ'D	DESCRIPTION	REMARKS
1	GASKET	2	1/16" NEOPRENE RUBBER, 3 7/8" OD x 3 1/4" ID.	6 BOLT HOLES – 3/16" DIAM ON 3 5/8" DIAM BOLT CIRCLE.
2	GLASS DISK	2	3 1/4" DIAM x 0.045" THICK.	CUT FROM LANTERN SLIDE GLASS, CLEAN CAREFULLY BEFORE INSTALLING. CEMENT IN PLACE WITH PLIOBOND OR EQUIVALENT.
3	PAPER RING	1	2 7/8" OD x 5/8" ID BLACK VELOUR PAPER.	CEMENT UNTEXTURED SIDE CONCENTRICALLY TO GLASS DISK – USE PLIOBOND CEMENT OR EQUIVALENT.
4	BODY HALF	2	EPOXY RESIN CASTING POURED IN MOLD, ORNL DWG. 63-3904.	EPOXY MIX: CIBA ARALDITE 502 OR EQUIVALENT 125 g CIBA ARALDITE HARDNER 951 12.5 g DECOLORIZING CARBON 1 g SETTING TIME 24 hr IMPORTANT – BEFORE CASTING, COAT MOLD WITH JOHNSONS PASTE WAX OR EQUIVALENT HARD FINISH WAX. TO JOIN BODY HALVES – SANDPAPER ENDS AND COAT WITH EPOXY MIX – PRESS TOGETHER UNTIL SET. PAINT INTERNAL SURFACES WITH FLAT-BLACK LACQUER AND COAT WITH CAMPHOR SMOKE.
5	SAMPLE CONNECTION	2	1/4" SCH. 40 BRASS PIPE, 2" LONG.	PAINT AND COAT SAME AS BODY HALF.
6	PAPER DISK	1	1 3/4" OD BLACK VELOUR PAPER.	CEMENT SAME AS PART NO. 3.

Fig. 4. Disposable Light Chamber Components and Assembly Details.

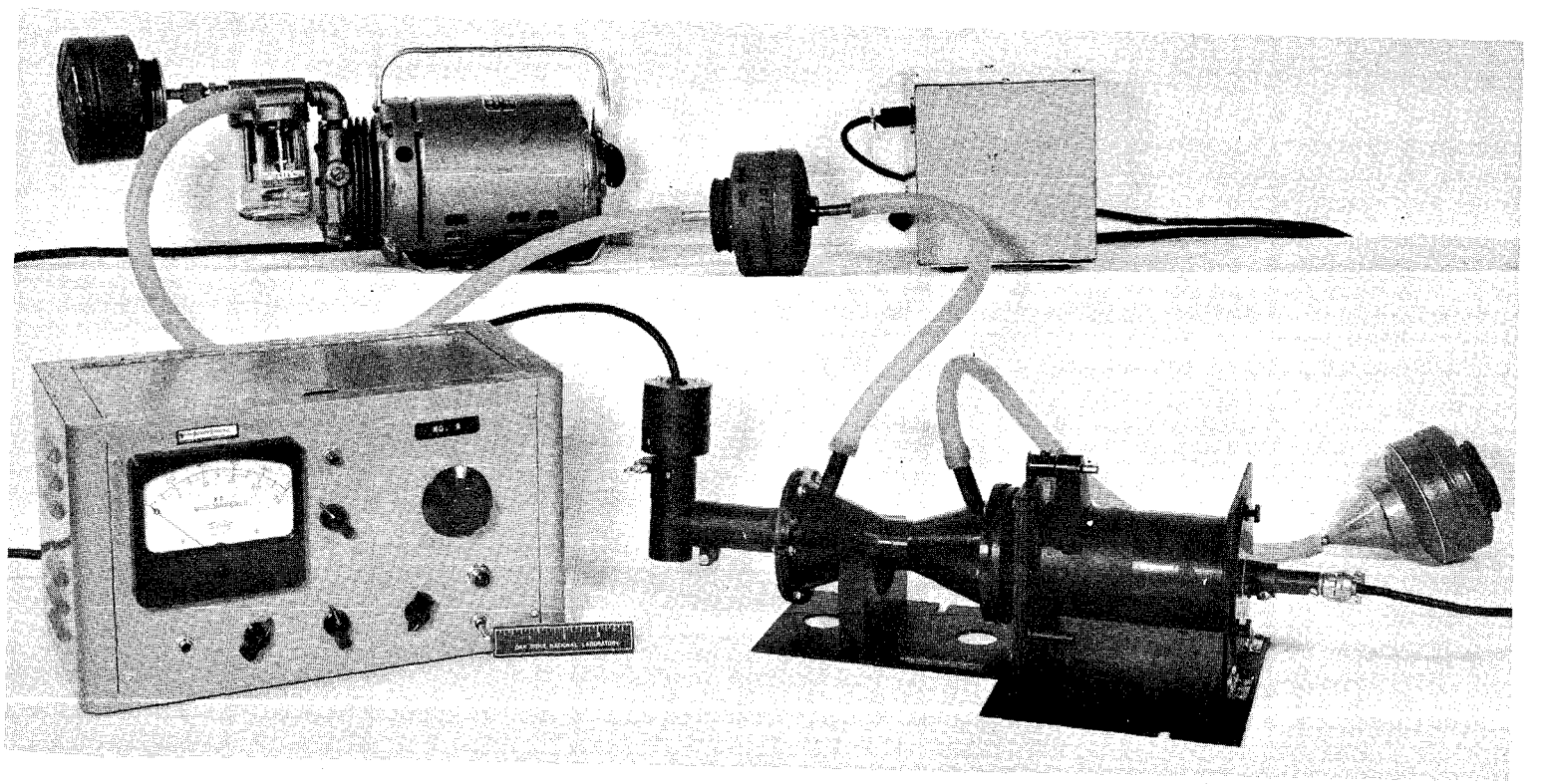


Fig. 5. NRL Percent Penetration Meter with Disposable Light Chamber.

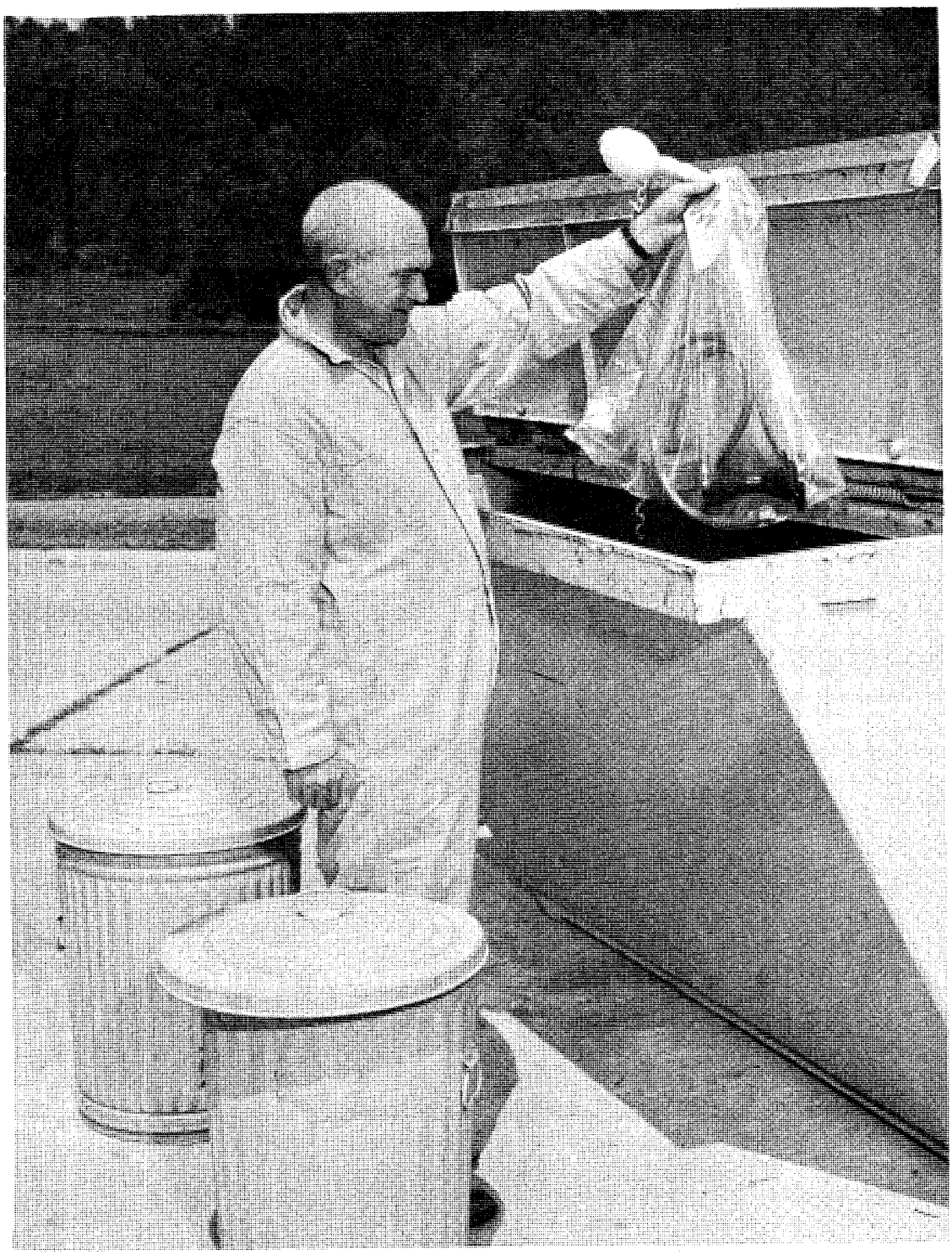


Fig. 6. Disposal of Light Chamber, Canister Filter, and Sample Line Tubing after Filter Test.

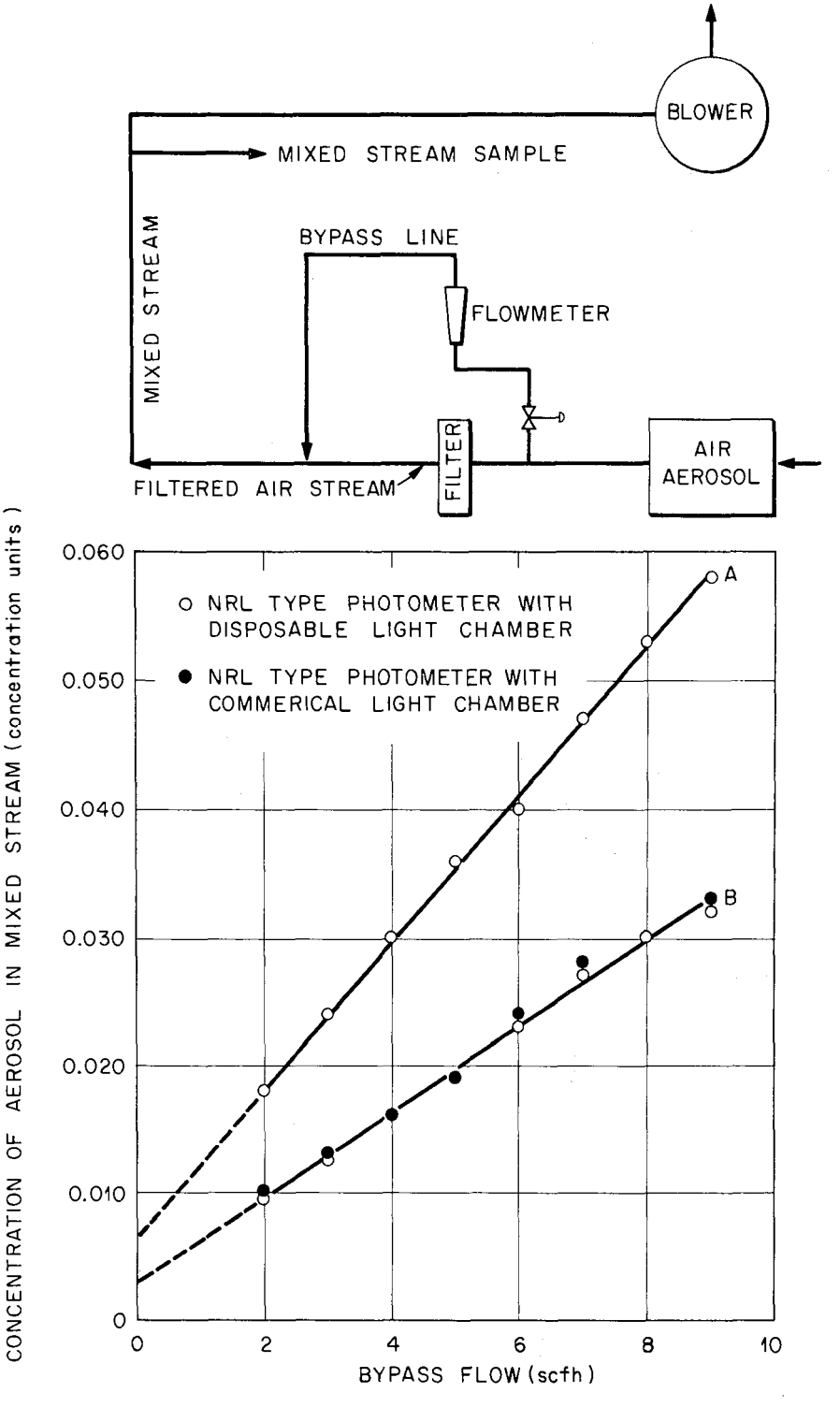


Fig. 7. Linearity of NRL Photometer with Disposable Light Chamber Over a Wide Range of Aerosol Concentrations.

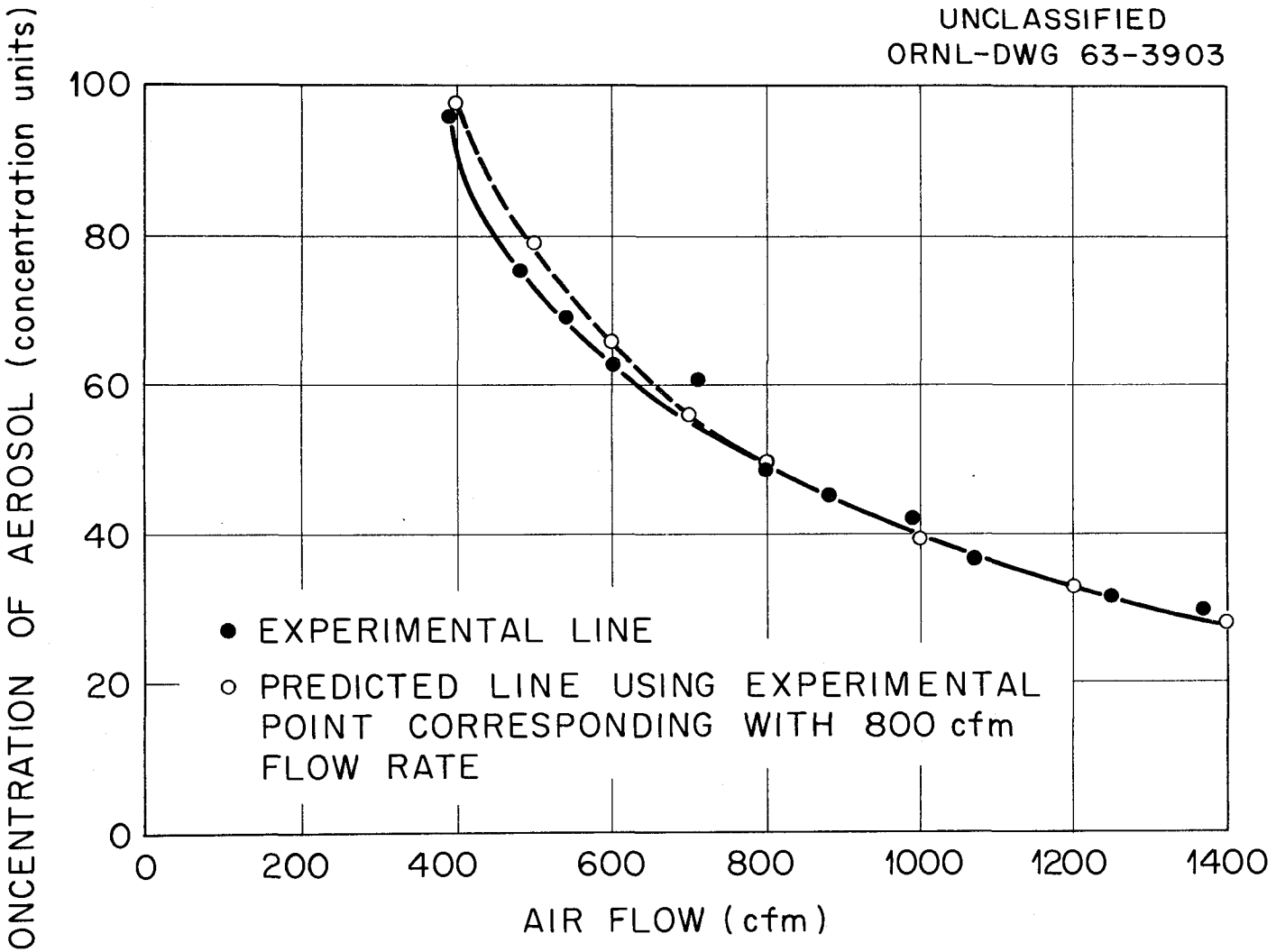


Fig. 8. Comparison of Standard Light Chamber with Disposable Unit in the Low Concentration Range.

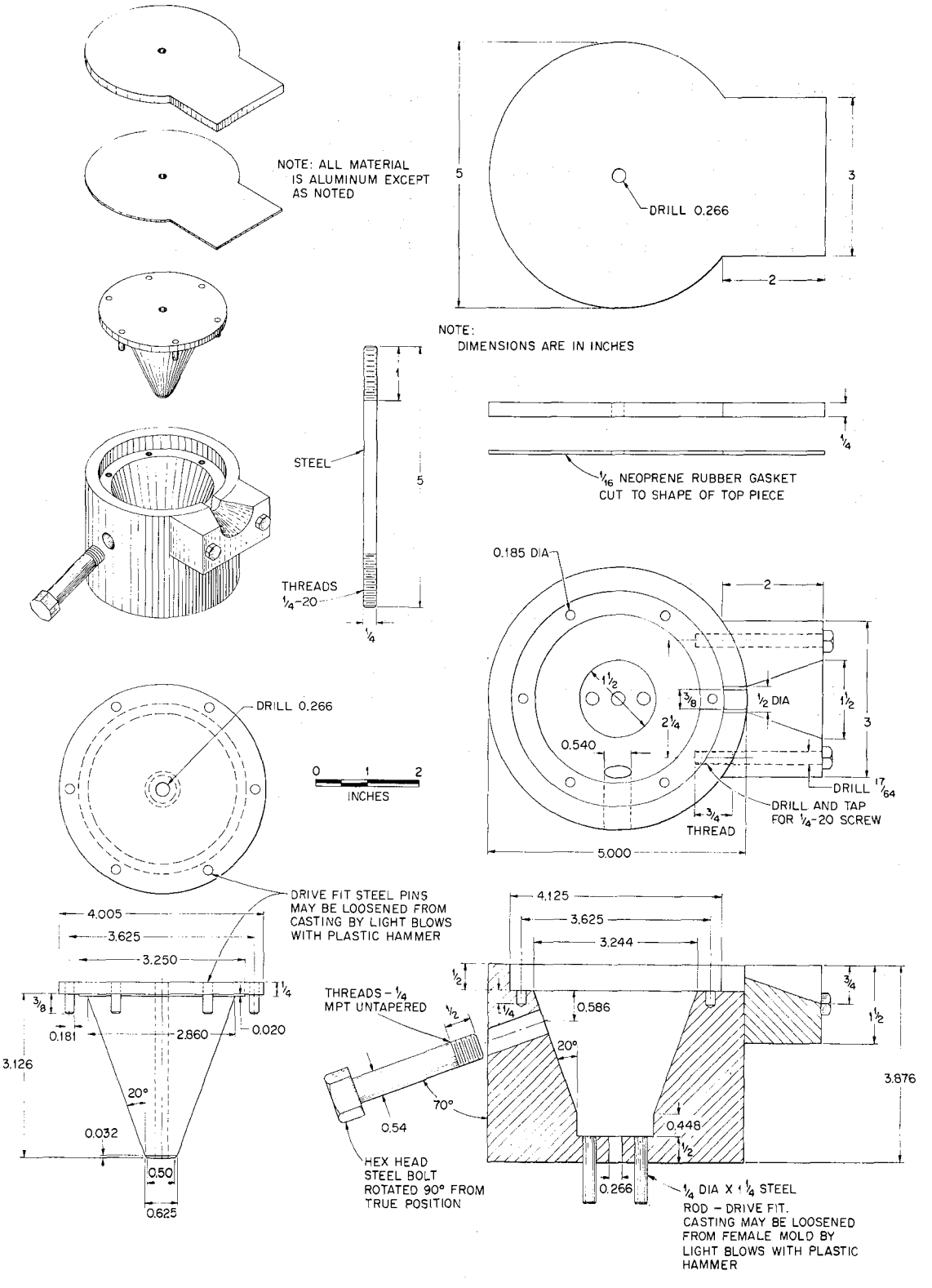


Fig. 9. Mold Details for Disposable Light Chamber Body-Half.

Finally, two NRL photometers, one equipped with a disposable light chamber, and the other with the commercial chamber were connected in series and adjusted to read full scale on the upstream sample. Curve B, Fig. 8, is a plot of the downstream concentration readings of the two instruments over the range of the bypass flow. The agreement between the two instruments is excellent. Extending curves A and B (Fig. 8) to zero bypass flow gives two different efficiencies for the same filter but since the difference is only a few thousandths of a percent it is not considered to be significant.

CONSTRUCTION DETAILS

Figure 9 provides details of the mold in which the disposable light chamber body castings are poured.

CONCLUSION

The cost of measuring the efficiency of highly contaminated particulate filter systems can be reduced by substituting a disposable light chamber for the commercial unit supplied with the Naval Research Laboratory Percent Penetration Meter. Tests indicate that the disposable light chamber is a suitable substitute from the standpoint of performance requirements. Additional tests are planned before the disposable chamber is released for routine in situ testing applications.

ELECTROSTATIC PRECIPITATOR FOR TREATMENT OF DIRECT-CYCLE, AIR-COOLED REACTOR EFFLUENT

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At the sixth AEC Air Cleaning Conference held in Idaho Falls in July of 1959, several papers were presented pertaining to the specialized air cleaning problems encountered in the direct-cycle nuclear aircraft power plant development program. One of these, by C. L. Storrs and D. C. Foster (Proposed Side Loop Program at the IET), described a series of tests to be performed on a pilot plant electrostatic precipitator for removing fission products, both particulate and gaseous, from the high volume, high temperature air coolant discharged from a nuclear aircraft gas turbine engine. Since the aircraft nuclear propulsion program is no longer active, there is no specific requirement for such an effluent treatment system at present. Nevertheless, the results of these air cleaning experiments may be of interest for future application.

SYSTEM REQUIREMENTS

The homogeneous ceramic-UO_2 fuel elements developed for the Advanced Core Test (ACT) power plant released a very small percentage of the fission products produced continuously during power operation. The release mechanism was a combination of recoil of the fission fragments directly into the coolant air stream, diffusion through the fuel matrix and water vapor corrosion; with recoil evidently the predominant effect in the normal operating temperature range. Water vapor corrosion was effectively eliminated in the prototype fuel elements by application of a suitable coating material. The magnitude of this continuous fission product release was such that it would have presented essentially no health hazard from flying aircraft, but might have been of some concern for a prolonged stationary ground test.

For the ACT application, the effluent handling system would have been required to handle 175 pounds per second of air at a turbojet engine exhaust gas temperature of about 1000° F, at cruise power. At full power operation the air flow would have approximately doubled. An important design consideration was that the back pressure presented to the jet engine was required to be kept as low as possible; that is the pressure drop across the effluent handling system was required to be very small.

A survey was made of the various air cleaning processes available to determine which of them offered the greatest promise of success. Various forms of scrubbers, filters, separators and precipitators were studied with the result that an electrostatic precipitation process

was found to most nearly meet the operating requirements, particularly because of the low pressure drop associated with such systems.

PILOT PLANT TESTS

In 1959 a pilot plant electrostatic precipitator was installed at the Initial Engine Test Facility at the NRTS in order to study the performance of such a system and evaluate its worth. This installation is described in the aforementioned paper.

The HTRE-2 reactor, operating with a central insert composed of ACT-type ceramic fuel elements, supplied the fission product source for the tests.

Experience gained during the effluent monitoring program at IET had indicated that collection efficiencies of the radioactive gases on conventional filter papers were much higher when the turbojet engines were operated partially on chemical power than when operated on nuclear power alone. This effect was, of course, due to the adsorption of these gases on the carbon produced in the combustion process and subsequently removed by the sampling filters. This process (i.e. adsorption or chemical combination with a particulate or aerosol) was to be utilized to enable the electrostatic precipitator to attain removal efficiencies high enough for the proposed use.

Early testing of the precipitator was primarily for the purpose of evaluating a number of different air stream additives in order to permit optimization of cleaning efficiency and cost. The additives tested included carbon black, fly ash, converter fume, precipitator fines, $CuSO_4$, AgI, and $AgNO_3$. The precipitator was also tested with no additives, achieving removal efficiencies of only 25 per cent of the radio-iodines and 70 per cent of the gross fission products. The tests indicated that any additive to the airstream, upstream of the precipitator, would substantially increase its efficiency, but that the presence of silver compounds in the additive had a substantial advantage. The silver additives had two effects; they improved the operating characteristics of the precipitator, itself, as well as improving the efficiency for iodine removal. The best results of all were obtained using $AgNO_3$ injection plus combustion products from partial chemical operation of the jet engines or from a separate oil-fired burner in the exhaust duct upstream of the precipitator. Since the ACT was not designed to have a chemical combustion capability, however, it was not deemed worth the additional cost and complication to combine these two additives in a full-scale treatment plant.

The $AgNO_3$ additive was injected in two alternate locations; the first being in the side loop duct and the second in the tailcone of the turbojet; thus allowing a comparison of the effect of mixing time. Figure I shows the inferred effect of mixing time on iodine removal efficiency.

The concentration of $AgNO_3$ in the airstream was also varied by changing both the concentration and injection rate of the solution. Essentially no difference in efficiency as a function of $AgNO_3$ concentration was observed within the range investigated, as shown in Figure II.

The variation in iodine removal efficiency with face velocity (or total airflow through the precipitator) is shown in Figure III. Most of the testing was performed at a volume flow of 12,500 cfm (face velocity = 150 feet/min).

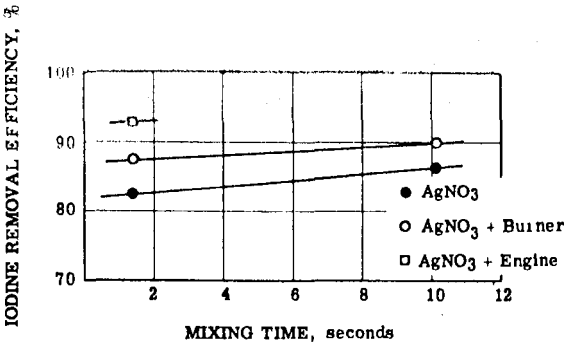


Fig. I - Precipitator Efficiency With Variable Mixing Time.

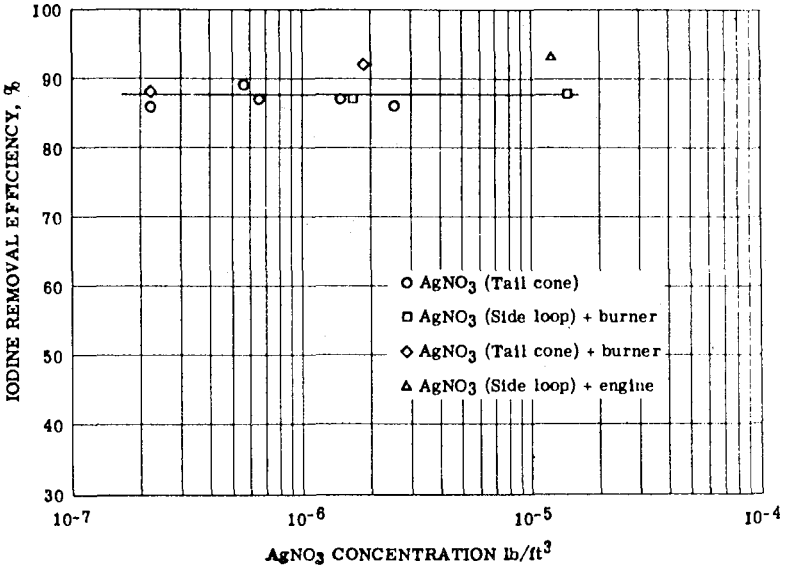


Fig. II - Precipitator Efficiency With Variable Additive Concentration.

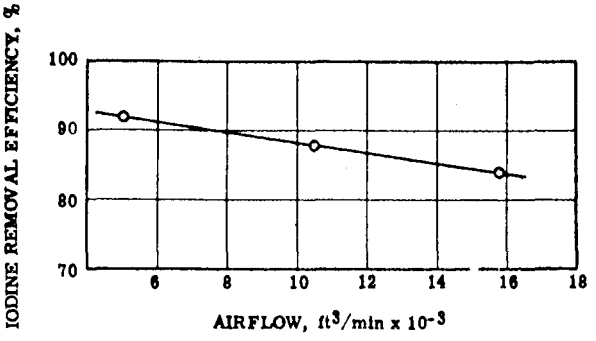


Fig. III - Precipitator Efficiency With Variable Gas Flow.

In addition to the above tests conducted with the relatively low fission product release rates associated with normal power plant operation, one test (the Limited Melting Experiment, or LIME) was conducted to simulate the higher release rates of a coolant loss accident. This was done by restricting the air flow through a ceramic fuel test sample, thus deliberately inducing a partial melt. During this test the chemical combustion system of the jet engine was in operation and $AgNO_3$ was injected into the airstream. The measured removal efficiency of the precipitator is shown in Table I.

TABLE I

Efficiency of Fission Product Removal by Electrostatic Precipitator in Per Cent

Isotope	I^{131}	I^{132}	I^{133}	I^{134}	I^{135}	Sr^{91}	Sr^{92}	Ba^{139}	Ba^{140}	Gross*
Efficiency	92	96	94	98	97	95	95	95	93	96

* Exclusive of the noble gases.

The results of the testing program led to the conclusion that an effluent cleaning system could be designed for the ACT that would provide a removal efficiency of at least 90 per cent of the iodine isotopes and their precursors. The thyroid seekers were, of course, the major concern. Removal of the bone seekers and gross activity exclusive of the rare gases would probably be greater than 90 per cent.

PRELIMINARY DESIGN OF EXHAUST SYSTEM

A design study of an effluent cleaning system for ground testing of the ACT was completed by the Ralph M. Parsons Company. Figure IV is an artist's conception of this system. The preliminary design described below was based upon this study but differed in the selection of silver nitrate as an additive rather than carbon black and in a reduction in the design airflow by a factor of approximately two. This reduction was based upon the premise that the desired efficiency of the system would be obtained under test conditions simulating cruise power, and that lower efficiencies would be permitted during tests of short duration at maximum power.

The design was therefore based upon an airflow of 500,000 cfm at 300° F, corresponding to testing at cruise power conditions. This condition was expected to apply for approximately 90 per cent of the endurance testing. Operation at maximum power would have involved approximately twice the airflow from the engine. During such operations, the additional airflow could be accommodated by operating the precipitator at a face velocity of 600 feet per minute instead of the usual 300 feet per minute. This would theoretically reduce the efficiency from 97 per cent to 90 per cent. It was considered possible to increase the efficiency of the precipitator by converting it to full wave rectification or by installing additional banks of plates had this become desirable.

As designed, the system consisted of a bellmouth to accept the exhaust from the engine as well as additional augmenting air, a section of ducting in which silver nitrate solution and cooling water would be introduced, a diffuser for pressure recovery, an electrostatic precipitator, and an exhaust stack. Auxiliary systems were included for handling the silver nitrate and cooling water, for cleaning the precipitator,

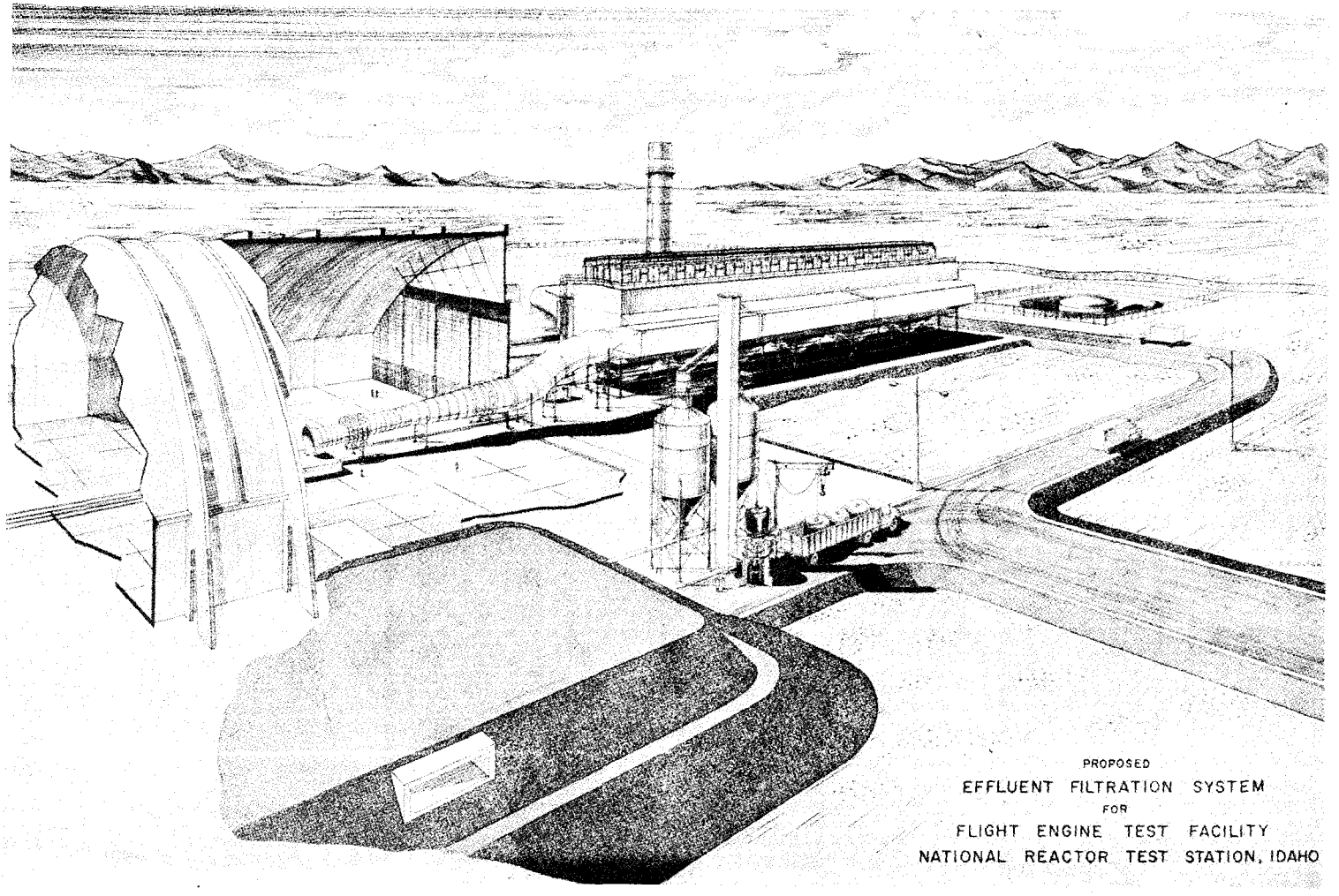


Fig. IV - Proposed Effluent Filtration System for Flight Engine Test Facility

and for contaminated waste disposal. Recovery of the silver nitrate was an economically attractive possibility.

The bellmouth and augmenter section was to provide free discharge conditions for the engine, permitting normal engine operation and accurate thrust measurements. The primary jet from the engine would induce a flow of secondary air into the augmenter throat by jet pump action. This secondary air would help to cool the effluent, thereby reducing the cooling water requirements. However, it was desirable to minimize the secondary air, consistent with satisfactory operation over the entire range of operating conditions, in order to keep the total volume flow low. The augmenter diameter was approximately 8 feet.

The bellmouth was followed by a straight section of duct 40 feet long. In this section were located spray rings for injecting silver nitrate dissolved in demineralized water, and for cooling water. The data from the tests at IET indicated that a suitable amount of additive could be obtained by injecting 60 gpm of .003 M silver nitrate for cruise test conditions, or 120 gpm for maximum power. This would provide about 5×10^8 molecules of silver nitrate for each fission product atom. Cooling water would be introduced at the rate of 150 gpm (300 gpm for maximum power) to reduce the volume of the effluent and consequently the size of the precipitator. A shock wave would form in this straight duct, enhancing the mixing of the additive with the primary exhaust stream.

Leaving the straight duct, the air would pass through a diffuser section and enter a main duct, approximately fourteen feet in diameter by seventy feet long, leading to the precipitator inlet plenum. This chamber would extend across the inlet face of the precipitator and serve to distribute the gas flow to each precipitator section. Adjustable vanes or louvers would be provided at the inlet face to accomplish this, and to control the amount of secondary air.

The electrostatic precipitator was of the wire and dry plate electrode type, specially designed to remove silver nitrate particles from the effluent efficiently. The precipitator consisted of three sections, each having four separate banks of plates in the direction of flow. The over-all structure size was approximately 60 feet high by 80 feet wide by 40 feet deep. Extra space was provided in the front of the precipitator shell to accommodate the future installation of two banks of plates, in case higher collection efficiencies were required. This extra space would also increase the mixing time of silver nitrate and fission products.

An effective plate length of 24 feet was required. Plates in each of the four banks were approximately 24 feet high by 6 feet long, and spaced 8 to 9 inches apart. The plates were designed to resist corrosive attack from the silver nitrate deposited on them in combination with the moisture in the gas stream during operation and the water during spray cleaning operations. High voltage, stainless steel wires, located midway between the plates at a spacing of 6 to 7 inches, were kept straight and taut by cast iron weights.

The power supplies were high voltage transformers with half-wave rectifiers. A minimum of 70 KV secondary peak voltage was required. Precipitator power consumption was estimated at 500 KVA. For increased system flexibility, power supplies having sufficient current capacity for conversion to full-wave rectification could be provided.

A water spray cleaning system was required to remove the collected silver nitrate from the plates after shutdown. Due to the great amount of surface area to be washed, a recirculating wash system was considered desirable.

The cleaned effluent leaving the precipitator entered multiple plenum sections, with ducts leading to a common exhaust stack. The stack was a carbon steel structure, approximately 18 feet in diameter by 150 feet high.

A processing and injection system was provided to prepare the additive in its proper form and concentration. Demineralized water was to be used to dissolve the silver nitrate. This system which would continuously prepare and control the injection into the effluent stream was to be located in a 600 square foot addition to the basement level of the existing Control and Equipment Building at the Flight Engine Test Facility (FET).

Processing capacity for a maximum injection rate of 120 gpm was required. Storage capacity for 2000 pounds of silver nitrate was required for 100 hours of continuous operation at a normal injection rate of 60 gpm allowing 30 per cent excess storage capacity.

A contaminated waste disposal system was provided to handle the radioactive wastes removed from the precipitator plates by spray washing. These wastes would have drained into hoppers beneath the shell from whence they would be pumped through underground piping to a waste disposal system. The disposal system process and equipment requirements were not determined pending a study of the economic justification of alternate methods. Waste concentration, silver recovery, and methods of ultimate disposal could have led to a rather complex chemical processing operation, with additional complications due to the contaminated nature of the waste.

Several auxiliary features were needed to complete the system. Utility services, such as cooling water, demineralized water, and a new sub-station for electrical power, were required. Suitable process instrumentation and control equipment were to be provided for the precipitator proper, as well as all auxiliary systems. Effluent sampling and radiation monitoring equipment was also required.

An estimate of the construction cost of such a system is given in Table II and of the operating cost in Table III.

In view of the relatively low removal efficiencies obtainable, it was decided ultimately, that the installation of the described system would not result in a gain in operating flexibility commensurate with its high initial and operating costs. A test control program based upon the prediction and postevaluation of effluent hazards and the selective use of favorable atmospheric dispersion conditions was believed to be nearly as effective and far less costly. Accordingly, no further work was undertaken.

TABLE II

CONSTRUCTION COST ESTIMATE

Improvements to Land		
Site preparation, including roads and fencing		$ 52,000
Buildings		
Underground injection equipment room - 600 square feet		30,000
Underground monitoring vault		20,000
Equipment (Installed)		
Augmenter, ducting and plenums		325,000
Precipitator		1,200,000
Exhaust Stack		125,000
Additive Processing and Injection System		150,000
Demineralized Water System		30,000
Cooling Water Spray System		75,000
Contaminated Waste Disposal System		150,000
Controls and Utilities		
Electrical Distribution		83,000
Water Supply		5,000
Process Controls and Instrumentation		50,000
Sampling and Monitoring Systems		50,000
	Sub-Total	$ 2,345,000
Contingency @ 10%		235,000
Escalation @ 5%		117,000
Engineering, Design and Inspection @ 10%		235,000
	ESTIMATED TOTAL PROJECT COST	$ 2,932,000

TABLE III

OPERATING COST
(based on 800 hours operation per year)

Item	Consumption	Unit Cost	Cost Per Hour
Silver Nitrate Additive	15 lbs/hr	$10 per lb.	$150
Electric Power	900 KW	1-1/2 ¢ per Kwh	13
Maintenance		1% of equipment cost	22
Operating Personnel			20
	Total Cost Per Hour		$205
	Estimated Annual Operating Cost		$164,000

PRELIMINARY DESIGN CONSIDERATIONS - EFFLUENT CLEANING SYSTEM FOR THE 630A GAS-COOLED MARITIME REACTOR

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INTRODUCTION

The General Electric Company under contract to the AEC is presently developing an air-cooled nuclear steam generator for maritime service. Although this a closed-cycle power plant there are several conditions that will or may be expected to arise which will require treatment of radioactively contaminated air prior to its release to the atmosphere. These conditions are:

1. Normal blower seal leakage - Seal pressurizing air normally leaks into the primary loop through the seals on the primary loop blower shafts. A corresponding amount of air must be bled to the atmosphere to maintain a constant pressure in the primary loop.

2. Bleed-down of the primary loop to perform routine maintenance.

3. Bleed-down of the primary loop or the containment vessel following a fuel melt.

To accomplish the required air treatment for these conditions it is planned that any air passing to the atmosphere from the primary cooling loop will flow through charcoal adsorption beds. For continuous releases such as the seal leakage the noble gases in the contaminated air will be delayed long enough in their passage by adsorption on the charcoal to decay to acceptable concentrations in the effluent. During intermittent releases such as depressurizing the primary loop the noble gases will be delayed long enough for the adsorption bed to be valved off when the required amount of air has been treated but prior to the elution of any noble gases. The halogens and volatile solids in the air will be permanently adsorbed by the charcoal, and due to the length of the adsorption beds their concentrations will be reduced to insignificant levels in the exhaust air. This phenomena of the adsorption by charcoal of noble gases, halogens, and volatile solids has been well covered in current literature[1, 2, &4] and substantiated during previous fuel element and reactor testing in Idaho.

TYPICAL ADSORPTION BED DESIGN

The design layout of a typical adsorption bed is shown in Figure 1. This particular bed has a diameter of 30 inches and a length of 12 feet which gives it an active volume of 58.9 ft^3 and a total weight including the shielding of 15 tons. As may be seen, the adsorption bed is comprised basically of four main components - a steel clad lead shield, a 400 psi carbon steel pressure vessel, 1770 pounds of activated charcoal, and an aluminum heat exchanger. The shield is tapered in thickness from 7" at the air inlet end of the adsorption bed where the halogens and the volatile solids will concentrate to 2" for the final 9 feet of bed. The pressure vessel will be designed with sufficient corrosion allowance to allow for acid decontamination so that the vessel may be fabricated from standard 32" OD carbon steel pipe and flanges.

The design of the aluminum heat exchanger is important because one of the major problems occurring when large amounts of fission products are adsorbed by charcoal is the removal of the decay heat. Although the quantities of heat to be removed may not be too large, the poor thermal conductivity of the carbon makes it fairly difficult to remove the heat while keeping the hot spots in the carbon within acceptable limits. This internally contained aluminum heat exchanger is one feature of these particular adsorption beds that is substantially different from any previously reported adsorption bed design and is therefore worthy of further discussion.

A detailed drawing of a section of the water-cooled heat exchanger is shown in Figure 2. Notice that for the top 11.5 feet of the filter each water tube has six fins located in an uniform rectangular pattern to take full advantage of the good thermal conductivity of the aluminum fins. Due to the uniform length of the heat conduction paths, the maximum hot spots in the last 11.5 feet of charcoal are only about 10° F above the cooling water temperature for the largest conceivable decay heat load.

The bottom six inches of the full length cooling fins have additional fins to transfer to the cooling water the heat generated by the halogens and volatile solids which tend to concentrate in that area. The maximum hot spot in this lower area is about 50° F above the water temperature. This temperature will have an insignificant effect on the adsorption of the halogens and volatile solids.

There are twelve 1/4" OD U-tubes for circulating the cooling water within the heat exchanger. At a total flow of 4.15 gpm there will be a pressure drop of 1.36 psi and a water temperature rise of 10° F maximum over the length of a U-tube.

The main advantage of this heat exchanger design over others investigated is that a minimum of pressure vessel volume is taken up by aluminum fins and water tubes. This results in maximum utilization of the pressure vessel volume for containing charcoal so that the weight of the shielded unit is minimized.

Although a first glance at the drawing might give the impression that the heat exchanger will be hard to fabricate, it will not. Two special aluminum extrusions are required. The rest of the fin parts may be sheared from either the special extrusions or 16 gauge plate. Except for the water headers and the additional fins in the lower six inches of the bed, all welding may be accomplished with automatic seam welding equipment.

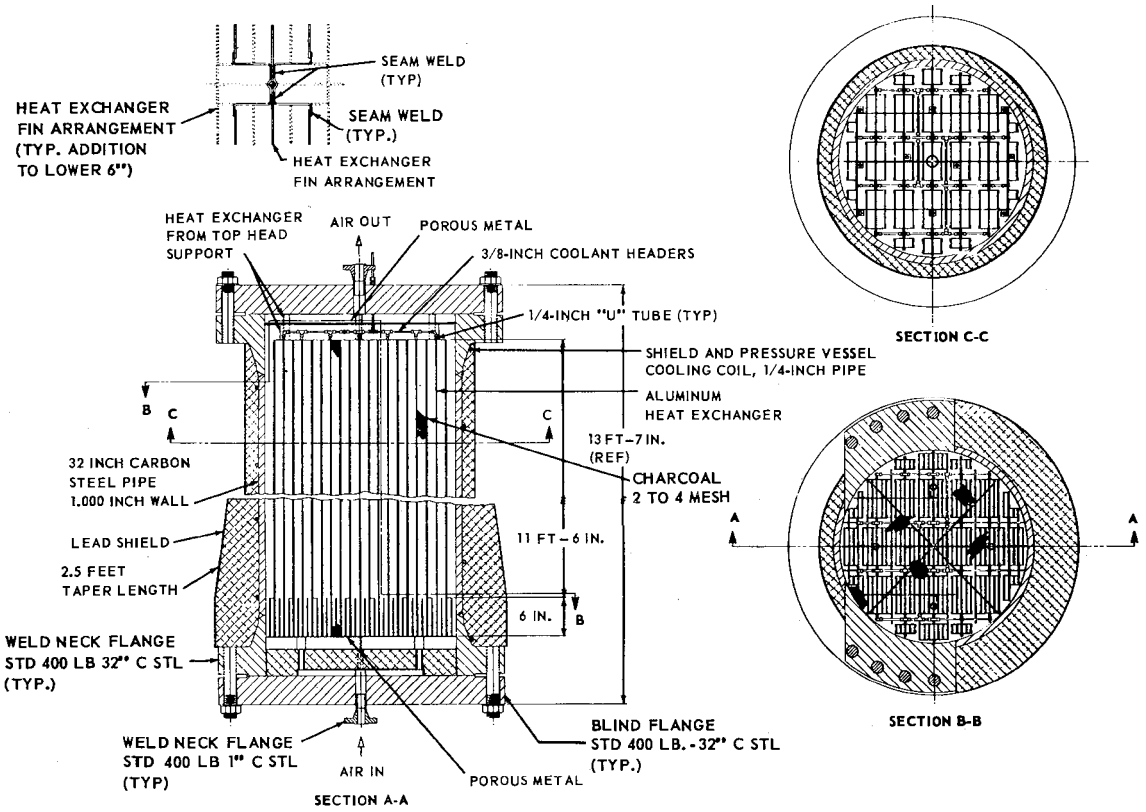


Fig. 1—Waste-air filter

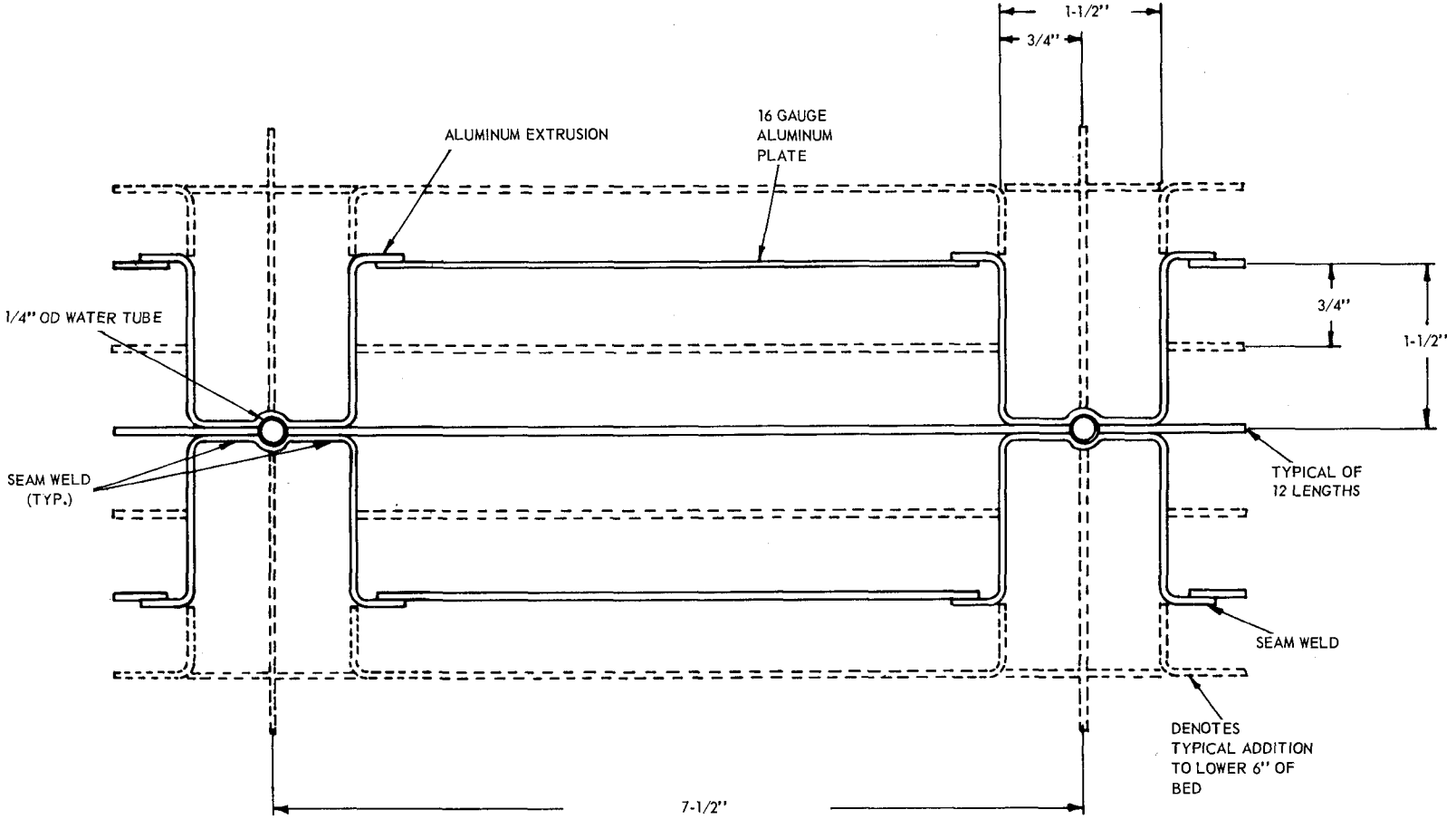


Fig. 2 – Typical detail of heat exchanger fins

OPERATION OF THE AIR CLEANING SYSTEM

Two adsorption beds of the type described will be utilized in the air cleaning system shown in Figure 3. During normal operation the bleed air which compensates for the normal inward seal leakage around the primary loop blower drive shafts will be bled to the air cleaning system at a rate of about 0.2 scfm. It will first pass through the heat exchanger and then through the 12-inch diameter, 12-foot long seal leakage adsorption bed. Any noble gases present will be delayed for the times shown in Figure 4. During this delay time they will also decay as shown on Figure 4 so that the release of noble gases to the atmosphere will be well below the maximum permissible concentration, even for 100% release of the noble gases from the fuel.

For normal depressurization of the primary loop the air will be bled through the heat exchanger and the depressurizing adsorption bed. The delay of the noble gases will be sufficient to allow complete depressurization of the primary loop before elution of the noble gases from the adsorption bed occurs. The adsorption bed may then be valved off so that all of the noble gases will be contained for later disposal. Complete depressurization may be accomplished in about 30 minutes with a face velocity of 16 ft/min and total pressure drop of 7.5 psi for the adsorption bed.

If a reactor melt should ever occur, the seal leakage air will be bled through the seal leakage adsorption bed for about 30 hours following the melt at which time the primary loop may be depressurized through the depressurizing adsorption bed without exceeding allowable radiation levels at the surface of the adsorption bed shield. Since the delay time for the seal leakage adsorption bed is greater than 30 hours, and the depressurizing adsorption bed will be valved off at the completion of the depressurization, all noble gases from the melt will be contained within the primary loop and the adsorption beds.

There are several factors that affect the required size for the adsorption beds. One of these is the total volume of air to be treated. The volume of air to be treated will be minimized by controlling the flow of air through the adsorption beds at the outlet of the beds so that the beds will always operate at approximately primary loop pressure.

Although temperature has an effect on the delay time for noble gases, the adsorption beds will probably not be cooled to low temperatures because of the complicating factors involved in providing an adequate refrigeration system. The beds discussed were sized on the assumption of a cooling water temperature of 85° F. This would be attainable in all but the warmest tropical seas. For operation in warmer seas the possibility of making an emergency connection to the existing shipboard refrigeration systems will be investigated. Since this cooling load would only occur during planned depressurization, it should be within the capacity of most refrigeration systems for the ship's stores.

CONCLUSIONS

As a result of the design study, it is evident that the proposed air cleaning system utilizing charcoal adsorption beds may be easily built and will be reliable in operation. By utilizing the proposed air cleaning system it will be possible to:

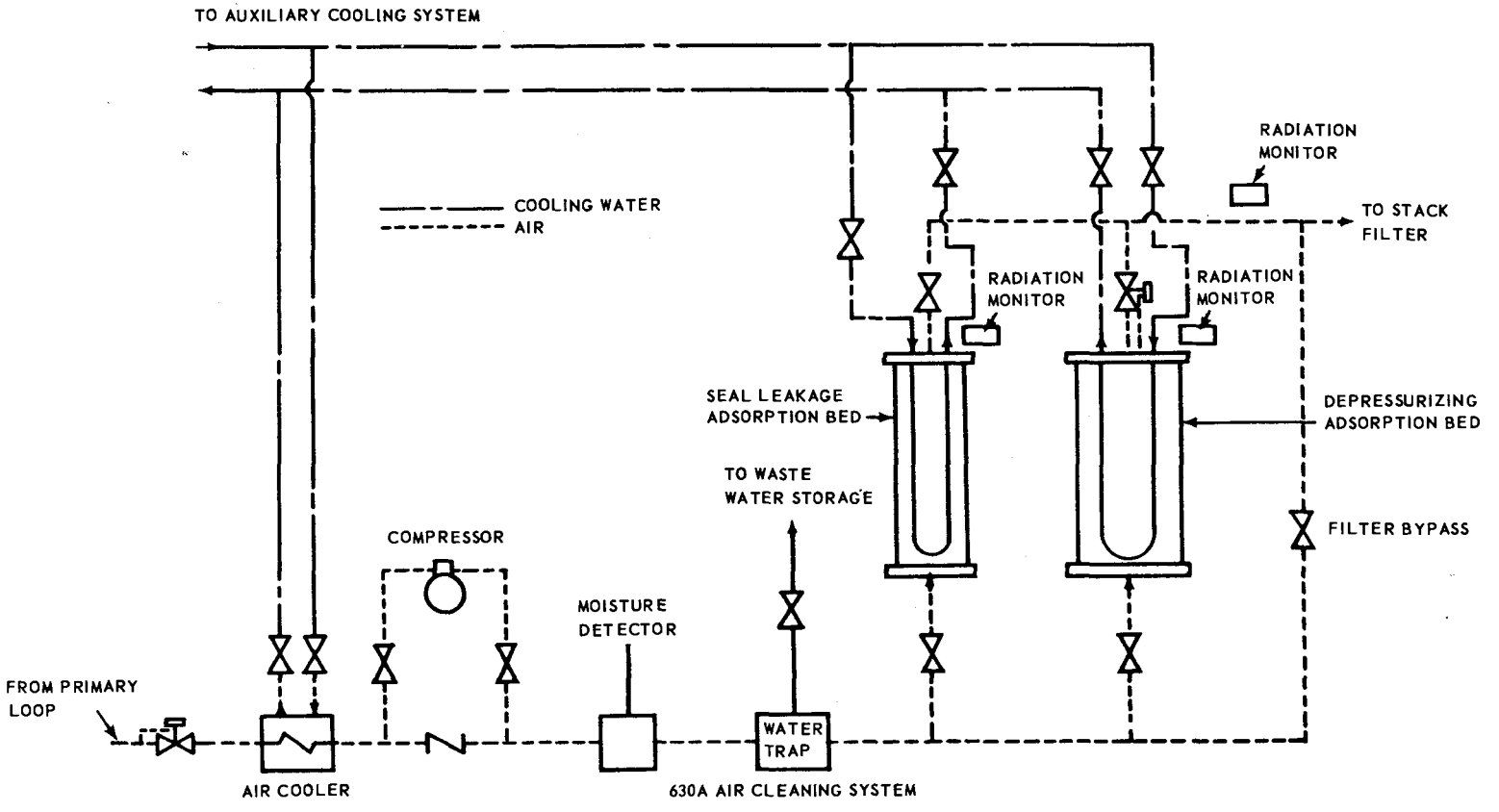


Fig. 3—Waste-air cleaning system

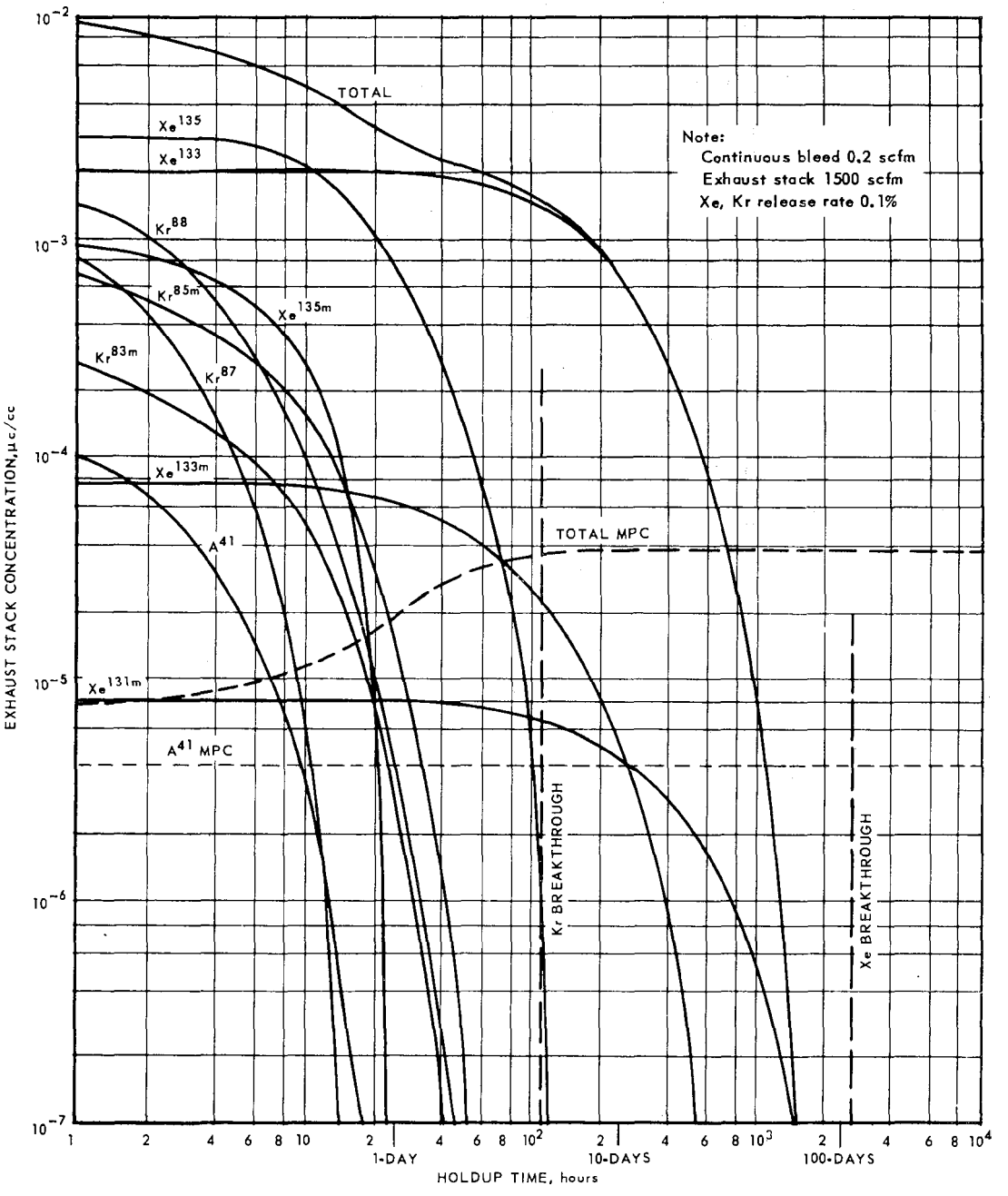


Fig. 4—Noble gas effluent activity versus holdup time

1. Keep the radioactive material in all air released to the atmosphere during normal operation well below maximum permissible concentrations.

2. Depressurize the primary loop at any desired time to perform routine maintenance such as changing a blower.

3. Depressurize the primary loop following a fuel melt of any magnitude without releasing significant amounts of radioactive material to the atmosphere.

REFERENCES

1. R. D. Ackley, R. E. Adams, and W. E. Browning, Jr., "The Disposal of Radioactive Fission Gases by Adsorption," Sixth AEC Air Cleaning Conference, TID-7593, July 7-9, 1959.

2. R. E. Adams and W. E. Browning, Jr., "Removal of Radioiodine from Air Streams by Activated Charcoal," ORNL-2872, May 10, 1960.

3. R. E. Adams and W. E. Browning, Jr., "Estimate of the Probability and Consequences of Ignition of the HRT Charcoal Beds," ORNL-CF-58-6-6, June 3, 1958.

4. E. E. Anderson, G. L. Wessman, and L. R. Zumwalt, "Fission Product Trapping - Sorption of Cessium by Activated Charcoal," Nuclear Science and Engineering, 12, Pp. 106-110, 1962.

A SODIUM FLAME PARTICULATE TEST FOR HIGH EFFICIENCY AIR-CONDITIONING FILTERS

by

R.G. Dorman, L.E.J. Yeates and P.F. Sergison

SUMMARY

This test method, developed at the Chemical Defence Experimental Establishment, Porton Down, England, employs a particulate cloud of sodium chloride particles of sizes ranging from 0.02 to 2 micron equivalent diameter. The cloud is generated by spraying a 2 per cent aqueous solution of common salt with subsequent liquid evaporation.

The measurement of penetration depends on the characteristic sodium flame emission at 5890 Å which, over the range of concentration employed in this test, is directly proportional to mass of salt. The flame is viewed by a sensitive photo-multiplier connected to a galvanometer and a steady reading is obtained in less than a minute. Penetrations of 0.001 per cent at 1000 ft^3/min are measurable with probable errors of $\pm$ 0.0002 per cent whilst penetrations of as little as 0.0004 per cent may be estimated.

Leaks in the filter material or sealing may be located by removing the effluent plate and searching the filter face with a probe connected to the flame photometer by a short length of rubber hosing.

INTRODUCTION

The routine testing, in the United Kingdom, of large volume high quality air filters for efficiency against particulates has hitherto been carried out using a methylene blue (1) method in which a sample of the filtered dye cloud has been taken on esparto paper and compared with the stain produced by a small volume of the unfiltered cloud on the same type of paper. This method, when used for high quality filters (0.001 per cent penetration at 400 ft^3/min), has taken some five hours of continuous test to produce a visible filtered stain. Proofing of such duration is wasteful of time and can cause serious delay in large scale manufacture; the long exposure of the filter to a concentrated particulate cloud also causes a considerable change in

the penetration of some types of filters through clogging whilst a further source of error may be encountered as the esparto paper is not an efficient collector of the smaller particles (2).

The sodium flame photo-electric penetrometer (3) based on the visual instrument developed by Walton (4) has been used for a number of years, both in this laboratory and in the factory, for testing small air filters at flow rates of $\frac{1}{2}$ to 3 ft^3/min, and it was decided to modify the apparatus so that it would be capable of testing filters of 0.001 per cent equivalent methylene blue penetration at flow rates of up to 1000 ft^3/min. In the course of these modifications a considerable simplification of the electronic system has been achieved and factory testing should be possible with, at most, semi-skilled labour; the test is practically instantaneous and the rate at which filters can be tested is likely to be controlled by the speed at which they can be connected to the test rig.

GENERAL DESCRIPTION

The test cloud is of common salt formed by evaporation of a spray from an aqueous solution. The particles are generally cubical and the size distribution of the longer diagonals is mainly between 0.02 and 1.0μ with a mass median size of 0.6μ. An electron micrograph of a sample of the cloud, gold-palladium shadowed at 45°, is shown in Fig. 1. The concentration of salt and the spraying pressure were chosen so that the size range of the particles would be very close to that employed in the methylene blue test and there would be reasonable agreement between penetrations measured by either method.

The apparatus is shown diagrammatically in Fig. 2. A continuous stream of droplets from a 2 per cent salt solution is produced by the atomizers A, which are operated at a pressure of 100 lb/in^2. Most of the larger droplets are removed by the baffles around the atomizers and the remainder of the cloud is blown down the trunking B, towards the filter C, by the main flow. Close to the entrance is a small detachable sump which collects any surplus liquid. The dimensions of the trunking should preferably be such that the air velocity is less than 30 ft/sec and the time of passage to the filter under test is at least 2 sec. A centrally situated circular plate of diameter $D/\sqrt{2}$, where D is the trunking diameter, is fixed at some $\frac{2}{3}$ of the distance from spray box to filter. The main air flow was not dried during the development of the apparatus but under normal conditions all the water evaporates from the droplets before they reach the filter leaving a test cloud of small particles of salt. After passing through the filter under test the air flows down the trunking V and through the orifice plate, O, which is connected to a manometer to measure the main air flow and which also serves to mix the effluent particles. Just inside from the open end of the trunking is an elbow bend tube E which is connected through a brass cock and rubber hosing to the horizontal tube H when the cock is in the 'Test' position. The pressure of the air emerging from the trunking is generally sufficient to blow air through H, the flow being metered to between 1 and 2 ft^3/min by an inclined tube flowmeter and controlled by a screw clip on the rubber hosing. In case, however, with low main air flows the flow through H is smaller than 1 ft^3/min a flap valve is sited at the end of the trunking, V, so that the flow may be increased to the requisite value.

Whilst most of the air flowing down H emerges from the open end and mixes with room air some is drawn up from the flame tube T (in which is housed the hydrogen burner Q) by convection and it has been found that the convective flow is almost independent of the flow in the horizontal tube, the flame burning quite freely. When the cock is in the 'Standby' position the tube H is connected to a supply of filtered air from a small blower G so that the burner does not become contaminated with dirty air from the test room when tests are not in progress.

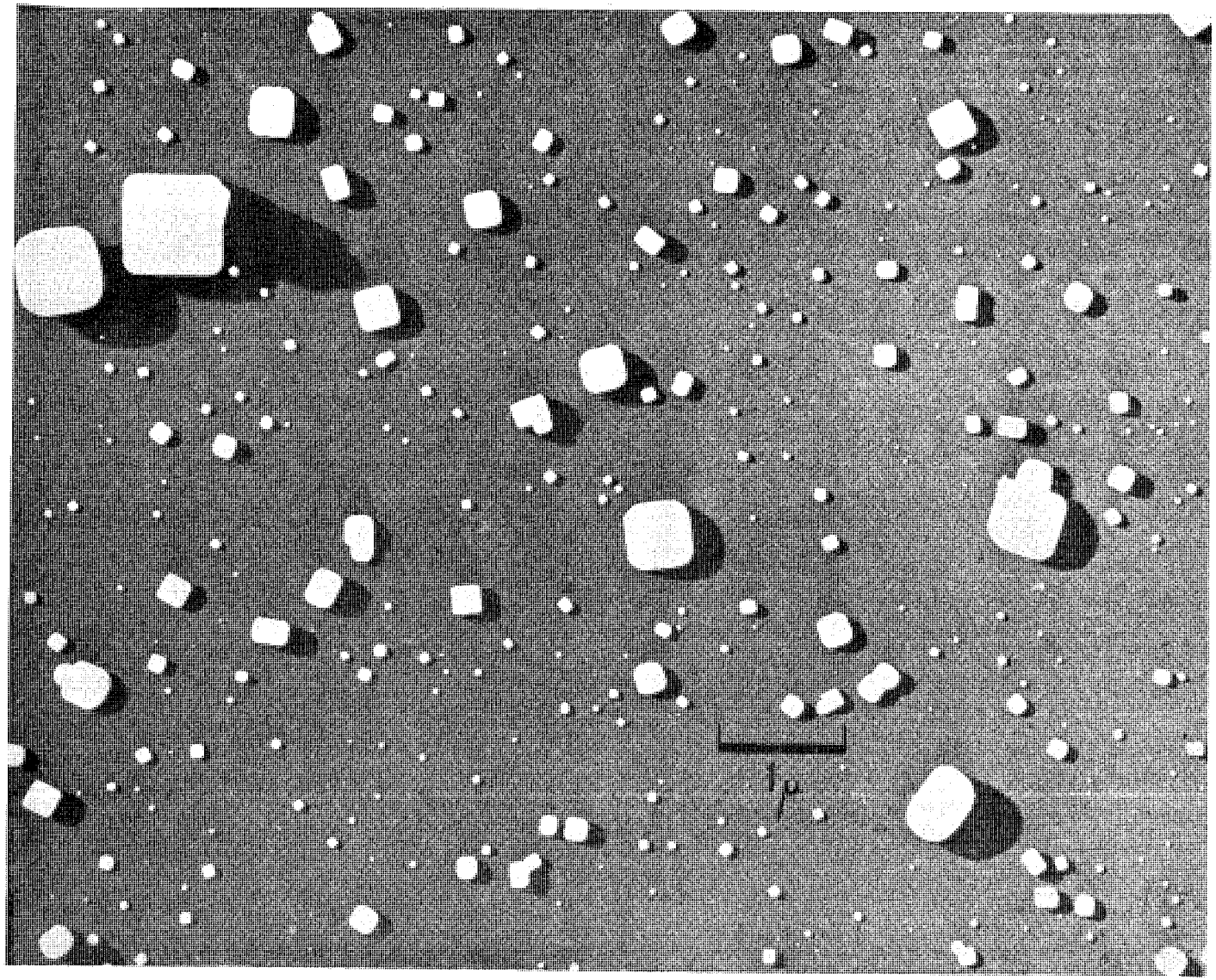


Fig.1. Electronmicrograph of sample of test cloud

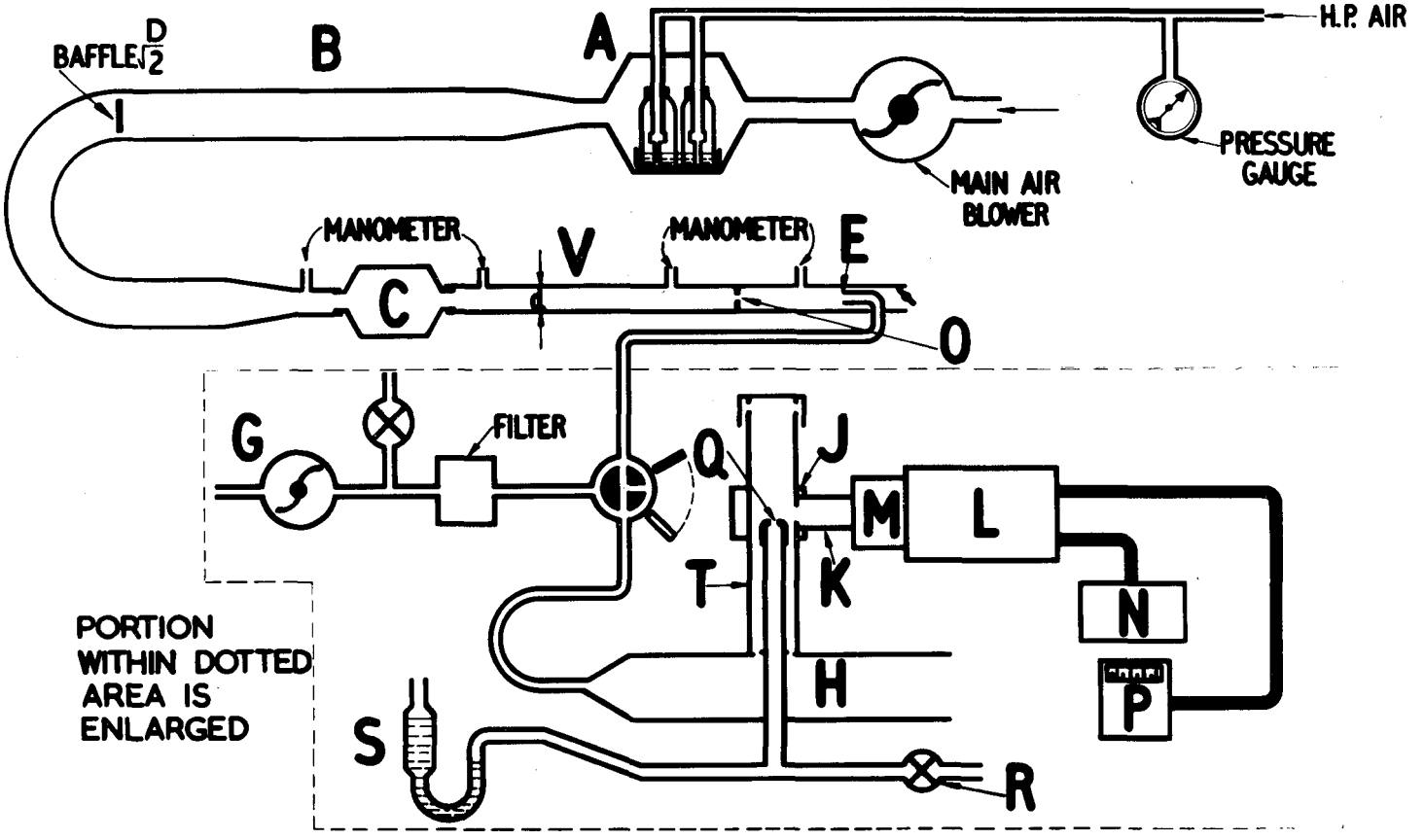


Fig.2. Schematic diagram of apparatus

Inside the flame tube is a closely fitting glass chimney which is silvered on the outside and has a clear circular patch opposite to the flame and, at the same height, there is a metal head, J, which bears the horizontal tube, K, and the photo-multiplier housing, L; the height of the head is adjustable so that the flame, the clear circular patch on the glass chimney and the photo-multiplier cathode are in line. The ceramic burner (Bray Ceto No. 310 $10\frac{1}{2}$ l./h) produces a flat fan-shaped flame and is positioned so that the long side faces the photo-multiplier. Just in front of the housing, L, is a box, M, which contains an interference light filter, permanently installed, to isolate the sodium lines in the yellow, and space is also left for neutral density filters to reduce the light intensity to a convenient level. The photo-multiplier E.H.T. is provided by a half-wave rectifier with corona discharge stabilizer, N, and the output is led to the Pye 'Scalamp' galvanometer, P.

The pressure of hydrogen at the burner is regulated to 1.6 in. water gauge, indicated by the manometer, S. The gas is supplied from a cylinder fitted with reducing valve and consumption is approximately $\frac{1}{3}$ ft^3/h.

ATOMIZER

The necessary characteristics of any nozzle are that:

(a) The spray distribution of sizes remains constant for any given pressure.

(b) The orifices are large enough to ensure that blockages do not occur when reasonable precautions are taken to keep the liquid and compressed air clean.

(c) It is easily reproducible, and the throughput of droplets in the required size range is as large as possible for a given volume of compressed air.

Experience has shown that the Collison atomizer (5), or some modification of it, meets these conditions probably as effectively as any other design and, after some trials of other types, a modified Collison nozzle was adopted.

In order to increase the throughput of spray the compressed air holes of the standard Collison nozzle were enlarged to 0.03 in. (standard 0.011 in.) diameter and the central air feed hole was also enlarged to prevent the spray from cutting out at about 50 lb/in^2. The final design, made in stainless steel to avoid corrosion, is shown in Fig. 3. This atomizer is operated at 100 lb/in^2, the flow being metered by a manometer-orifice type flowmeter, and the larger droplets are removed by baffles $1\frac{1}{4}$ in. from the orifices. The baffles are constructed from polythene bottles (Fig. 4) and are held in position by drilling the screw caps and sliding them over the atomizer air feed tube, a tight fit being obtained by packing the caps with rubber tubing before screwing them on to the bottles. The liquid feed tube of the atomizer projects through the bottom of the bottle into the salt solution and drain holes are made in the bottom so that excess liquid will run back into the perspex tray containing the solution. The spray escapes to the main air flow through the three slots, each 5 in. long and 1 in. wide, the long sides of which are turned inwards for 3/16 in., cut in the sides of the bottles. The baffles must be positioned carefully opposite to the orifices as shown in the figure. An atomizer with three spray orifices needs about $3\frac{1}{3}$ ft^3/min of atmospheric air, compressed to 100 lb/in^2, and for testing filters to 0.001 per cent methylene blue penetration at 1000 ft^3/min at least four such atomizers are required. For smaller, or lower efficiency, filters it is often possible to dispense with one or more atomizers and in some cases to use only a single spray orifice instead of three.

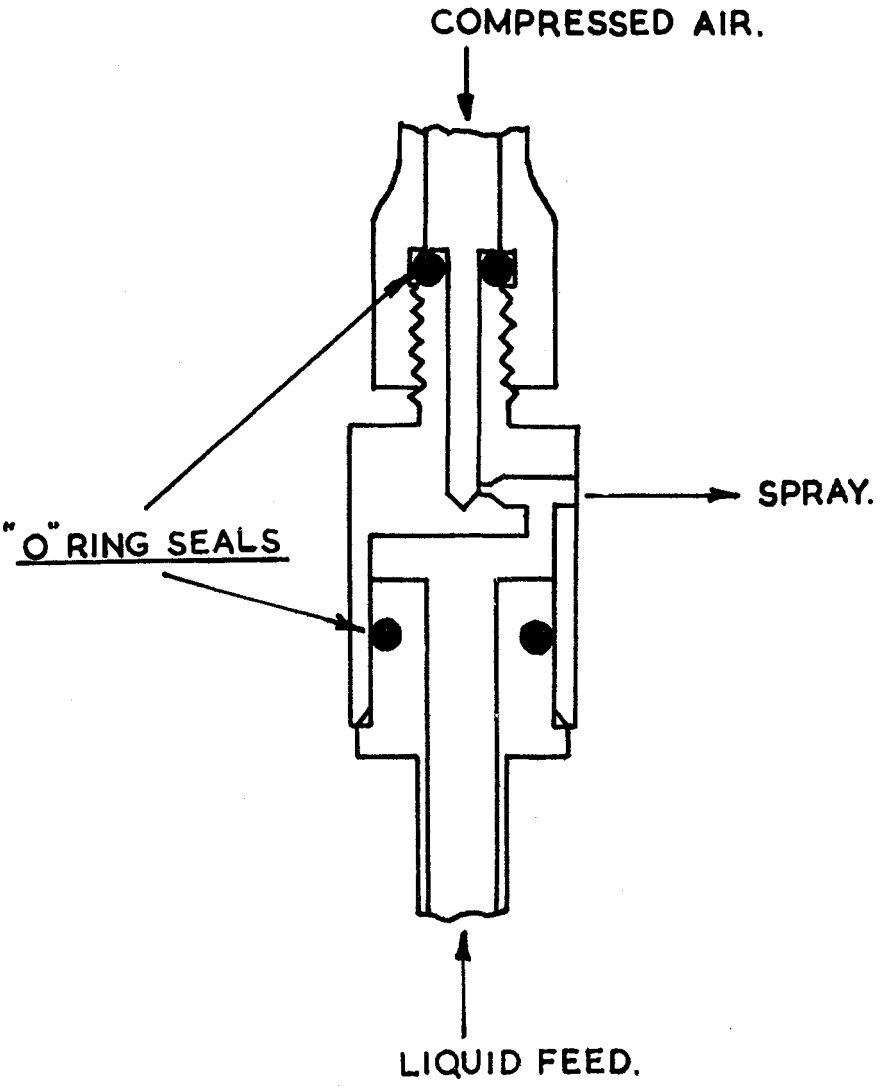


Fig.3. Nozzle

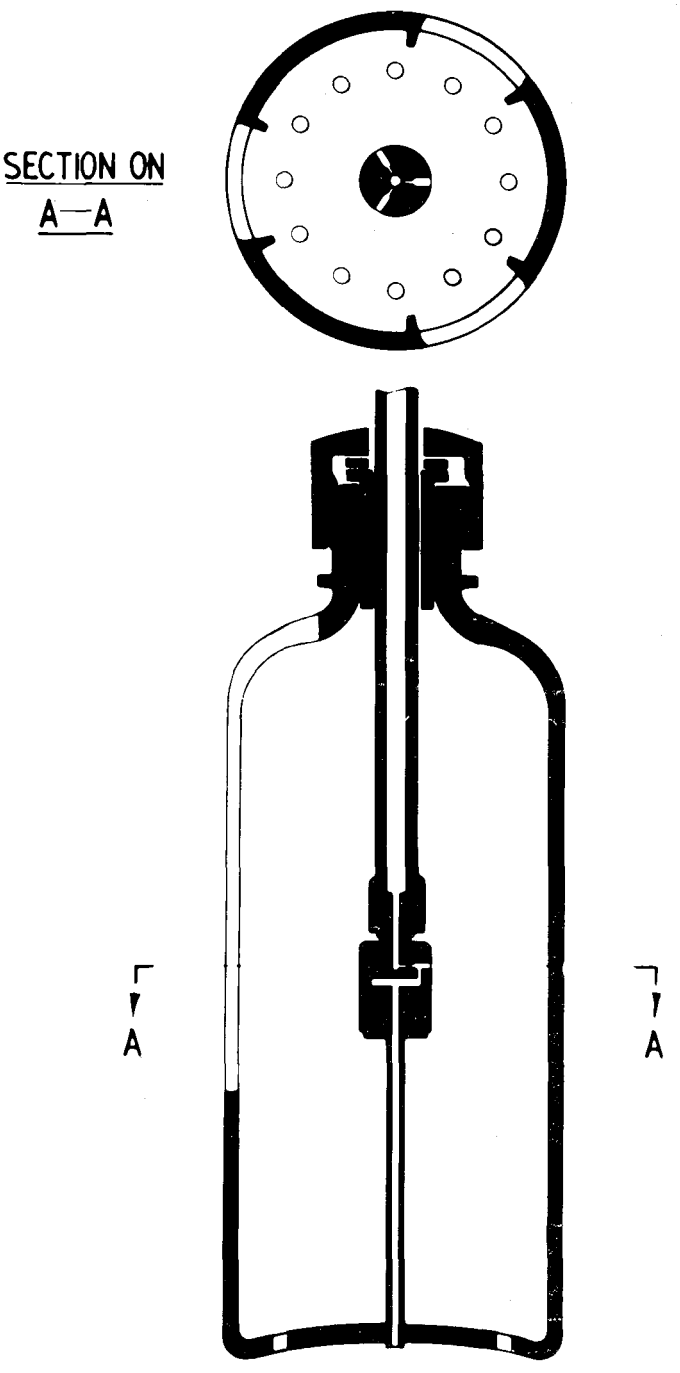


Fig.4. Polythene bottle showing nozzle and baffle system

SPRAY BOX

This consists of a 22 inch cube wooden or non-corrodible box with 12 inch diameter vents at each end, one of which is connected to the blower and the other to the main trunking (an 18 inch cube is sufficient for 2 atomizers and flows of up to 500 ft^3/min). The top is of perspex, a half inch thick, held in position by spring clips, and a sponge rubber gasket is included to make it air-tight. The atomizer feed tubes pass through this lid and are clamped in position by a circular brass boss, containing a rubber sleeve, which is tightened by hand with a knurled nut making an air-tight seal. In order to keep the salt solution free from dust and lint it is contained in a tray with a loosely fitting perspex cover in which holes are drilled, at the appropriate places, to accommodate the polythene bottles which serve as spray baffles. It is also desirable that a filter be connected to the inlet side of the blower so that the main air flow through the spray box is kept reasonable clean.

TRUNKING

Although metal ducting was employed during the development stages it was considered that the trunking in front of the filter should be salt-resistant and the final design incorporates poly-vinylchloride ducting.

The conduit, V, on the effluent side is of metal, 6 inches in diameter for flows of up to 500 ft^3/min whilst for flows of 1000 ft^3/min an 8 inch duct is recommended. The conduit carries the orifice plate which, besides its primary function of providing a pressure drop for metering the air flow, ensures good mixing of the effluent cloud. Particulate laden air from small leaks in the filter material or sealing follows flow lines for considerable distances, and thorough mixing is necessary to measure the average penetration. It has been found (6) that the orifice plate at a distance of greater than 3d (where 'd' is the diameter of the conduit V) from the filter followed by a sampling point at least a further 8d down the ducting and a final straight length of 5d provide satisfactory mixing and sampling. The apparatus is under discussion as a British Standard test and for this purpose effluent ducting will be specified to conform to British Standard practice. Isokinetic sampling is not essential, velocities of between $x\frac{1}{4}$ and x4 duct velocity being satisfactory.

DRYING SYSTEM

To obtain accurate results it is essential that the particulate at the filter face consists of dry salt particles and this is almost certainly the case for relative humidities in the trunking of 60 per cent and below. It has, however, been found, in small scale laboratory experiments, that there is a decrease in measured penetration at relative humidities of above 60 per cent because of inadequate drying of particles. At a relative humidity of 70 per cent in the trunking, when testing a cotton-asbestos filter of penetration about 0.001 per cent at 200 ft^3/min, the error is likely to be -0.0004 per cent. An error of such magnitude, whilst it is an undesirable feature, is not inordinately large for this type of work; it will, however, be different for different filter materials and flow rates, and will increase rapidly with increasing relative humidity, and it is therefore necessary to incorporate a drying system into the equipment if it is to be used for accurate and regular testing. Suitable drying equipment may be bought although it is comparatively expensive. A considerable reduction in relative humidity can be achieved more simply by heating the main air-flow and this method may be sufficient when it is not necessary to have the apparatus always available for use. Whether or not a drying system is employed it is recommended that apparatus be installed to measure relative humidity in front of the filter. After assessment of relative humidity the device should be removed to prevent long term contamination by salt from affecting its accuracy.

PHOTO-MULTIPLIER, E.H.T. UNIT AND GALVANOMETER

The photo-multiplier must be of high sensitivity and, for ease of use, should show only a small dark current, and a comparatively recently developed photo-multiplier marketed by Messrs. E.M.I. was found to be suitable. This photo-multiplier, an end-window E.M.I. Type 9524 A, has proved to be very stable and tubes of approximately 200 amps/lumen sensitivity at 1000 V with dark currents of less than 0.003μ A have been specified for the apparatus. Special attention must be paid to the housing in order to prevent ingress of stray light.

The E.H.T. power unit circuit for the photo-multiplier is shown in Fig. 5. It consists of a half-wave rectifier with condenser input and resistance-capacity smoothing followed by a corona discharge stabilizer. The stabilizer, a GEC SC1/1000, is stated by the manufacturers to provide a negative output voltage stable to $\pm$ 1 per cent over several thousand hours of use. Under normal operating conditions the total current loading consists of 80μ A through the dynode chain and less than 2μ A through the photo-multiplier. The signal is measured on a Pye 'Scalamp' galvanometer (Type 7904/S) which has a time constant of 2 seconds. In order to damp the galvanometer and to reduce the effects of occasional flicks when dust or fibre are blown through the flame a 25 KΩ resistor and 250μ f electrolytic condenser are connected across the galvanometer terminals.

The deflexion of the galvanometer when the photo-multiplier views the clean flame depends upon the attenuation in the interference filter and any neutral density filter in the light filter box, on the sensitivity of the photo-multiplier and on the E.H.T. value. In order to simplify the power unit the voltage is fixed so that the deflexion is controlled by the interference filter and the photo-multiplier sensitivity, both of which vary from article to article. The voltage recommended is therefore one which is high enough to give a good clean flame deflexion even with a high attenuation interference filter and a comparatively low sensitivity photo-multiplier; if a high sensitivity photo-multiplier is used it may therefore be necessary to insert a neutral density light filter permanently in the box to reduce the galvanometer readings to a reasonable level. To test particulate filters of penetration in the 0.001 per cent region it is recommended that a clean flame background of 5 to 7 cm should be used when the galvanometer is switched to range 1 (the most sensitive range). The galvanometer should always be read on range 1 and deflexions reduced to scale by insertion of neutral density filters in order to preserve linearity of response. The galvanometer is sensitive to vibration and should be clamped to a wall bracket or well-cushioned to withstand shocks.

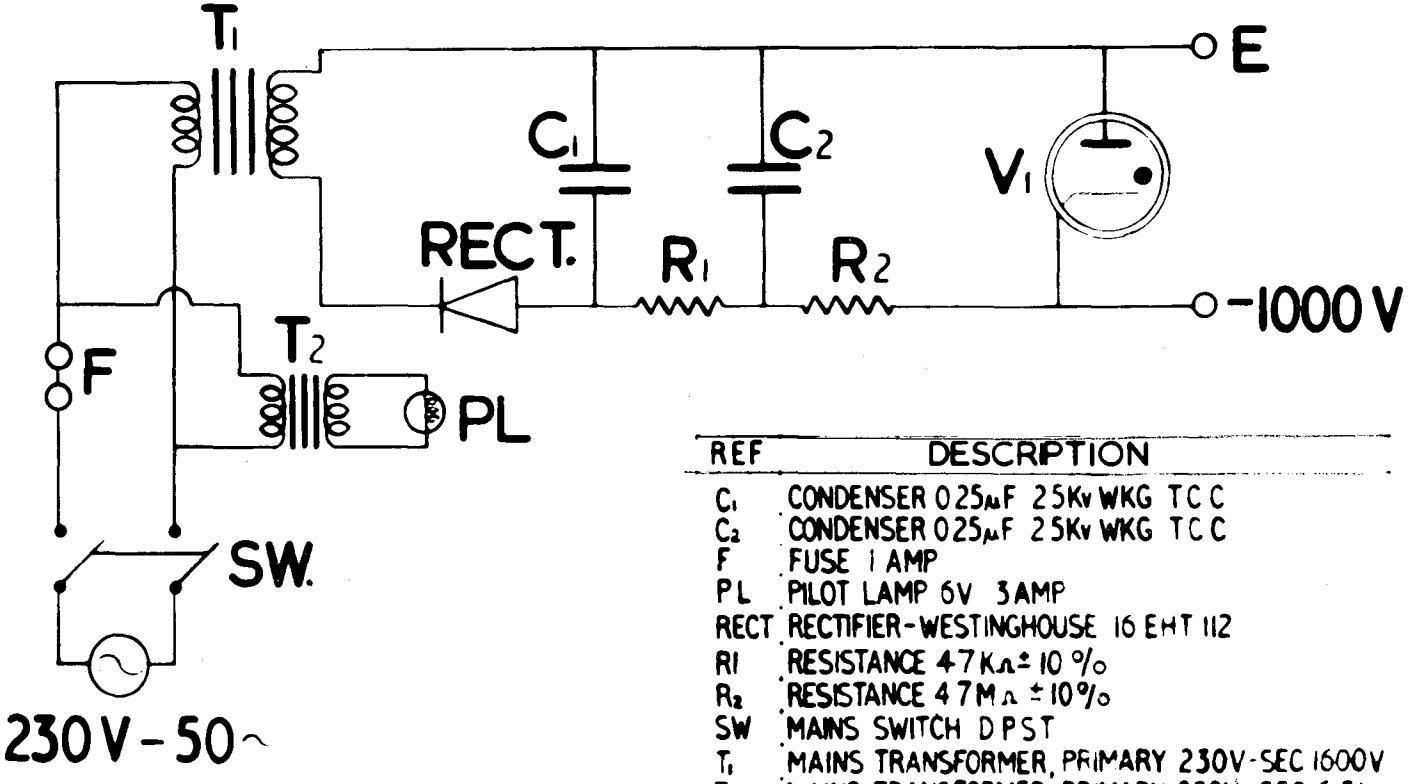
FLAME TUBE ASSEMBLY

A diagram of the flame tube assembly is shown in Fig. 6. The dimensions of the horizontal tube, H, and the vertical chimney, T, are such that the flame burns freely for flows of about $\frac{1}{2}$ to 3 ft^3/min along the horizontal tube.

CALIBRATION

1. Clean flame background.

The mains supply to the power unit is switched on with the photo-multiplier masked and five minutes allowed for the dark current to stabilize. A good quality particulate filter is placed in circuit and the impeller fan switched on with the cock in the 'Test' position and the air flow adjusted to the correct rating; the ancillary blower is also switched on. When the dark current is steady it is backed off on the galvanometer by adjusting the zero, the meter being switched to range 1. The hydrogen flame is then lit (the burner having



REF	DESCRIPTION
C_1	CONDENSER 0.25μF 25Kv WKG TCC
C_2	CONDENSER 0.25μF 25Kv WKG TCC
F	FUSE 1 AMP
PL	PILOT LAMP 6V 3AMP
RECT	RECTIFIER-WESTINGHOUSE 16 EHT 112
R_1	RESISTANCE 4.7KΩ ± 10 %
R_2	RESISTANCE 4.7MΩ ± 10%
SW	MAINS SWITCH DPST
T_1	MAINS TRANSFORMER, PRIMARY 230V-SEC 1600V
T_2	MAINS TRANSFORMER PRIMARY 230V-SEC 6.3V
V_1	GEC SC1/1000 CORONA STABILIZER

Fig.5. E.H.T. Unit

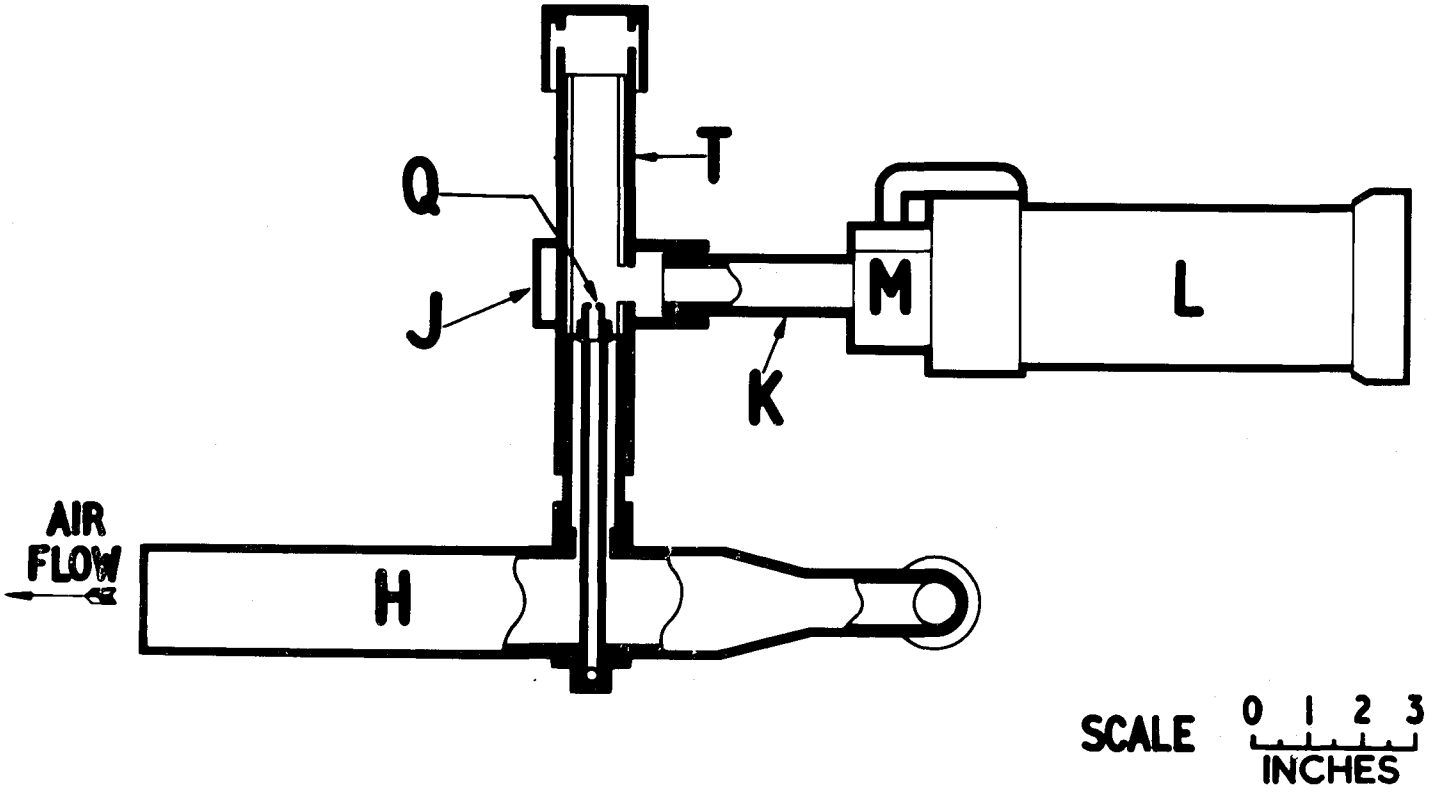


Fig.6. Flame tube assembly

been cleaned as directed) and the pressure adjusted to 1.6 in. water gauge. The sodium interference filter and neutral density filters to the optical density value of at least 3 are placed in the light filter box and the galvanometer turned to the most insensitive range. The flow of air passing along the horizontal tube, H, is adjusted to between 1 and 2 ft^3/min (measured by means of the inclined tube flowmeter), and the photo-multiplier unmasked. After switching the galvanometer to its most sensitive range the neutral density filters are gradually removed, whilst at the same time the galvanometer deflexion is watched. When neutral density filters have been removed in sufficient quantity to give the recommended background deflexion of 5 to 7 cm the apparatus should be left for at least half an hour and the deflexion checked at regular intervals.

It is necessary to follow these instructions carefully to check on the clean air background. If the burner is dirty, or salt contaminated air reaches the flame, the background deflexion will be too large and it is this background which is used in penetration measurements as a check on the stability of the whole apparatus. A small amount of contaminant on the burner will usually clear itself in a few minutes whilst gross contamination may be seen by removing the cowling of the flame tube and inspecting the flame for yellow coloration - the normal flame should be scarcely visible and slightly blue.

A large background reading will also be obtained if there are light leaks in the photo-multiplier housing. Such leaks may usually be detected by wrapping black cloth around places at which light may enter.

When it is obvious that the background is constant the meter reading should be noted and in future work the reading should not vary by more than $\pm$ 10 per cent. As a further check one or two more burners, previously cleaned, ought also to be inserted and should give similar background deflexions. The meter reading should be fairly steady, varying by less than 1 millimetre, although occasional flicks will occur if dust particles or fibres are blown from the filter into the flame. These flicks are especially noticeable with some types of filter such as asbestos paper and may be eliminated, or greatly reduced, by inserting a small coarse filter close to the test cock. A suitable filter may be made from one or two sheets of coarse glass fibre such as that commonly used in battery separators which, being almost completely penetrable by sub-micron particles, stops a negligible amount of effluent salt but removes the fibres. In order to avoid the dangers of clogging this filter should be removed after 20 tests. All tubes and trunking should, of course, be cleaned before the apparatus is used, rubber hosing being washed to remove all traces of french chalk.

2. Main Calibration.

An absolute measure of salt penetration and deflexion is obtained by successive bleedings off and dilutions of the initial cloud (Fig. 7). A small proportion of about 10 l./min of the unfiltered main cloud is bled off from the elbow joint Y, which is of such area that sampling is practically isokinetic, and mixed with a larger volume flow of clean filtered air of the order of 150 l./min. A flow of a few litres per minute of the mixture is diluted with a larger volume of clean air and passed to the horizontal flame tube and hydrogen flame. By varying the proportions, concentrations of from 0.005 to 1 per cent of the original cloud are obtained and the galvanometer deflexion is noted for each concentration. To prevent contamination of the test room the main flow is filtered after it has passed the sampling elbow. It is obvious that the use of a 10 l./min sample from a flow of, say, 500 ft^3/min is only permissible if the cloud is thoroughly mixed before reaching the sampling tube and subsidiary experiments must be carried out by moving the sampling tube across the main trunking to prove that mixing is in fact satisfactory. The deflexion is not

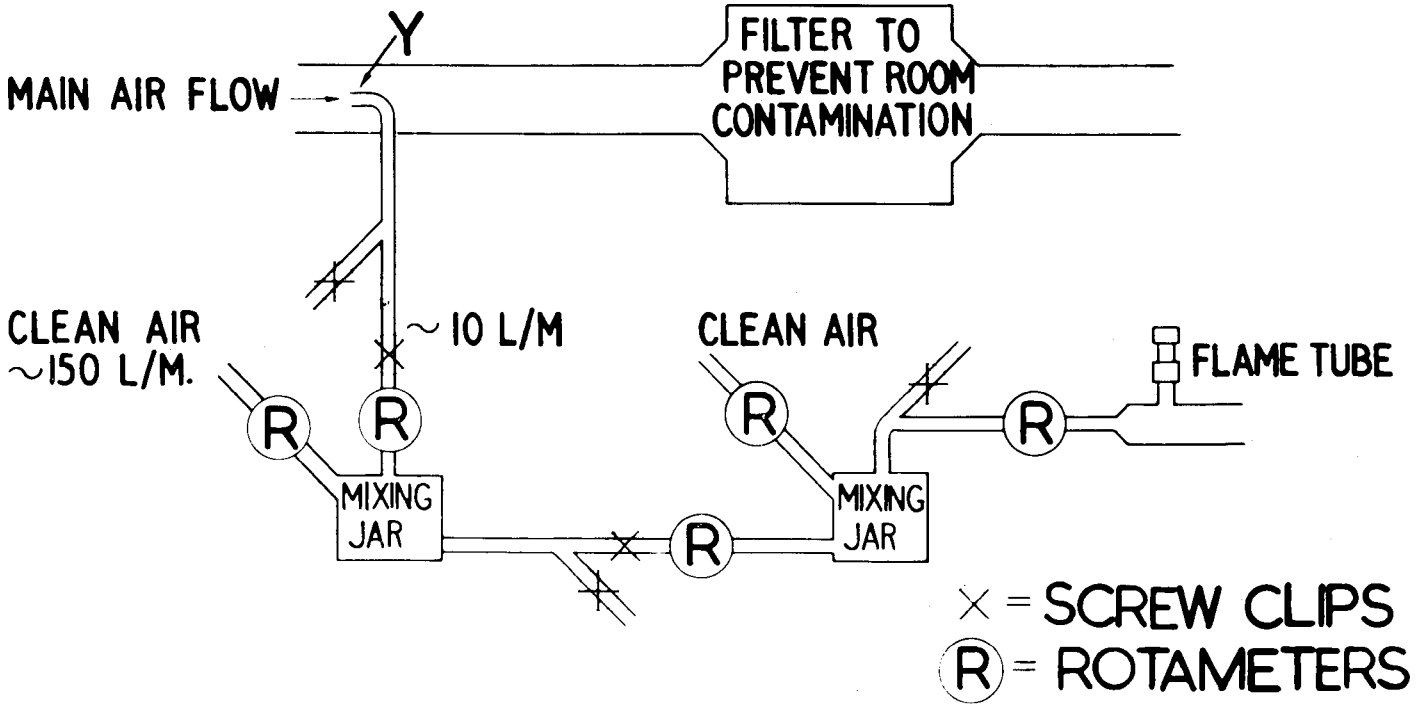


Fig.7. Calibration circuit

read until a few minutes after each flow adjustment has been made in order to be certain that the correct concentration has been reached.

A plot of deflexion against percentage concentration leads to a straight line passing through the origin (Fig. 8). The deflexion is independent of particle size and directly proportional to the mass of salt passing through the flame until high concentrations are reached when the deflexion increases more slowly because of self-absorption in the flame. This will not occur at the concentrations of interest in high efficiency filtration whilst for low efficiency filters it may be avoided by reducing the number of spray orifices.

The flowmeters and tubes must be cleaned thoroughly before calibrating as small particles of dust will colour the flame and cause unsteady galvanometer deflexions. It is also necessary to ensure good mixing of the salt-laden air or else the flame intensity will vary. When these precautions are taken it may still be found that small pulses of air cause fluctuations in the low volume flowmeters, with consequential galvanometer fluctuations, so that errors of $\pm$ 10 per cent in both estimation of concentration and galvanometer reading are possible in any one observation. In practice, by estimation of the mean reading of galvanometer and flowmeters, surprisingly good linearity of deflexion v. concentration graphs has been obtained and, although by careful design of the calibration lay-out the uncertainties could be reduced, a possible small improvement in accuracy does not justify great trouble to achieve it.

Four annual checks have confirmed the original calibration within $\pm$ 10 per cent and although a calibration circuit may be incorporated into the rig there appears to be little need for this.

TESTING OF FILTERS

The electronic apparatus is switched on and a short warming up period allowed. The photo-multiplier dark current is checked and the galvanometer zeroed. The hydrogen flame is lit, the ancillary blower turned on and with the cock on 'Standby' the clean flame reading measured. The filter to be tested is placed in circuit and all flows adjusted to the correct values, the cock turned to 'Test' and the clean flame reading again measured. If this reading is within the limits specified the apparatus is ready for the test to be carried out. Should the reading be outside the limits the fault must be found and remedied before testing begins. Neutral density filters are now inserted, appropriate to the value of the expected air filter penetration, and the salt spray turned on and adjusted to 100 lb/in^2 pressure. The reading of the galvanometer should be steady within a few seconds and a note is made of its value. The spray is switched off, the cock turned to 'Standby' and the filter removed. The apparatus is now ready for the next filter to be tested.

A specimen calculation is given below assuming that on calibration:-

(a) The apparatus gave a clean flame background of 5.0 cm with a neutral density filter of 0.3 and the sodium interference filter in the box.

(b) The deflexion - percentage of main cloud at 200 ft^3/min curve was as shown in Fig. 8.

Let it be assumed that the test is in fact carried out at 400 ft^3/min and a deflexion of 6.3 cm is obtained with a neutral density filter of 1.0 in the light filter box; the clean flame reading with a neutral density of 1.0 is found to be 1.0 cm. The extra deflexion caused by the salt penetration is thus:

$$6.3 - 1.0 = 5.3 \text{ cm.}$$

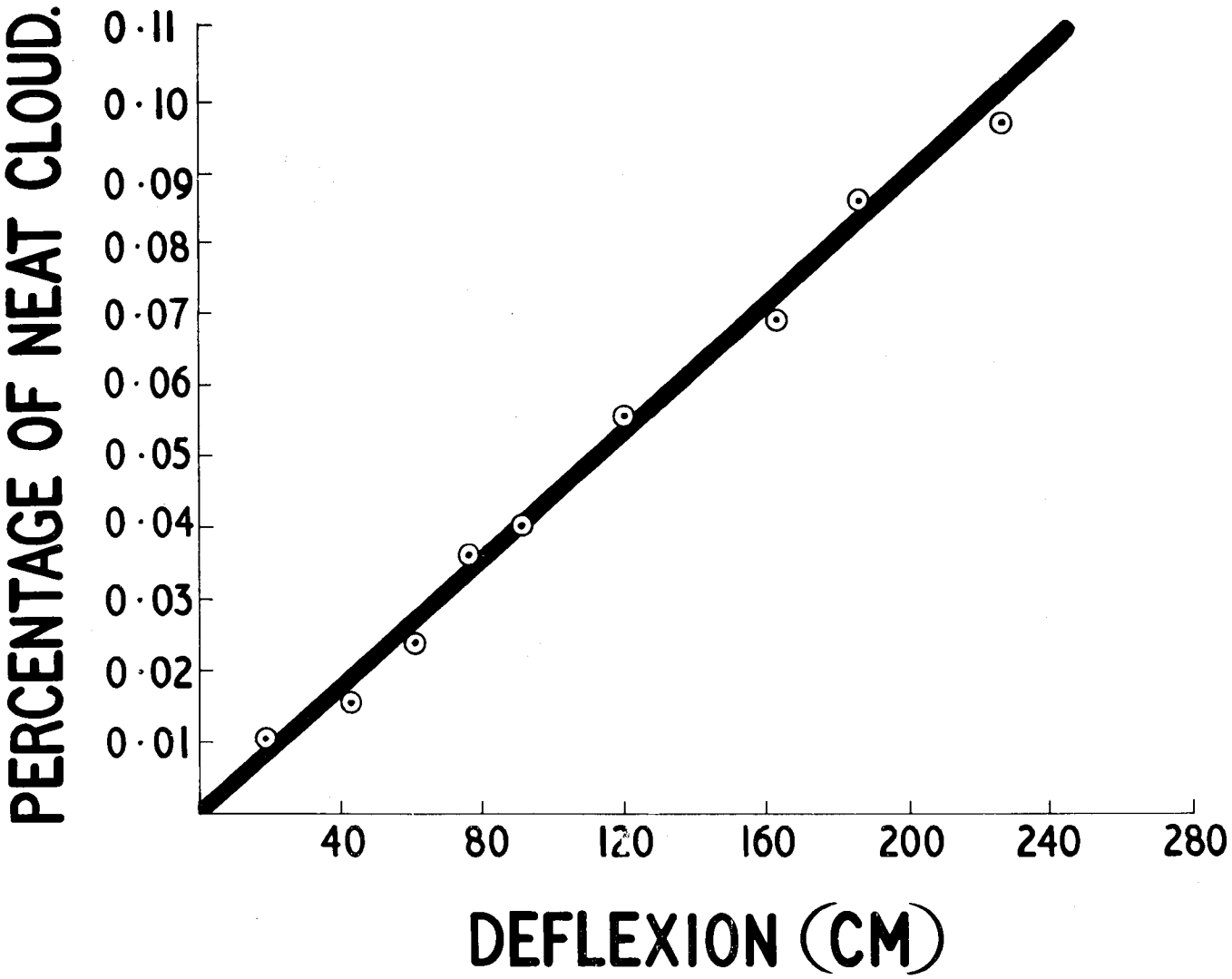


Fig.8. Calibration curve

The deflexion with a neutral density value of 0.3 would have been 5.3 x anti-log (1.0 - 0.3); that is 5.3 x 5 or 26.5 cm.

The test cloud of 400 ft^3/min is only half that of the calibration cloud concentration of 200 ft^3/min so that the deflexion measured must be multiplied by 2, i.e. 26.5 x 2 = 53 cm. The penetration read from Fig. 8 is therefore 0.023 per cent.

Sealing and leakage tests

The presence of leaks in the filter material or sealing can be detected by removing the effluent ducting and searching the filter face by means of a probe attached, by tubing, to the control cock and horizontal flame tube.

MAINTENANCE

Once the apparatus has been set up satisfactorily there should be little need for major maintenance tasks unless the flame tube and burner become grossly contaminated. When the clean flame background is within ± 10 per cent of the normal reading for given values of interference and neutral density filters it may be assumed that the apparatus is functioning correctly. Errors in this reading are likely to be positive - caused by a dirty burner, which must be replaced or, if not badly contaminated, allowed to burn in the clean air stream for a minute or so when the contaminant will probably disappear. With reasonable care any one burner should last for months. In setting up the apparatus new burners should be examined and any with chips or gross faults rejected; the remainder should be heated at the ceramic end by a small pointed air-gas blow pipe flame until the flame is no longer coloured yellow. They should then be tested for uniformity of clean flame background and, if satisfactory, stored in dust-free containers, care being taken to avoid touching the ceramic tips. Experience has shown that there is very little variation from burner to burner, a clean burner rarely differing by more than 5 per cent from the mean of, say, six tested. Errors in the clean flame background may occur because the flat side of the flame is not facing the photo-multiplier, because of lack of co-linearity of flame, chimney window and photo-multiplier cathode or because different glass chimneys have different sizes of windows. When a chimney is changed the calibration curve must be altered by the ratio of clean flame background of new/old chimney. An occasional dusting of the chimney is also required, both inside and outside.

The salt solution should be filtered through a coarse paper or good cloth filter before being used and blockage of the liquid feed will then be unlikely, but regular inspection of the spray nozzle is desirable to ensure that all orifices are functioning properly. Blockage of the high pressure line may occasionally occur, caused by dirt or particles of rubber from the pressure hose, but this fault is immediately apparent as the reading of the high pressure flowmeter will fall. The nozzle must then be removed and cleaned, by turning it upside down and tapping it vigorously on a hard surface or, if this fails, by pricking with blue steel wire. Before closing down the apparatus after the day's work it is advisable to withdraw the nozzles from the salt solution and to clear them of liquid with a short burst of compressed air. The salt solution should be replaced daily, or more frequently if necessary.

N.B. Slight difference may be found between clean flame background readings on 'Test' and 'Standby' if the air from each part of the circuit is not quite of the same standard of cleanliness. This difference should be less than 5 per cent if the apparatus is clean and the reading when the cock is on 'Test' is the one which must be used in calculation.

When the apparatus is used regularly for testing filters of high penetration (1 per cent or greater) it may be found that the burner becomes contaminated and that it must be replaced if the instrument is afterwards required to test high quality filters. It is of course necessary to ensure that the optical filters are kept clean and free from moisture.

COMPARISON WITH METHYLENE BLUE AND DIOCTYL PHTHALATE PENETRATION RESULTS

The concentration and conditions under which the salt is sprayed were deliberately adjusted to provide a salt cloud of approximately the same size distribution as that of the methylene blue cloud so that comparisons could be made between results obtained by the two methods and, although it is expected that the method described here will gradually replace the methylene blue test, there will be no marked break with past results.

A large number of small filters has been tested on the sodium flame apparatus by bleeding off 30 l./min from the main flow and results compared with those found on the laboratory methylene blue rig. Satisfactory agreement has been found for various fibrous materials made into filters of methylene blue penetration from 0.01 to 1 per cent but below the 0.01 per cent level there is a gradual falling off in methylene blue penetration as compared with that of the sodium chloride. It has been shown that these discrepancies at low penetrations are caused by the inefficiency of the esparto test paper in retaining small methylene blue particles which have penetrated the filter under test and are not due to any marked difference in the physical composition of the two clouds. If the sodium flame apparatus were to be used for measuring penetrations much above 1 per cent at high velocities differences between the two methods might become apparent as the inertial effects of the salt particles (density 2.3 g/cm^3) are greater than those of methylene blue (density 1 g/cm^3).

The penetrations of large flow-rate filters (50-500 ft^3/min) have also been compared by the two methods and show good agreement although, as in the case of the small filters, the inefficiency of the esparto paper in the methylene blue test causes errors with high efficiency filters. Discrepancies are also found in results from both small and large flow rate tests for certain types of filters, notably of paper, where clogging rates are high. In such filters, especially those of high efficiency, the clogging during the methylene blue test produces a filter with a higher final efficiency and the figure obtained for the penetration by this test is somewhere between the initial and final true penetrations. In order to obtain a realistic comparison it is necessary to carry out a sodium flame test before and after the methylene blue test and to take the average of the two sodium flame readings.

No direct comparison of the sodium flame and DOP tests has been made on large flow rate filters but comparison tests have been carried out on paper sheets at a velocity of 14 cm/sec on small rigs. The results showed that at the 0.01 per cent penetration level the numerical values of the sodium chloride percentage penetrations were between 2 and 3 times those of the DOP figures. (DOP tests were carried out by DRCL, Ottawa). It should be noted, however, that the test velocity was considerably greater than that normally employed in large volume filter testing and the penetration ratio may alter with velocity.

THE EFFECT OF HUMIDITY ON THE FLAME

As the humidity in the flame tube is increased the galvanometer deflexion decreases. This depressive effect is illustrated in Fig. 9, which was obtained by spraying clean water with a high quality filter in circuit, and is approximately 2 per cent of clean flame background for a 10 per cent increase in relative humidity. Turning on the salt spray increases the relative humidity in the trunking by some 12-15 per cent at 200 ft^3/min (when two atomizers are

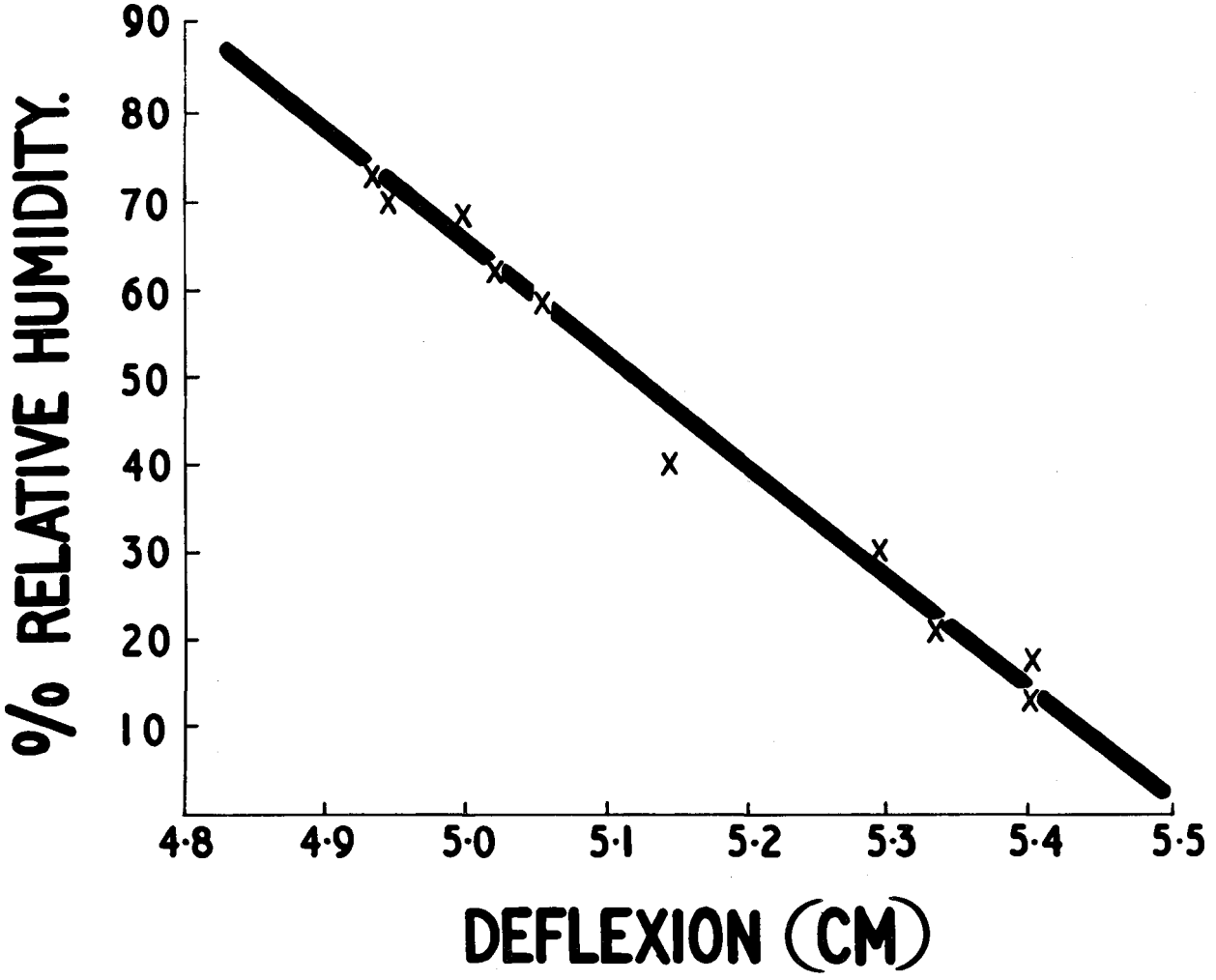


Fig.9. Variation in clean flame deflexion with humidity

employed) so that whilst the salt penetrating causes an increase in galvanometer deflexion this increase is smaller than would be found if no humidity changes were involved. The error involved in measuring penetrations of 0.001 per cent at 200 ft^3/min is thus about 0.0001 per cent, and may be neglected. When, however, the apparatus is employed in testing high quality filters of say, 0.0001 per cent, some allowance must be made for humidity depression of the flame. As an example we may quote the case of two 0.001 per cent penetration filters in series where the deflexion actually decreased when the salt spray was turned on, the whole of this decrease being attributable to the increase in trunking humidity.

DISCUSSION

The apparatus described has been in use for more than four years and has shown itself to be capable of giving reproducible results for filters of from 0.001 to 3 per cent penetration at flow rates of from 50 to 1000 ft^3/min. It is almost instantaneous in its response and its use does not clog the filter under test, this latter being a serious fault of the methylene blue method when used with certain types of filter, notably those made of glass paper of high efficiency. Comparisons with filters tested on the methylene blue apparatus show, in general, a satisfactory agreement and where divergencies exist it can be shown that they are likely to be caused by errors inherent in the use of the methylene blue method.

ACKNOWLEDGMENTS

Thanks are due to J.M. Creasey for electromicrographs of the salt cloud, and to P.D. Yeats for general assistance during the development of the apparatus.

REFERENCES

1. Methods of test for air-filters used in air conditioning and general ventilation. British Standard Specification 2831: 1957.

2. Dorman, R.G. and Yeates, L.E.J., Unpublished report, 1960.

3. Thomas, D.J. and Dorman, R.G., Unpublished report, 1953.

4. Walton, W.H., Unpublished report, 1941.

5. Collison, W.E., "Inhalation Therapy Technique", (Heinemann, London), 1935.

6. Dorman, R.G. and Yeates, L.E.J., Unpublished report, 1962.

HUMIDITY TEST REPORT
NPR HIGH-EFFICIENCY FILTER BID EVALUATION

by

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I. INTRODUCTION

In order to meet the NPR confinement philosophy, it is essential that the ventilation exhaust air filters be able to pass extremely humid air resulting from an incident which would allow a high discharge of steam to the building atmosphere. To meet the above requirements, each high-efficiency filter in the 117-N Filter Building must be capable of passing a minimum of 825 cfm of 200 F saturated air at a maximum pressure drop of 2.5 inches water gage after having been subjected to this atmosphere for three hours. The filters must exhibit a minimum efficiency of 99.95%, by DOP[1] test when dry, following the aforementioned conditions.

No known test data regarding filter performance requirements was available. It was necessary to construct a unit to perform the desired tests and assure the installation of filters capable of meeting the specified conditions. Limitation of funds prevented installation of instrumentation to the desired degree. Consequently, manual controls were required which necessitates the presence of operating personnel at all times during testing to adjust valves and dampers and to record data.

A series of tests was performed to determine if the prototype filters, submitted by the bidders in accordance with the purchase specification, would meet the requirements previously stated.

An additional requirement was that the adhesives should be self-extinguishing after removal of the igniting flame.

II. SUMMARY

The first set of humidity tests was performed with saturated air at 200 F. Moisture separators were installed upstream of the filters thereby simulating the equipment installation in Cells "A" and "B" (Zone I

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[1]Minimum efficiency of 99.95% based on dioctyl-phthalate penetration (DOP) of 0.05% for 0.3 micron diameter homogeneous particles at a flow of 1000 cfm when tested in accordance with Military Standard MIL-STD-282.

exhaust) and Cell "D" (standby filters) of the 117-N Filter Building. Results of the tests showed a slight increase in pressure drop across the filters, but in no case did the total pressure drop exceed one inch water gage for flows corrected to 1000 cfm at 200 F. Upon drying, the filters were DOP tested and the required minimum efficiency of 99.95% was met with the exception of one damaged in handling.

The second set of humidity tests was performed with super-saturated air at 200 F. To meet the test requirements, it was necessary to remove the moisture separators used during the first tests. These tests, being conducted without moisture separators, simulated equipment installation of Cell "C" of the 117-N Filter Building. Water droplets formed on both the upstream and downstream faces of the filters and, as would be expected, the pressure drops across the filters were higher than those of the previous tests. Filter pressure drops were approximately two inches water gage or less. Upon drying, the filters were DOP tested and the required minimum efficiency of 99.95% was met with the exception of those damaged in handling.

The third set of humidity tests was performed to determine the ability of filters to meet conditions more severe than actual required test conditions. This third set of tests included spraying water directly on the filters in a 200 F saturated condition atmosphere. Results were inconsistent, but after two hours, three of five filters tested had pressure drop increases ranging from one to two and one-half inches of water. The other two plugged during this same length of time.

All of the above tests were performed on clean filters.

Burning tests verified that the adhesives used by three vendors met the self-extinguishing requirements.

III. FILTER DESCRIPTION

The filter units are of the high-efficiency particulate type measuring 24 inches x 24 inches x 11-1/2 inches deep and have a rating of 1000 cfm (minimum) at one inch water gage static pressure (maximum). Specified minimum efficiency is 99.95% based on dioctyl-phthalate penetration of 0.05% for 0.3 micron diameter homogeneous particles at a flow of 1000 cfm when tested in accordance with Military Standard MIL-STD-282.

The filter media is glass fiber paper of approximately 200 square feet area having a maximum of 5% combustible matter. The media is assembled in approximately 11-1/2 inch deep folds separated by corrugated aluminum sheets.

The frame is of fire resistant exterior plywood. Adhesive is self-extinguishing after removal of the igniting flame.

Gaskets are 3/8 inch thick by 5/8 inch wide ozone resistant, closed cell, expanded rubber or rubber-like material conforming to ASTM D1056, Grade SB41 or SC41.

IV. TEST EQUIPMENT DESCRIPTION AND FUNCTIONS

The test unit is capable of testing two filters simultaneously under high-humidity and high-temperature conditions. The unit consists of the following components listed in the direction of air flow as shown in Figure 1. (See Figures 9, 10, 11, 12, and 13 in the Appendix for pictures of the test unit.)

1. Intake duct.
2. Intake duct damper.
3. Pre-filters.
4. Steam coil.
5. High pressure steam and cold water spray headers with nozzles.
6. Two diffuser plates spaced two feet apart.
7. Cold water coil.
8. Four-inch thick stainless steel mesh moisture separators for each filter test section. (See Figure 14 in the Appendix.)
9. Cold water spray header and nozzles for each filter test section.
10. High-efficiency filter. (See Figure 15 in the Appendix which is a photograph of a tested filter.)
11. Opposed blade damper for each test section.
12. Exhaust fan inlet damper.
13. Exhaust fan.
14. Exhaust fan discharge damper (not used for control due to steam leakage).
15. Discharge duct to atmosphere.

The supply air flow is measured by a pitot-venturi flow element and an inclined manometer. The flow element is mounted in the intake duct (Item 1) and the manometer is mounted nearby on a wall. The manometer readings are converted to air flow based on data supplied by the flow element manufacturer.

Pre-filters (Item 3) are provided to remove lint and dust from the intake air stream.

A steam coil (Item 4) is installed for tempering the intake air as required. The steam flow is regulated by three manually controlled throttling valves of varying sizes to provide the desired conditions. The steam flow may be interrupted by a shut-off gate valve and then returned to service with only minor, if any, adjustment of the throttling valves required.

Steam, sprayed from multiple head nozzles (Item 5), is the main source of high temperature vapor approximating operating conditions during an incident when large amounts of steam may be released to the building atmosphere. The steam flow is regulated by four manually controlled throttling valves of varying sizes. The flow rate is measured by a direct reading flow element. The supply line is also equipped with a gate valve so that the steam flow may be interrupted and then returned to service with only minor adjustments of the throttling valves being required. Pressure gages are installed upstream and downstream of the control valves.

High Efficiency Filter and Moisture Separator Test Equipment

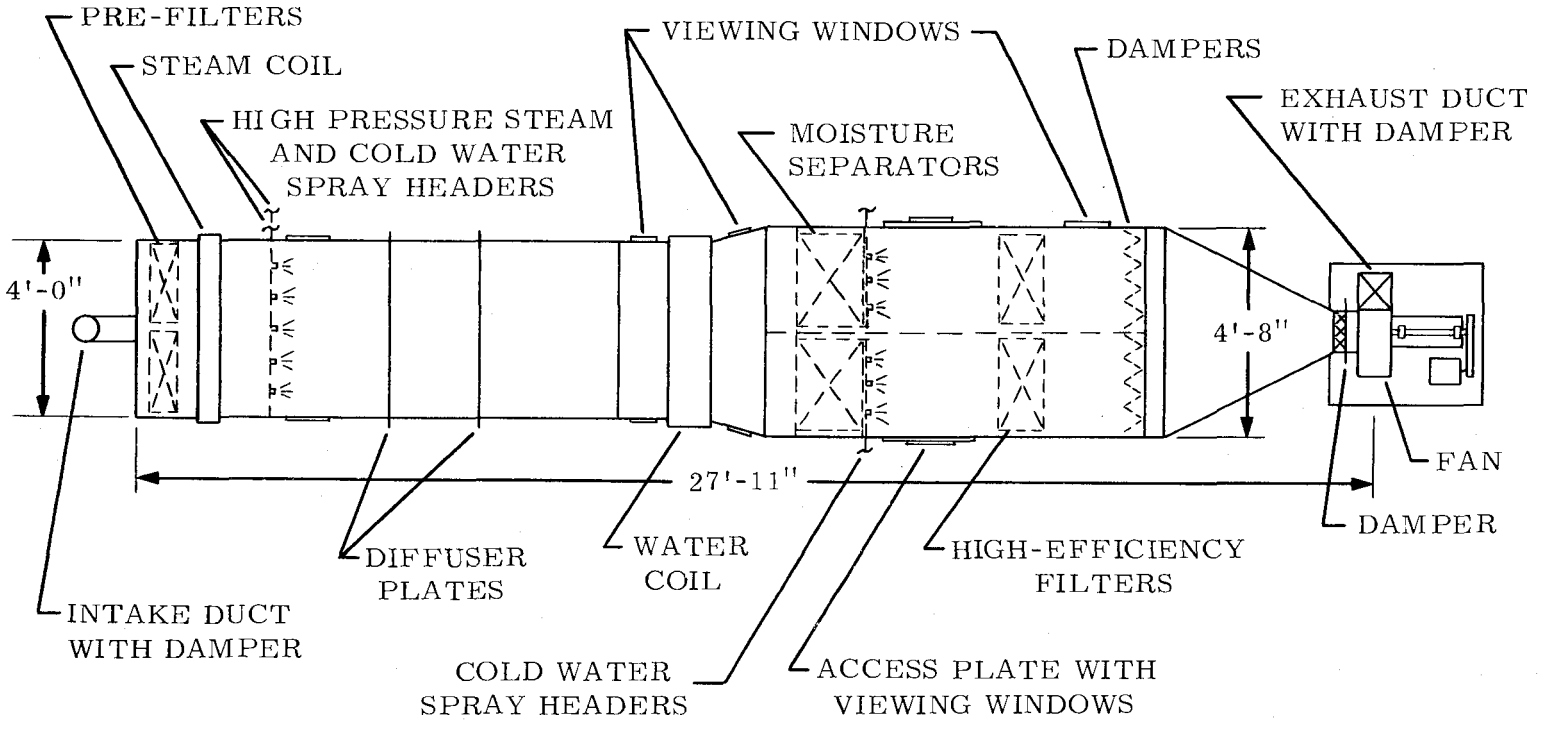


FIGURE 1

A water spray header (Item 5), equipped with multiple head nozzles, is located below the steam spray header and may be used in conjunction with the steam header and/or steam coil to provide the desired test atmosphere. The supply line is equipped with three manually controlled throttling valves of graduated sizes and a shut-off gate valve.

The two diffuser plates (Item 6) assist in mixing the air and steam to secure a homogeneous mixture.

A cold water coil (Item 7) is provided for removing superheat from the steam-air mixture and to provide additional regulation of the test atmosphere conditions. The supply line is equipped with two manually controlled throttling valves.

The test unit is divided into two sections downstream of the water coil. Each section contains a moisture separator (Item 8), access plate, water spray header equipped with nozzles (Item 9), high-efficiency test filter support framing (Item 10), and opposed blade air flow control dampers (Item 11). The moisture separators may be removed for testing the effectiveness of other types of similar units or to permit super-saturated air conditions at the high-efficiency test filters. The filter test section division terminates downstream of the control dampers. The dampers provide individual flow control for each section so that even though there is a variation in the pressure drop between the two test filters, the dampers may be manually controlled to provide similar flows for both filters.

The exhaust fan (Item 13) is of the centrifugal type rated for handling 200 cfm of 200 F saturated air at 14 inches water gage static pressure.

A guillotine damper (Item 12) is installed at the fan suction to provide additional flow control, as required, in conjunction with the filter section control dampers. A fan discharge damper (Item 14) was originally installed for fan flow control but was not used due to steam and water leakage.

Thermometer stations are provided in the air intake duct, downstream of the steam coil, upstream and downstream of the water coil, downstream of each moisture separator, and downstream of each high-efficiency test filter. Standard mercury manometers having ranges of 0 to 200 F and 0 to 600 F were used for temperature measurement.

Hygrometers are installed downstream of the water coil and in each test section downstream of the moisture separators.

Pitot tube air flow stations are located in the air intake duct, downstream of the prefilters, upstream of each high-efficiency test filter, and in the discharge duct.

Manometer connections are installed upstream and downstream of each moisture separator, and upstream and downstream of each high-efficiency test filter. Manometers are provided for indicating the pressure drops across the moisture separators and the filters.

Condensate and water drains are provided at the low points. Traps in each drain are designed to maintain a water seal at all operating pressures. Water is continuously supplied to each trap from a small line to assure the integrity of the water seal during operation.

Viewing windows are located upstream and downstream of the water coil and of each high-efficiency test filter.

The test unit is insulated with the exception of the intake duct, viewing windows, fan, and discharge duct.

The flow in each test section is measured by a propeller-type anemometer mounted on tubing which passes through an opening in the viewing window downstream of the high-efficiency test filter. Anemometer controls are operated by wires passed through the support tubing.

V. HUMIDITY TEST PROCEDURE AND DATA

Three vendors submitted quotations for filters. Each vendor submitted three prototype filters for testing under high humidity conditions. The tests are grouped into the following categories:

A. Saturated Air Flow Tests
B. Super-Saturated Air Flow Tests
C. Water Spray - Air Flow Tests

The total period of time the filters were subjected to test conditions amounted to approximately three hours. It took one or more hours to reach equilibrium due to heat loss from the equipment. Pressure drop across the moisture separators ranged from 0.010 to 0.015 inch water gage static pressure. Some filters were damaged in handling, but even though this caused a higher DOP penetration test result, damage was not extensive enough to affect humidity test conditions.

Figures 2 and 3 show the theoretical weight flow rate of air and steam over a range of saturated air temperatures bracketing the 200 F saturated air temperature design value. Design flow per filter unit is 1000 cfm. Inspection of the test data shows that steam and air flow rates versus the mixture flow compare favorably with the theoretical values. Some variations can be expected due to equipment heat loss and test equipment accuracy. In those tests where one of the filters plugged, the water coil was used also to control mixture temperature. Intake duct air flow was determined by converting the flow element manometer reading to cfm by means of the curve shown in Figure 4 which is based on vendor data. The volume flow rate was then converted to weight flow rate (pounds per minute) from intake air dry bulb and wet bulb temperatures and the respective psychometric chart data. Steam flow rate was read from the steam meter.

The following information was recorded for each test to arrive at information found in the data sheets described later:

1. Test number.
2. Date.
3. Time of test data readings.
4. Steam spray flow rate (pounds per minute).
5. Steam main pressure upstream of spray control valves.
6. Steam main pressure downstream of spray control valves.
7. Intake duct manometer reading (inches water gage).
8. Intake air dry bulb temperature.
9. Intake air wet bulb temperature.
10. Test unit hygrometer readings.
11. Hygrometer reading in each filter unit test section.
12. Air-steam mixture flow for each filter (cfm).

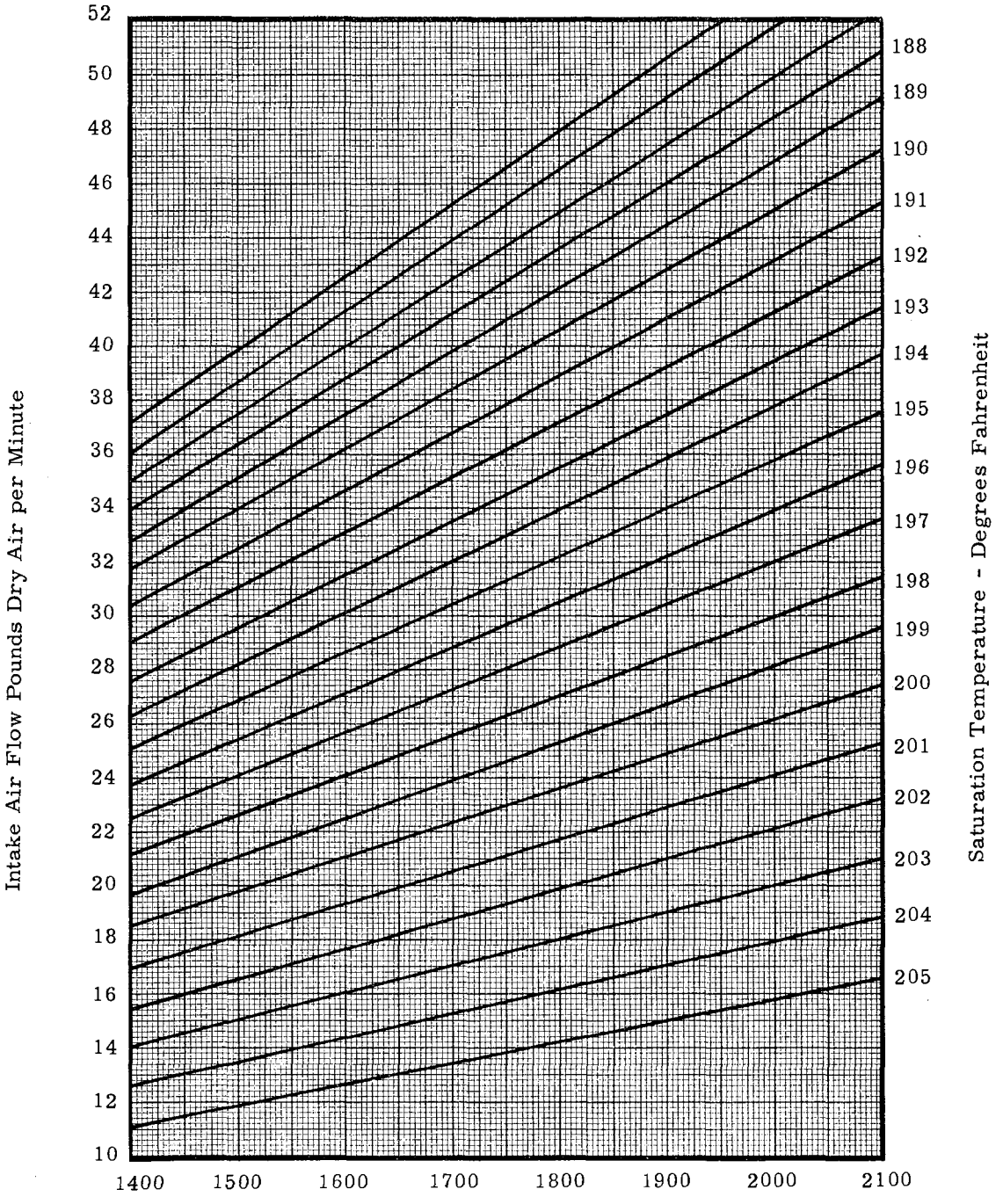


FIGURE 2

Intake Air Flow vs Saturated Air Flow

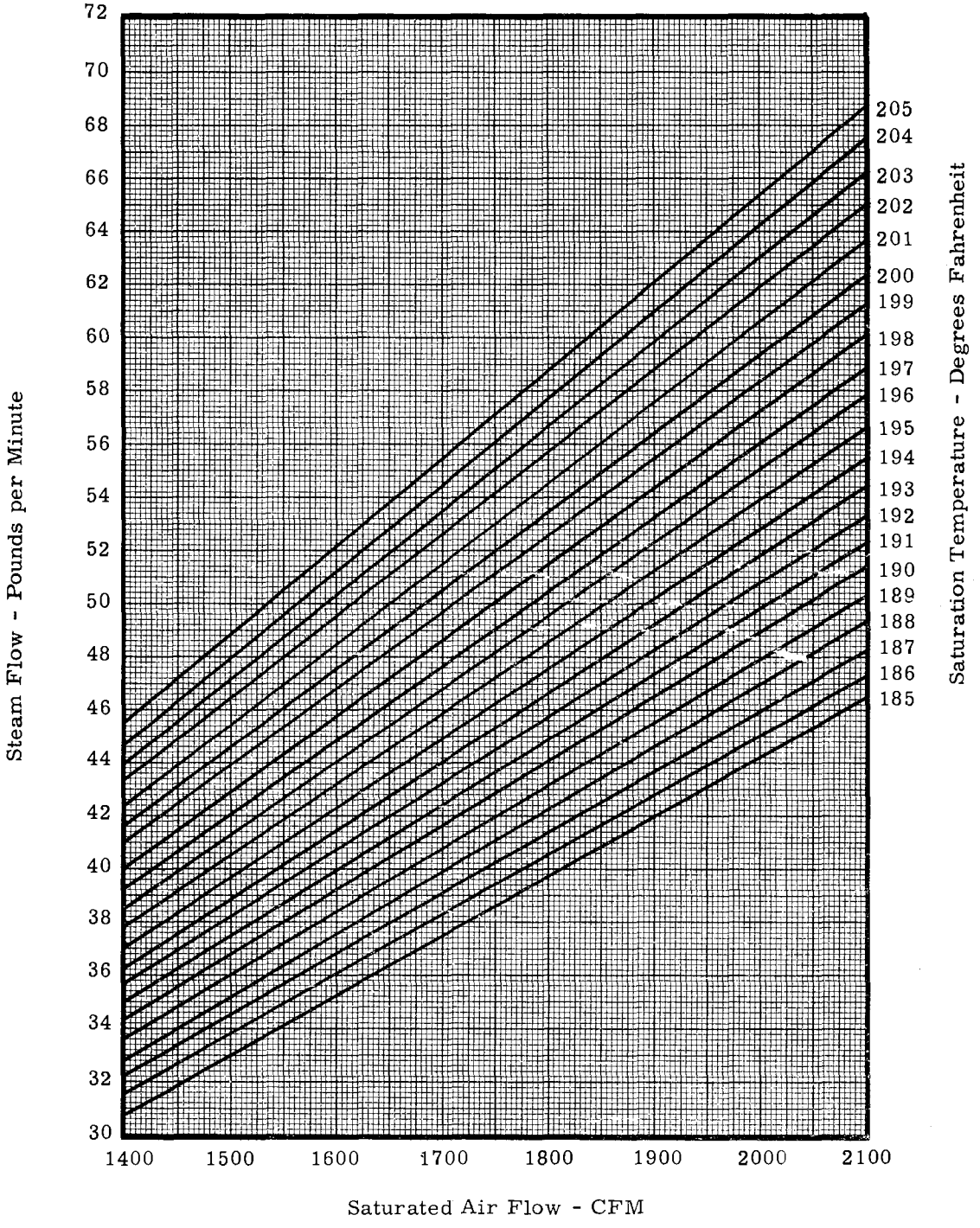


FIGURE 3

Steam Flow vs Saturated Air Flow

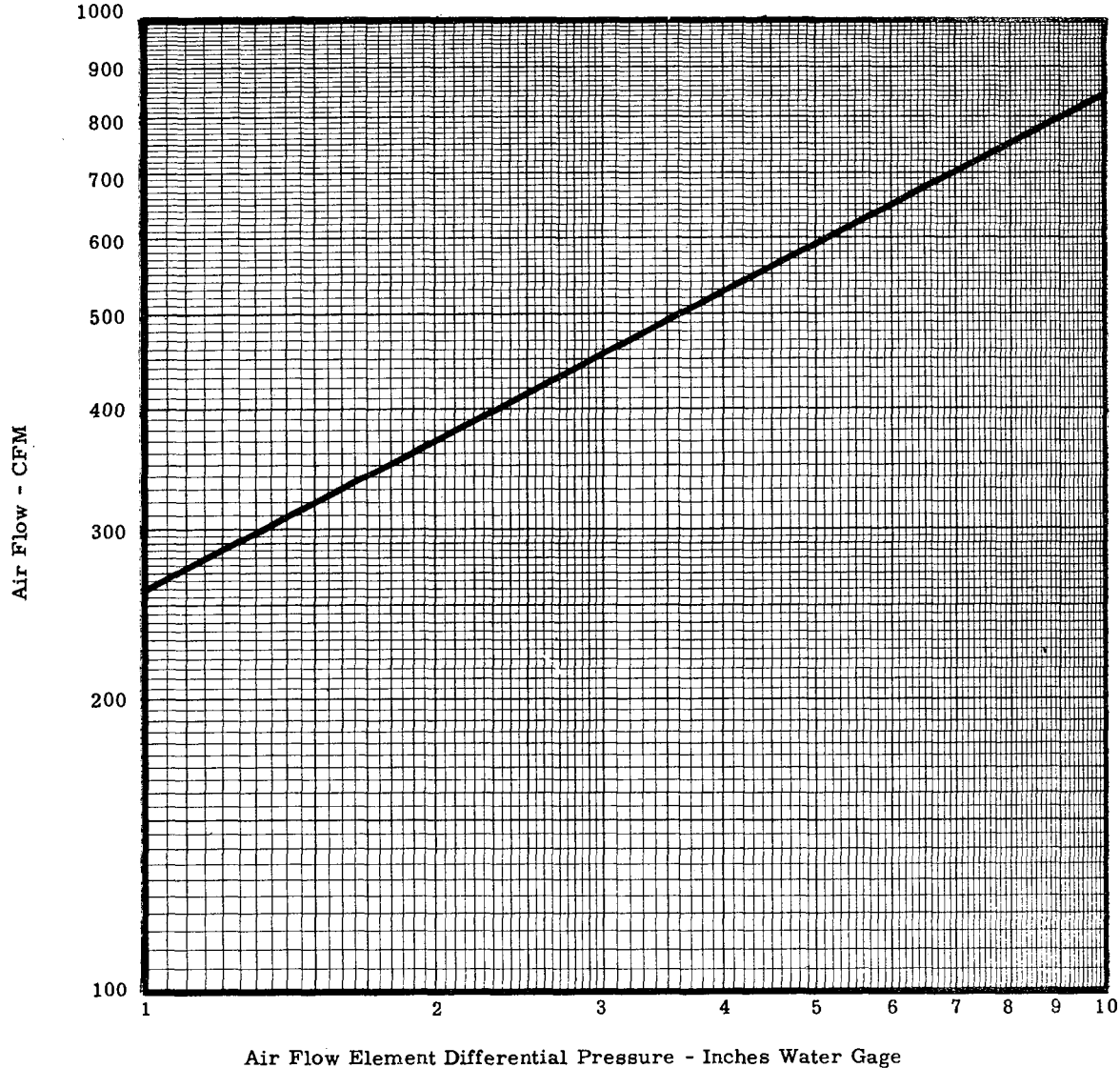


FIGURE 4

Air Flow Element Differential Pressure vs Air Flow

13. Pressure drop across each test filter.
14. Pressure drop across each moisture separator if significant.
15. Fan suction pressure.
16. Fan motor amperage.
17. Remarks on significant observations and on data not itemized.

A. Saturated Air Flow Tests

Two of each vendor's filters were subjected to tests at 200 F saturated air. Steam sprays at the inlet end of the test unit were turned on to supply heat and moisture. No other temperature or humidity sources were operated during this set of tests. The tests were performed with moisture separators installed upstream of the high-efficiency filters thereby simulating the equipment installation in Cells "A" and "B" (Zone I exhaust), and Cell "D" (standby filters) of the 117-N Filter Building.

In general, the initial pressure drop of the filters was 0.5 inch water gage static pressure at a flow corrected to 1000 cfm at 200 F. There was a slight increase in pressure drop across some of the filters. In all cases, the pressure drop was less than one inch water gage static pressure at a flow corrected to 1000 cfm at 200 F. Dioctyl-phthalate penetration and pressure drop tests conducted after the filters were dry showed little change in the DOP penetration and pressure drop tests, with the exception of the increase of the DOP penetration test result for the filter damaged in handling. On the basis of these tests, any of the three vendors who bid would have been able to supply filters capable of meeting the humidity and flow conditions specified in Section I.

Test data are listed in Tables I, II, III, IV, V, and VI. Rate of pressure drop change with respect to time, corrected for a flow of 1000 cfm at 200 F is shown in Figure 5.

B. Super-Saturated Air Flow Tests

The moisture separators, installed upstream of the high-efficiency test filters, were removed to determine the effect of the separators on a moisture laden air stream and to demonstrate their value. This simulates the equipment installation in Cell "C" (Zone II exhaust) of the 117-N Filter Building. Inlet air was pre-heated by the steam coil at the inlet end to approximately 185 F. Steam and water sprays at the inlet end of the unit were turned on to supply heat and moisture. No other temperature or humidity sources were operated during this set of tests.

Filters from all three vendors were comparable in behavior. Water droplets formed on both filter faces approximately 1-1/2 hours after the heating and humidifying operations began. Note that the various pressure drops, corrected to a flow of 1000 cfm, shown in Figure 6, are very close for two hours of testing (plus warm-up time of approximately one hour) but that the pressure drop rapidly increased during the additional one-half hour of testing conducted during Test Number 6.

Test data are listed in Tables VII, VIII, IX, and X. Variation in pressure drop with time, corrected to a flow of 1000 cfm, is shown in Figure 6.

TABLE I

Humidity Test No. 1

Date: 10-22-62

Time of Test	Steam Flow lbs/ min[1]	Air Flow lbs/ min	Filter No. A-2[2] Flow cfm	Pressure Drop, in. of Water	Pressure Drop at 1000 cfm	Filter No. C-2[2] Flow cfm	Pressure Drop, in. of Water	Pressure Drop at 1000 cfm
12:30 p.m.	59.5	30.5	1010	0.5	0.495	969	0.5	0.567
1:30 p.m.	59.5	30.5	969	0.55	0.568	985	0.5	0.507
2:30 p.m.	59.5	30.5	943	0.55	0.577	995	0.5	0.502

[1]Nominal steam pressure at main was 180 psig.
Nominal steam pressure downstream of valves was 75 psig.

[2]Air-steam mixture flow nominally at 200 F saturated.
Test flow pressure drops are corrected for a flow of 1000 cfm for comparison.

TABLE II

Humidity Test No. 1
Filter DOP Penetration and Pressure Drop

Test	Filter No. A-2 Before Test	Filter No. A-2 After Test	Filter No. C-2 Before Test	Filter No. C-2 After Test
DOP (Percent Penetration)	0.006	0.16*	0.018	0.016
Pressure Drop (Inches of Water)	0.88	0.84	0.74	0.74

*Damaged in handling

TABLE III

Humidity Test No. 2

Date: 10-23-62

Time of Test	Steam Flow lbs/ min[1]	Air Flow lbs/ min	Filter No. B-2[2] Flow cfm	Pressure Drop, in. of Water	Pressure Drop at 1000 cfm	Filter No. C-3[2] Flow cfm	Pressure Drop, in. of Water	Pressure Drop at 1000 cfm
11:00 a.m.	59.5	32.3	856	0.65	0.76	1006	0.47	0.467
12:00 noon	59.5	29.3	864	0.60	0.695	974	0.43	0.442
1:00 p.m.	59.5	28.9	864	0.60	0.695	974	0.43	0.442
2:00 p.m.	59.5	31.5	1010	0.60	0.594	1016	0.47	0.462
2:15 p.m.	59.5	31.5	865	0.65	0.752	1006	0.47	0.467

[1]Nominal steam pressure at main was 180 psig.
Nominal steam pressure downstream of valves was 75 psig.

[2]Air-steam mixture flow nominally at 200 F saturated. Test flow pressure drops are corrected for a flow of 1000 cfm for comparison.

TABLE IV

Humidity Test No. 2
Filter DOP Penetration and Pressure Drop

Test	Filter No. B-2 Before Test	Filter No. B-2 After Test	Filter No. C-3 Before Test	Filter No. C-3 After Test
DOP (Percent Penetration)	0.004	0.004	0.016	0.018
Pressure Drop (Inches of Water)	0.86	0.86	0.73	0.70

TABLE V

Humidity Test No. 3

Date: 10-24-62

Time of Test	Steam Flow lbs/ min[1]	Air Flow lbs/ min	Filter No. B-1[2] Flow cfm	Pressure Drop, in. of water	Pressure Drop at 1000 cfm	Filter No. A-3[2] Flow cfm	Pressure Drop, in. of Water	Pressure Drop at 1000 cfm
11:00 a.m.	59.5	31.7	996	0.45	0.452	1011	0.50	0.494
12:00 noon	59.5	30.3	996	0.65	0.652	996	0.50	0.502
1:00 p.m.	59.5	30.2	996	0.70	0.703	996	0.50	0.502

[1]Nominal steam pressure at main was 180 psig.
Nominal steam pressure downstream of valves was 75 psig.

[2]Air-steam mixture flow nominally at 200 F saturated. Test flow pressure drops are corrected for a flow of 1000 cfm for comparison.

TABLE VI

Humidity Test No. 3
Filter DOP Penetration and Pressure Drop

Test	Filter No. B-1 Before Test	Filter No. B-1 After Test	Filter No. A-3 Before Test	Filter No. A-3 After Test
DOP (Percent Penetration)	0.005	0.004	0.008	0.006
Pressure Drop (Inches of Water)	0.86	0.88	0.90	0.84

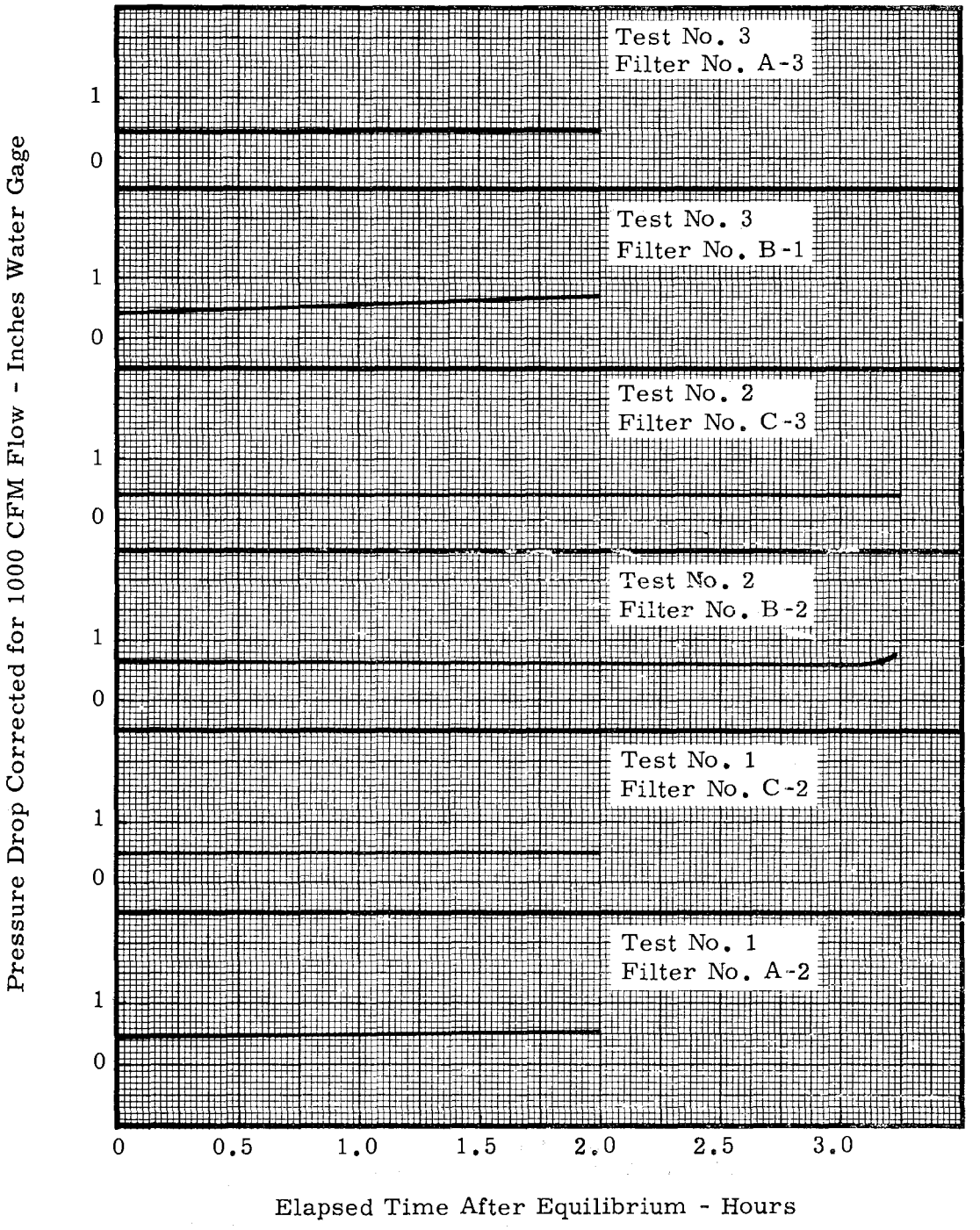


FIGURE 5

Saturated Air Flow Tests

TABLE VII

Humidity Test No. 6

Date: 11-7-62

Time of Test	Steam Flow lbs/ min[1]	Air Flow lbs/ min	Filter No. C-2[2] Flow cfm	Filter No. C-2[2] Pressure Drop, in. of Water	Filter No. C-2[2] Pressure Drop at 1000 cfm	Filter No. C-3[2] Flow cfm	Filter No. C-3[2] Pressure Drop, in. of Water	Filter No. C-3[2] Pressure Drop at 1000 cfm
11:30 a.m.	59.5	25.4	1016	0.9	0.886	1016	0.9	0.886
11:45 a.m.	59.5	25.4	995	0.9	0.905	1020	0.9	0.882
12:00 noon	59.5	25.4	995	0.9	0.905	1020	1.1	1.08
12:15 p.m.	59.5	25.4	1005	0.9	0.895	1017	0.9	0.885
12:30 p.m.	59.5	25.4	1010	1.1	1.09	1017	1.1	1.082
1:00 p.m.	59.5	25.4	990	1.0	0.99	1020	1.4	1.37
1:30 p.m.	59.5	22.5	990	1.5	1.515	995	1.5	1.51
2:00 p.m.	59.5	20.8	974	1.9	1.95	985	1.9	1.93

[1]Nominal steam pressure at main was 180 psig.
Nominal steam pressure downstream of valves was 75 psig.

[2]Air steam mixture flow nominally at 200 F saturated. Test flow pressure drops are corrected for a flow of 1000 cfm for comparison.

TABLE VIII

Humidity Test No. 6
Filter DOP Penetration and Pressure Drop

Test	Filter No. C-2 Before Test	Filter No. C-2 After Test	Filter No. C-3 Before Test	Filter No. C-3 After Test
DOP (Percent Penetration)	0.016	0.88*	0.018	0.12*
Pressure Drop (Inches of Water)	0.74	0.70	0.70	0.68

*Damaged in handling

TABLE IX

Humidity Test No. 7

Date: 11-13-62

Time of Test	Steam Flow lbs/ min[1]	Air Flow lbs/ min	Filter No. A-2[2] Flow cfm	Filter No. A-2[2] Pressure Drop,in. of Water	Filter No. A-2[2] Pressure Drop at 1000 cfm	Filter No. B-3[2] Flow cfm	Filter No. B-3[2] Pressure Drop,in. of Water	Filter No. B-3[2] Pressure Drop at 1000 cfm
10:30 a.m.	59.5	24.6	1005	0.9	0.895	1020	0.9	0.882
10:45 a.m.	59.5	24.4	990	0.9	1.1	1000	0.9	0.9
11:00 a.m.	59.5	24.4	1000	1.0	1.0	1020	1.0	0.98
11:15 a.m.	59.5	24.6	995	1.0	1.005	1015	1.0	0.985
11:30 a.m.	59.5	24.4	1000	1.2	1.2	1020	1.2	1.175
12:00 noon	59.5	22.5	975	1.5	1.54	980	1.5	1.53
12:30 p.m.	59.5	22.2	980	1.5	1.53	980	1.5	1.53

[1]Nominal steam pressure at main was 180 psig.
Nominal steam pressure downstream of valves was 75 psig.

[2]Air-steam mixture flow nominally at 200 F saturated. Test flow pressure drops are corrected for a flow of 1000 cfm for comparison.

TABLE X

Humidity Test No. 7
Filter DOP Penetration and Pressure Drop

Test	Filter No. A-2 Before Test	Filter No. A-2 After Test	Filter No. B-3 Before Test	Filter No. B-3 After Test
DOP (Percent Penetration)	0.16*	0.24*	0.010	0.010
Pressure Drop (Inches of Water)	0.84	0.84	1.0	0.87

*Damaged in handling

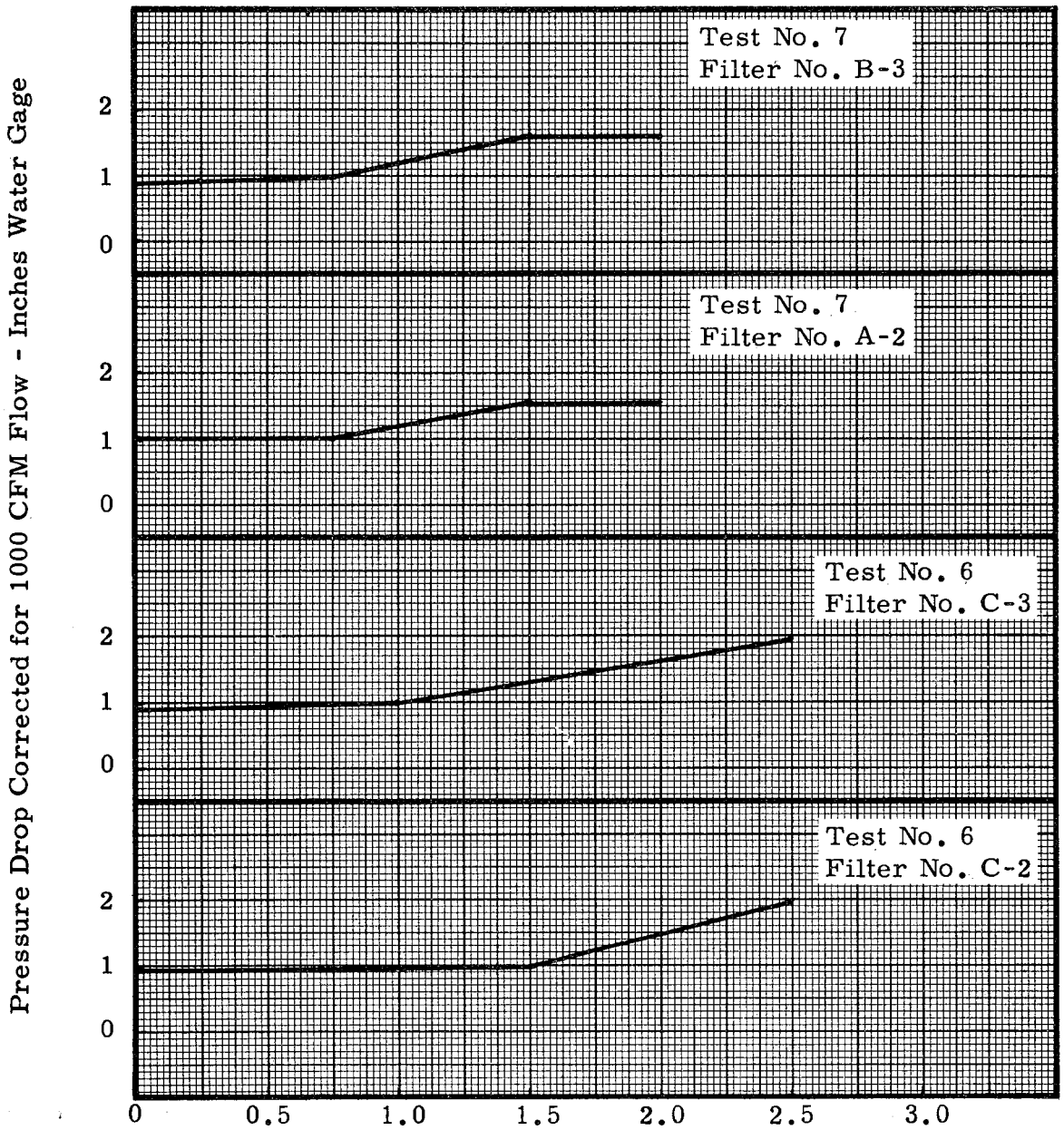


FIGURE 6

Super-Saturated Air Flow Tests

C. Water Spray - Air Flow Tests

Steam sprays at the inlet end of the unit were turned on to supply heat and moisture. After equilibrium had been established at 200 F saturated air conditions, the water sprays immediately upstream of the filters were turned on to determine the performance of water drenched filters. The water coil was turned on during the tests when a plugged filter created a rapid rise in the test unit temperature. No other temperature or humidity sources were operated during this set of tests.

One test filter supplied by vendor "A" plugged 25 minutes after the water sprays were turned on. A test on another filter furnished by vendor "A" showed a pressure increase of less than one inch water gage for a corrected flow of 1000 cfm during a test period of one hour and 40 minutes.

One of the filters supplied by vendor "B" plugged in two hours and 30 minutes. A different filter supplied by vendor "B" was tested for one hour and 40 minutes and showed an increase of 2.3 inches water gage pressure drop before termination of the test.

One filter supplied by vendor "C" was subjected to this set of tests and showed an increase of 1.4 inches water gage pressure drop over a period of one hour and 15 minutes and then remained constant until the test was terminated one hour and 15 minutes later.

Test results were inconsistent.

Test data are listed in Tables XI, XII, XIII, XIV, XV, and XVI. Variation in pressure drop with time, corrected to a flow of 1000 cfm, is shown in Figures 7 and 8.

TABLE XI

Humidity Test No. 4

Date: 10-24-62

Time of Test	Steam Flow lbs/ min[1]	Air Flow lbs/ min	Filter No. B-3[2] Flow cfm	Pressure Drop,in. of Water	Pressure Drop at 1000 cfm	Filter No. A-1[2] Flow cfm	Pressure Drop,in. of Water	Pressure Drop at 1000 cfm
11:45 a.m.	57.4	26.8	1048	0.92	0.88	1048	0.50	0.478
12:00 noon	Water spray turned on filters.							
12:25 p.m.	Filter No. A-1 plugged causing rapid rise in air temperature.							
12:35 p.m.	42	--	1677	2.1	1.25	0	--	--
1:15 p.m.	42	35.7	1000	1.2	1.2	0	--	--
2:10 p.m.	42	23.8	460	3.5	7.62	0	--	--
2:30 p.m.	Filter No. B-3 plugged.							

[1]Nominal steam pressure at main was 180 psig.
Nominal steam pressure downstream of valves was 75 psig.

[2]Air-steam mixture flow nominally at 200 F saturated. Test flow pressure drops are corrected for a flow of 1000 cfm for comparison.

TABLE XII

Humidity Test No. 4
Filter DOP Penetration and Pressure Drop

Test	Filter No. B-3 Before Test	Filter No. B-3 After Test	Filter No. A-1 Before Test	Filter No. A-1 After Test
DOP (Percent Penetration)	0.006	0.010	0.004	0.004
Pressure Drop (Inches of Water)	0.92	1.0	0.9	0.88

TABLE XIII

Humidity Test No. 5

Date: 10-26-62

Time of Test	Steam Flow lbs/ min[1]	Air Flow lbs/ min	Filter No. X[2] Flow cfm	Filter No. X[2] Pressure Drop, in. of Water	Filter No. X[2] Pressure Drop at 1000 cfm	Filter No. C-1[2] Flow cfm	Filter No. C-1[2] Pressure Drop, in. of Water	Filter No. C-1[2] Pressure Drop at 1000 cfm
12:00 noon	59.5	28	--	--	--	1000	0.5	0.5
	Water spray turned on filters							
12:10 p.m.	59.5	27.4	--	--	--	1000	0.9	0.9
12:20 p.m.	59.5	28	Spare filter plugged			1000	1.8	1.8
12:30 p.m.	59.5	25	--	--	--	1000	2.2	2.2
12:45 p.m.	59.5	18.25	--	--	--	1000	2.1	2.1
1:00 p.m.	59.5	--	--	--	--	1000	1.7	1.7
1:15 p.m.	59.5	--	--	--	--	1000	1.9	1.9
1:30 p.m.	59.5	20.2	--	--	--	1000	1.9	1.9
1:45 p.m.	59.5	20.2	--	--	--	1000	1.9	1.9
2:00 p.m.	59.5	19.3	--	--	--	1000	1.9	1.9

[1]Nominal steam pressure at main was 180 psig.
Nominal steam pressure downstream of valves was 75 psig.

[2]Air-steam mixture flow nominally at 200 F saturated. Test flow pressure drops are corrected for a flow of 1000 cfm for comparison.

TABLE XIV

Filter DOP Penetration and Pressure Drop

Humidity Test No. 5	Filter No. X Before Test	Filter No. X After Test	Filter No. C-1 Before Test	Filter No. C-1 After Test
DOP (Percent Penetration)	--	--	0.028	0.74*
Pressure Drop (Inches of Water)	--	--	0.076	0.80

*Damaged in handling

TABLE XV

Humidity Test No. 8

Date: 12-4-62

Time of Test	Steam Flow lbs/ min[1]	Air Flow lbs/ min	Filter No. A-3[2] Flow cfm	Pressure Drop,in. of Water	Pressure Drop at 1000 cfm	Filter No. B-1[2] Flow cfm	Pressure Drop,in. of Water	Pressure Drop at 1000 cfm
11:00 a.m.	59.5	31.6	1021	0.6	0.587	1021	0.6	0.587
11:15 a.m.	59.5	30.6	1021	0.5	0.49	1021	0.5	0.49
11:20 a.m.	Water spray turned on filters.							
11:30 a.m.	59.5	30.6	1021	0.9	0.881	1021	0.8	0.783
11:45 a.m.	59.5	30.6	1021	0.9	0.881	1021	0.8	0.783
12:00 noon	59.5	30.5	1010	1.1	1.09	1028	1.0	0.974
12:15 p.m.	59.5	30.5	979	1.1	1.125	985	0.9	0.914
12:30 p.m.	59.5	26.5	1010	1.3	1.288	1026	1.3	1.268
12:45 p.m.	59.5	18.5	1010	1.5	1.485	1020	2.5	2.45
1:00 p.m.	59.5	20.5	1010	1.5	1.485	1000	2.9	2.9

[1]Nominal steam pressure at main was 180 psig.
Nominal steam pressure downstream of valves was 75 psig.
[2]Air-steam mixture flow nominally at 200 F saturated. Test flow pressure drops are corrected for a flow of 1000 cfm for comparison.

TABLE XVI

Filter DOP Penetration and Pressure Drop

Humidity Test No. 8	Filter No. A-3 Before Test	Filter No. A-3 After Test	Filter No. B-1 Before Test	Filter No. B-1 After Test
DOP (Percent Penetration)	0.006	0.008	0.004	0.034
Pressure Drop (Inches of Water)	0.84	0.84	0.034	1.5*

*Filter was not completely dry.

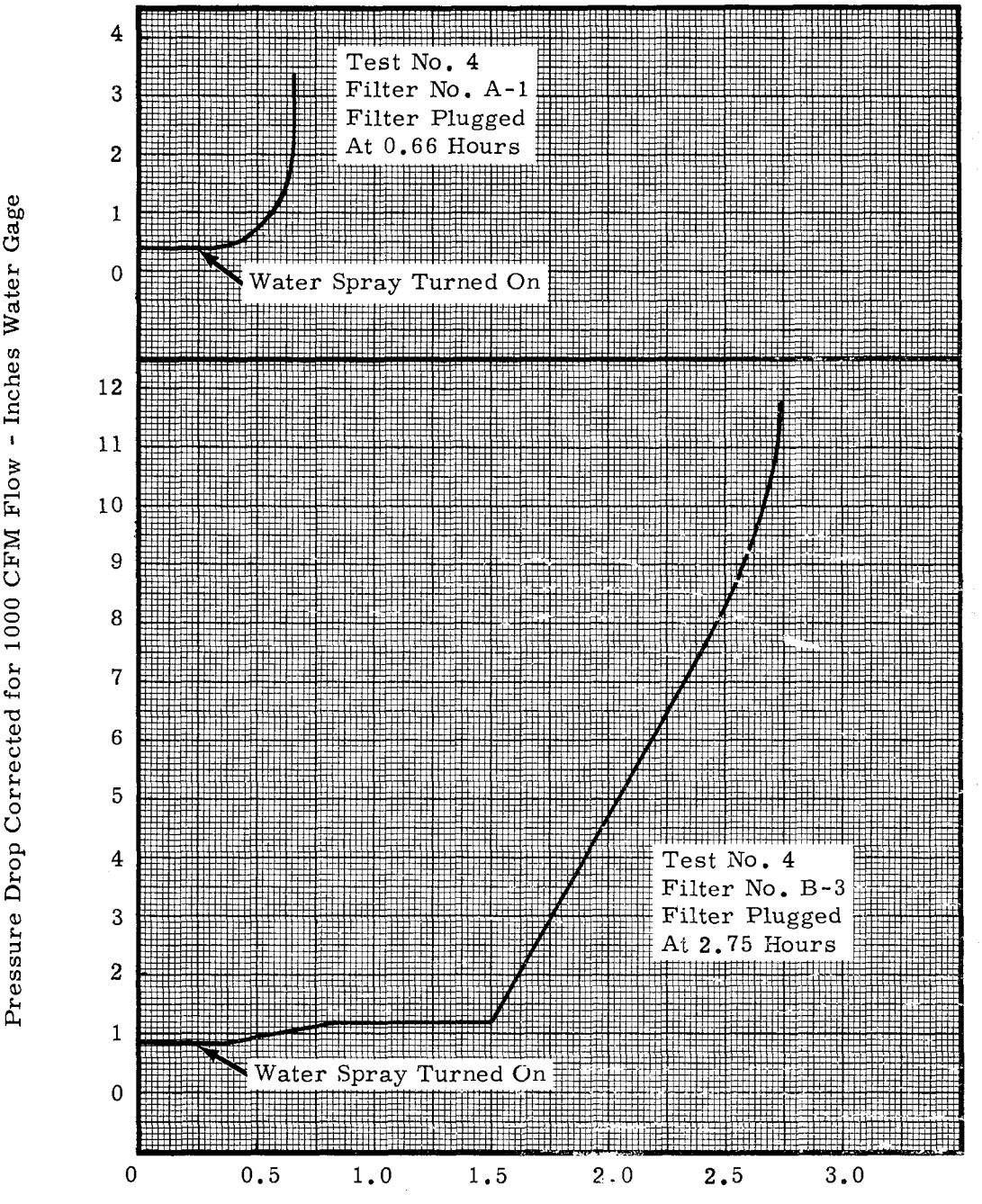


FIGURE 7

Water Spray - Air Flow Tests

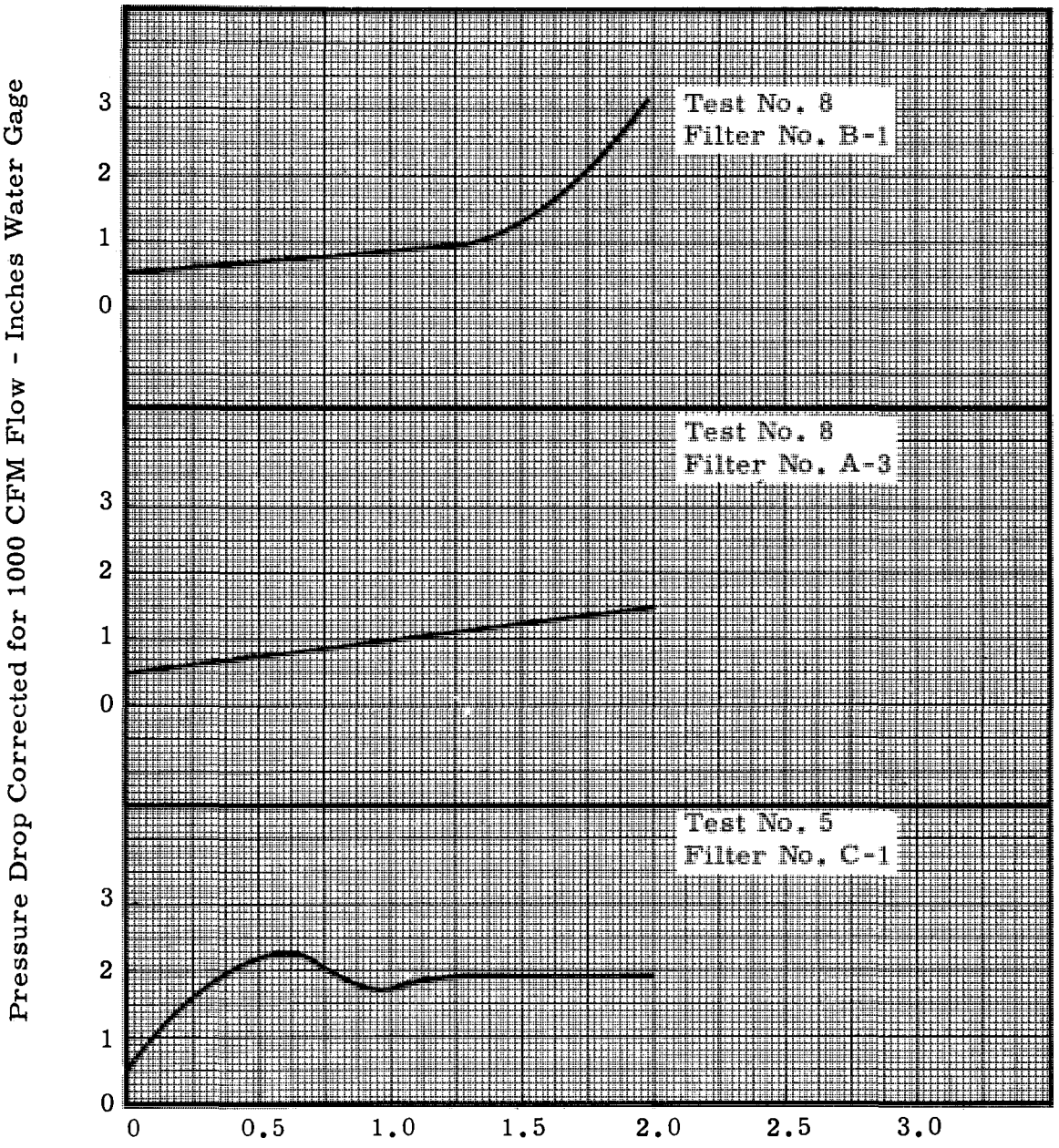


FIGURE 8

Water Spray - Air Flow Tests

VI. GLUE AND ADHESIVE BURNING TEST PROCEDURE AND DATA

Glue and adhesive samples from the three filter bidders were tested for fire resistance characteristics. The tests were performed by smearing a sample 2 inches by 5 inches on a piece of transite and then applying the flame of an oxyacetylene torch to each sample after it had dried.

Test results are as follows:

Bidder "A" - Media glue burned two and one-half minutes after flame removed. Black color smoke evolved.

Bidder "B" - Media glue burned two minutes after flame removed. Light color smoke evolved.

Bidder "C" - Original glue sample failed to ignite.

Bidder "C" - Substituted glue sample burned two minutes after flame removed. Light color smoke evolved.

APPENDIX

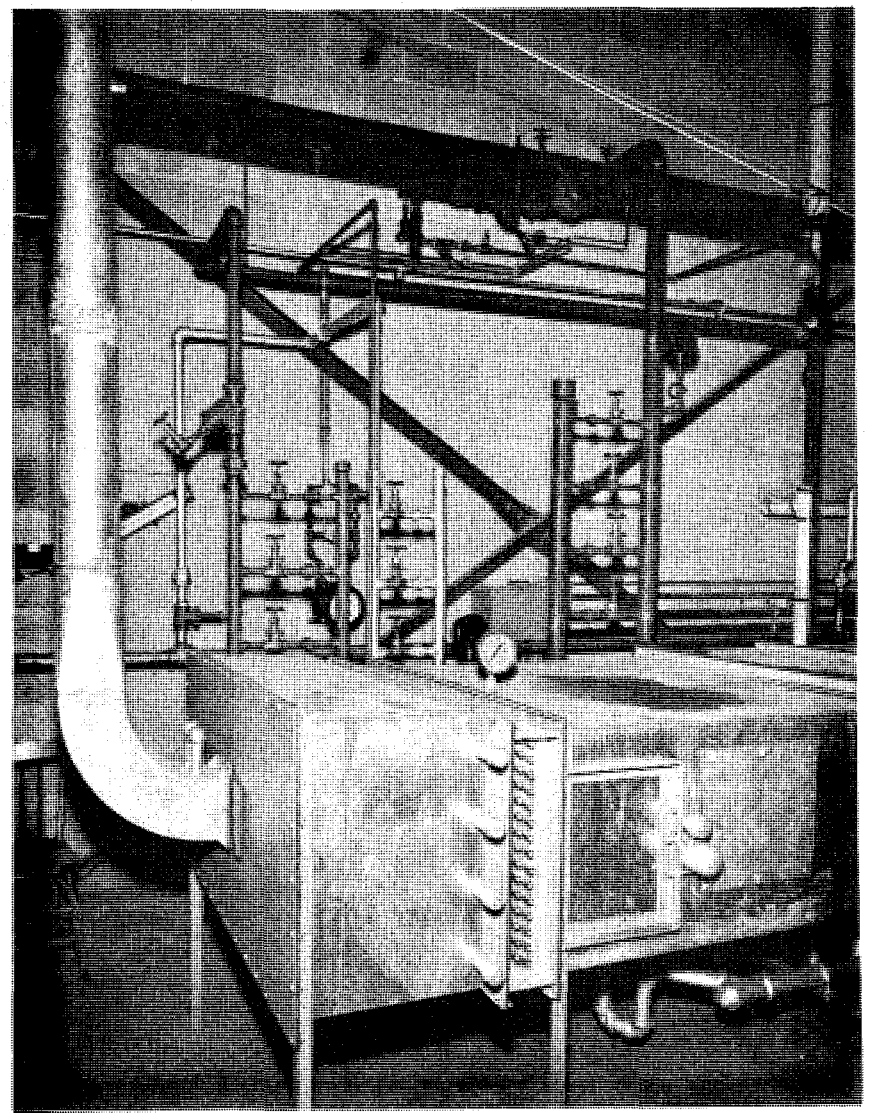


FIGURE 9

HUMIDITY TEST UNIT - UNINSULATED
AIR INTAKE END

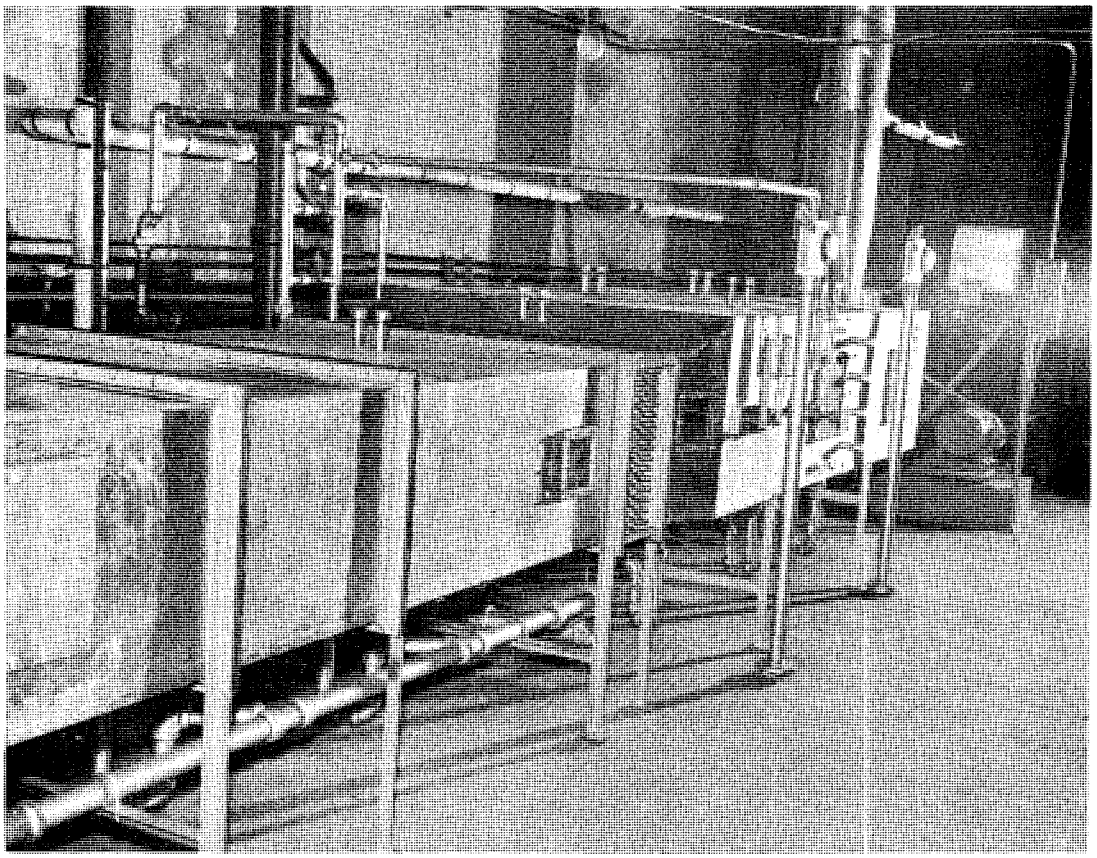


FIGURE 10

HUMIDITY TEST UNIT - UNINSULATED
DOWNSTREAM OF AIR INTAKE END

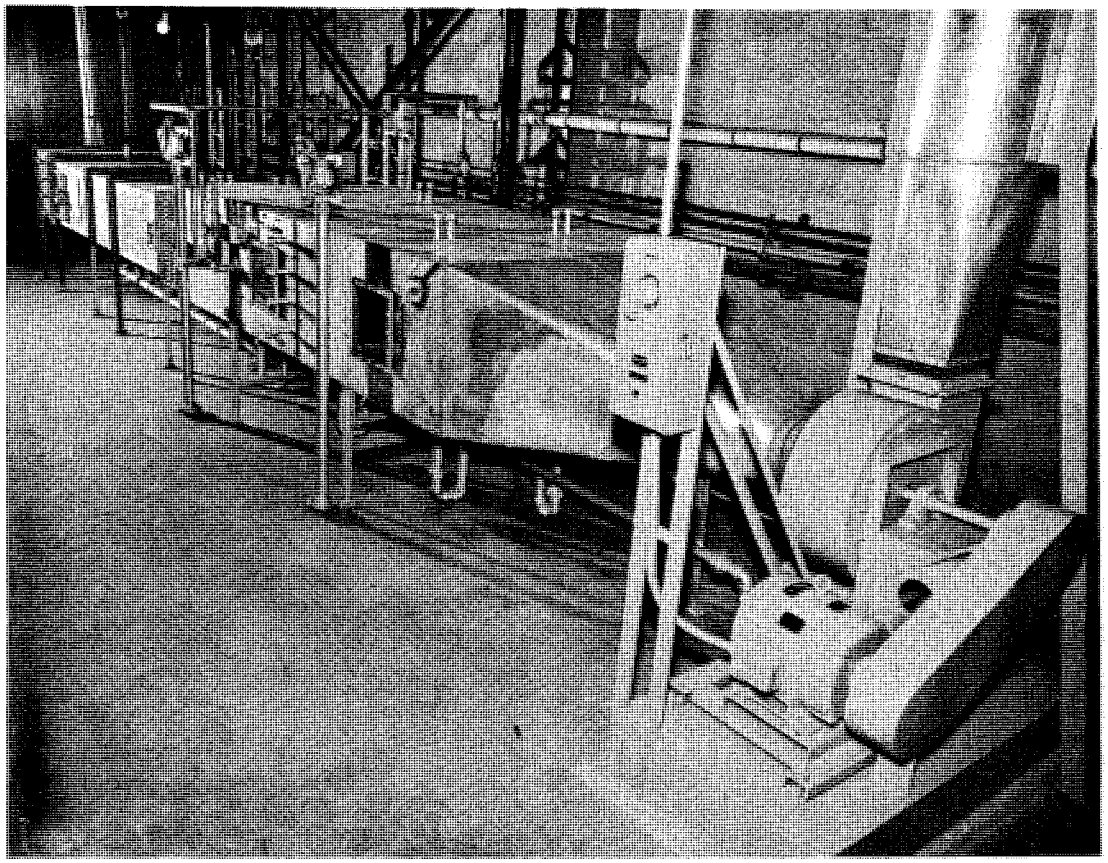


FIGURE 11

HUMIDITY TEST UNIT - UNINSULATED
EXHAUST END

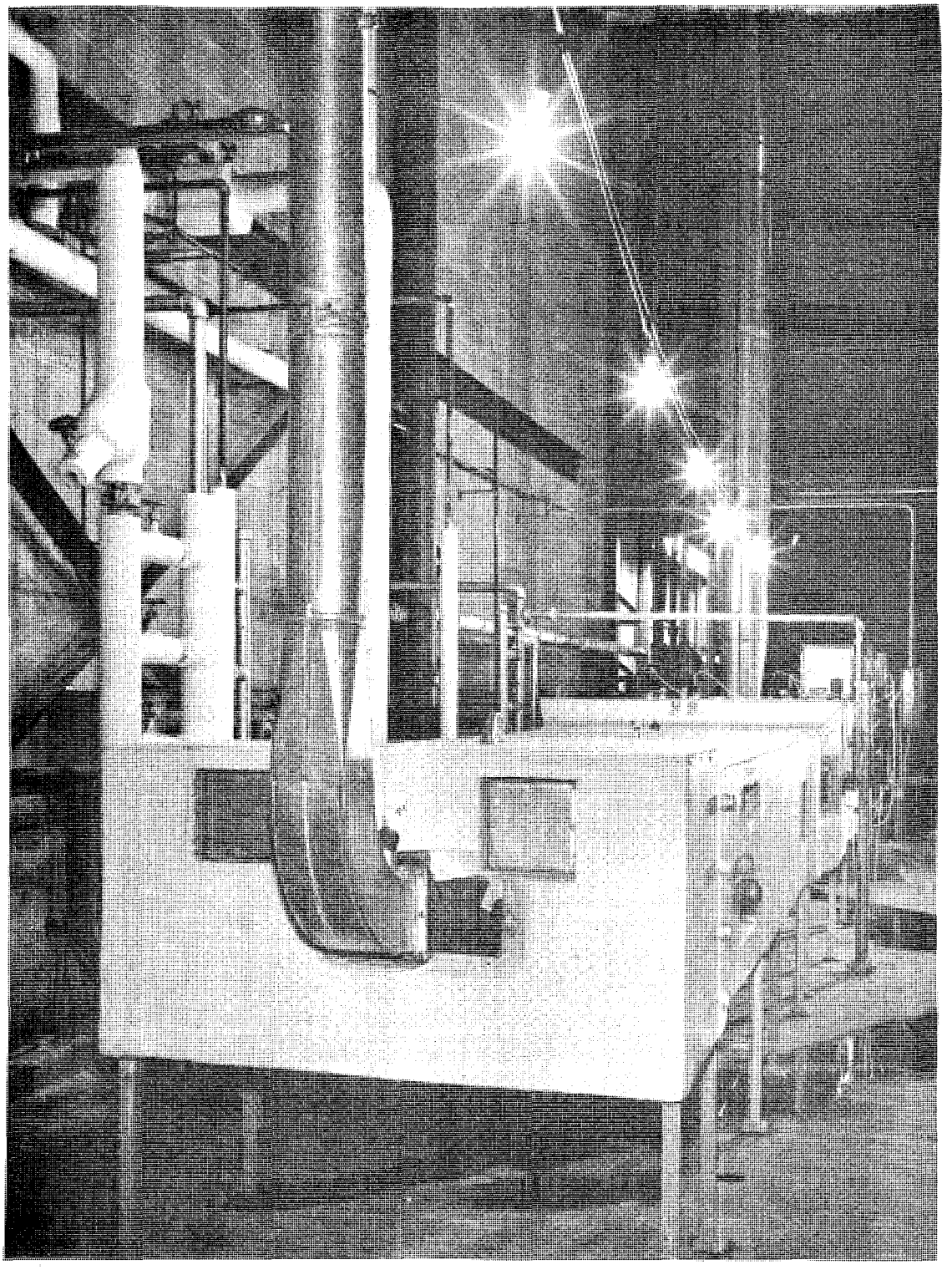


FIGURE 12

HUMIDITY TEST UNIT - INSULATED
AIR INTAKE END

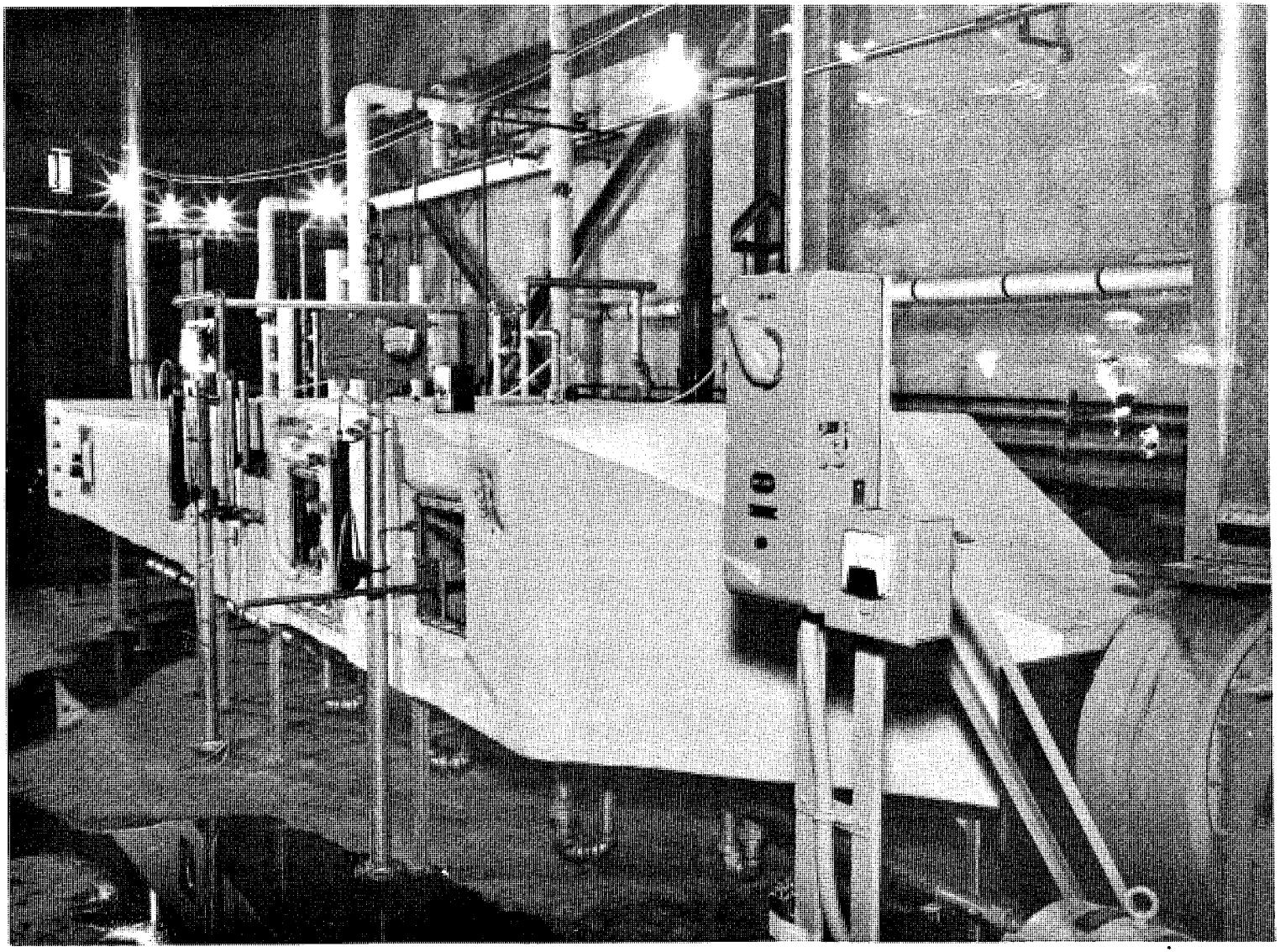


FIGURE 13

HUMIDITY TEST UNIT - INSULATED
EXHAUST END

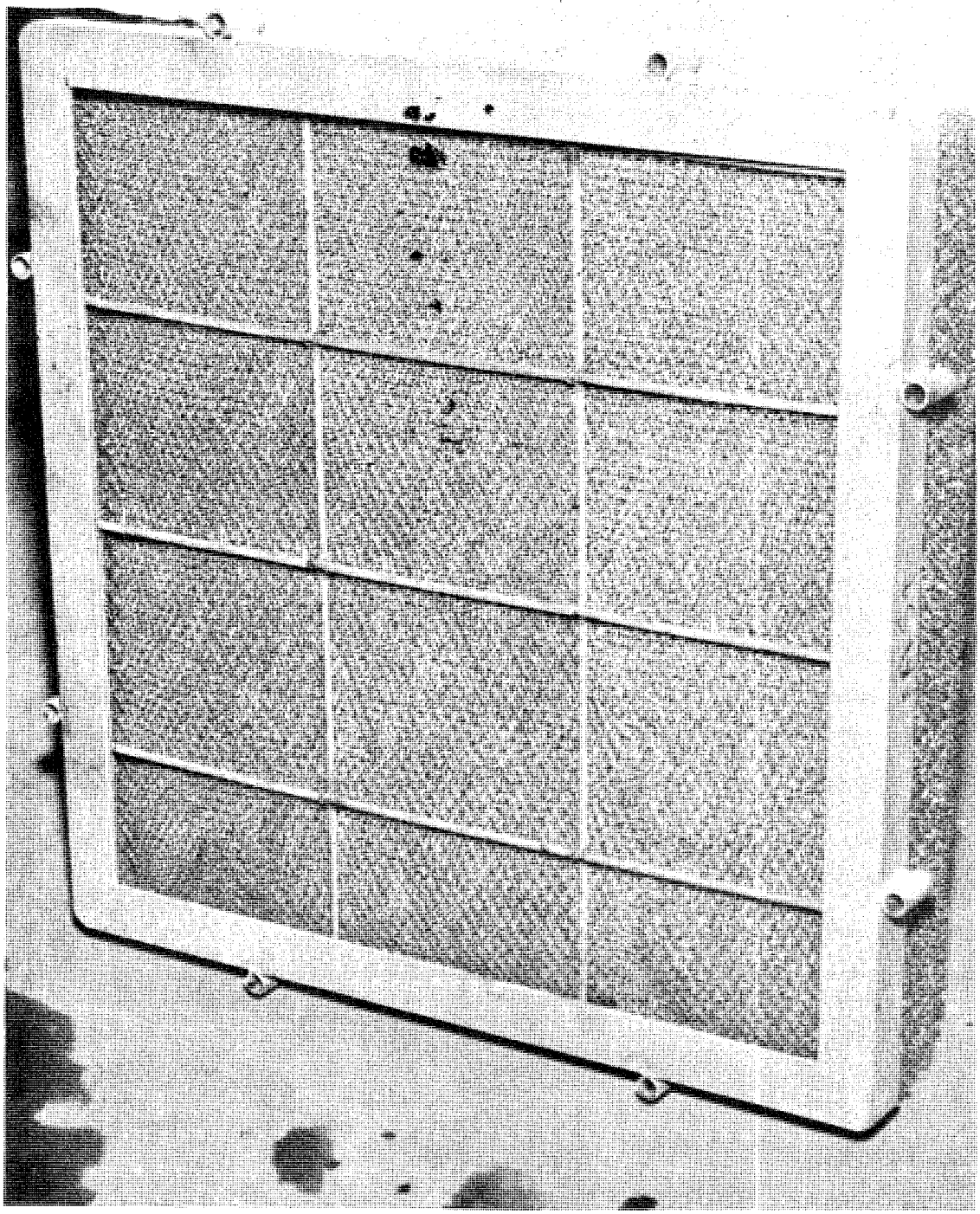


FIGURE 14

MOISTURE SEPARATOR

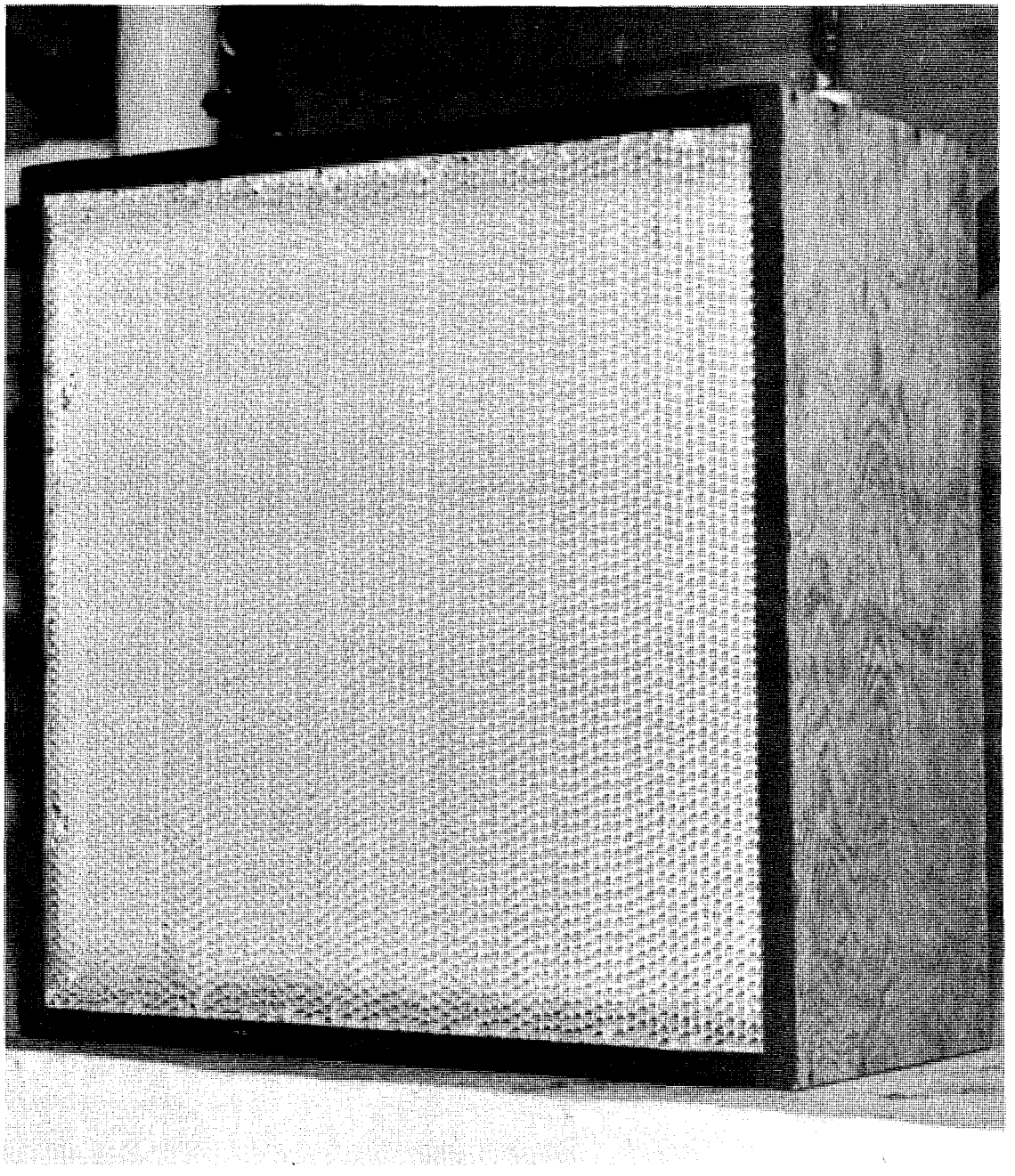


FIGURE 15

HIGH-EFFICIENCY FILTER

AIR FLOW PERFORMANCE IN FUME HOOD EXHAUST SYSTEMS IN CENTRAL RESEARCH AND ADMINISTRATION BUILDING 4500-SOUTH, ORNL

R. H. Forde
Oak Ridge National Laboratory

INTRODUCTION

During the execution of the balance of air-handling systems in Building 4500-South, it became apparent that there were fume leakage problems resulting from the present operation of fume hoods. A series of performance tests was conducted to determine causes and possible corrections.

DISCUSSION OF HOOD TESTS

The purpose of the first air flow performance tests was to determine the cause of fumes flowing out of the fume hoods and back into the laboratories via the bypass grille. The "test" hood, located in Laboratory E-49, was manufactured by Metalab Equipment Company of Hicksville, Long Island, New York, and is similar to Metalab's H-200 Series, Flo Line Fume Hood (Sketch No. 1). All of the fume hoods in Building 4500-South resemble this type.

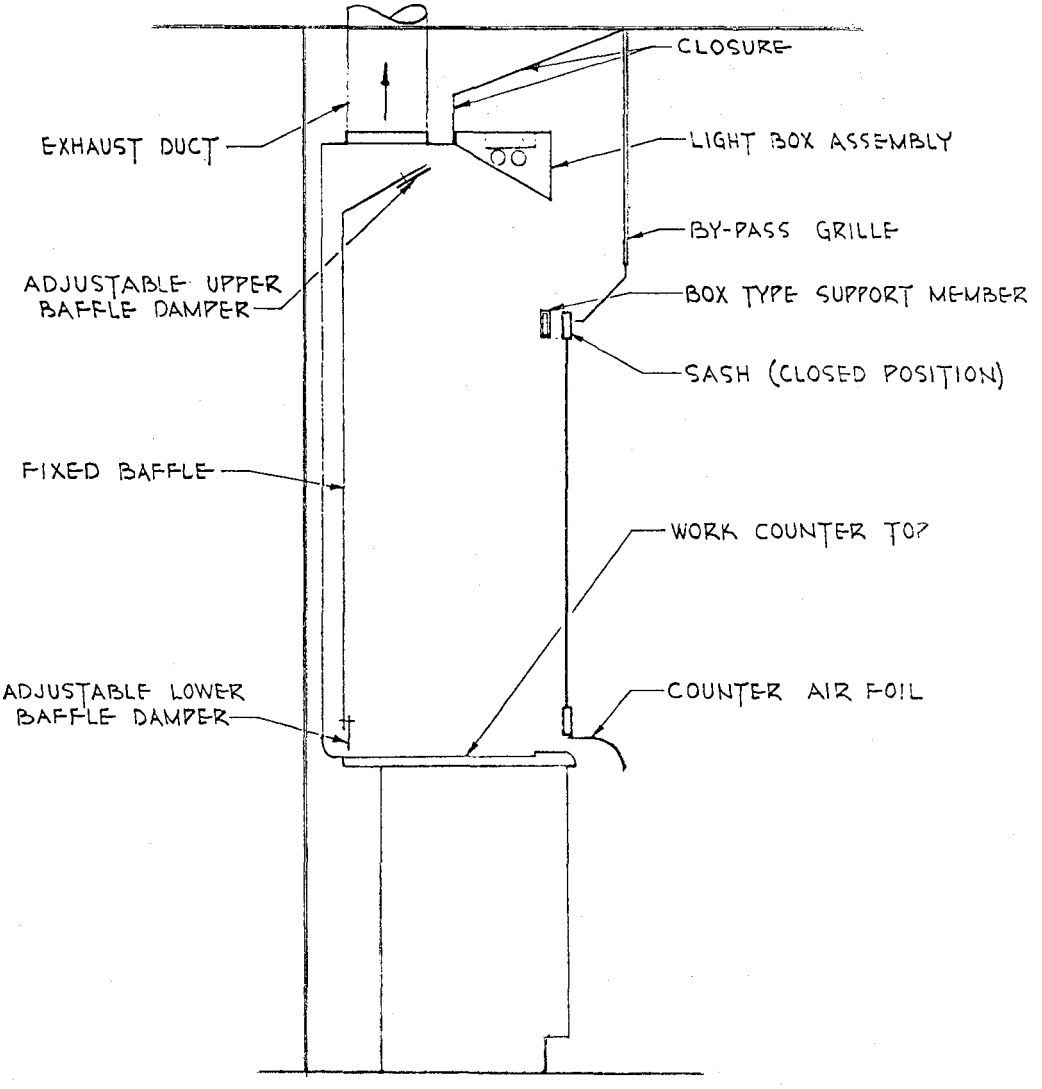
The leakage out of the bypass grille was emitted through a crack between the upper sash frame and the light box assembly (Sketch No. 2). The crack is 1 3/4 inches wide and for a nominal 8-foot hood, 82 inches long. This represents an opening of 1 square foot area.

The upper baffle damper was adjusted wide open, and the lower baffle damper was adjusted to a 1-inch maximum opening. After adjustment, smoke from a one-half-minute smoke bomb set off inside the hood did not flow through the crack when the hood sash was at 15-inch and 30-inch openings.

Heat sources were then placed inside the hood. No leakage was observed when two 1.2-kw electric hot plates were operated at maximum heat. When two blast burners (Sketch No. 3) were ignited in the hood, smoke from a bomb flowed out of the bypass grille into the laboratory.

Measurements taken before the heat sources were added indicated an air flow into the hood through the crack. This air flow velocity was approximately equal to that of the hood face velocity. Measurements taken after the heat sources were added indicated an increase in hood face velocity and an air flow of higher velocity out of the hood through the crack.

It was concluded that the convection currents induced by the heat inside the hoods were the basic cause of the disturbance in flow pattern. The heat also expanded the air in the upper part of the hood. These conditions produce a



HOOD CROSS-SECTION

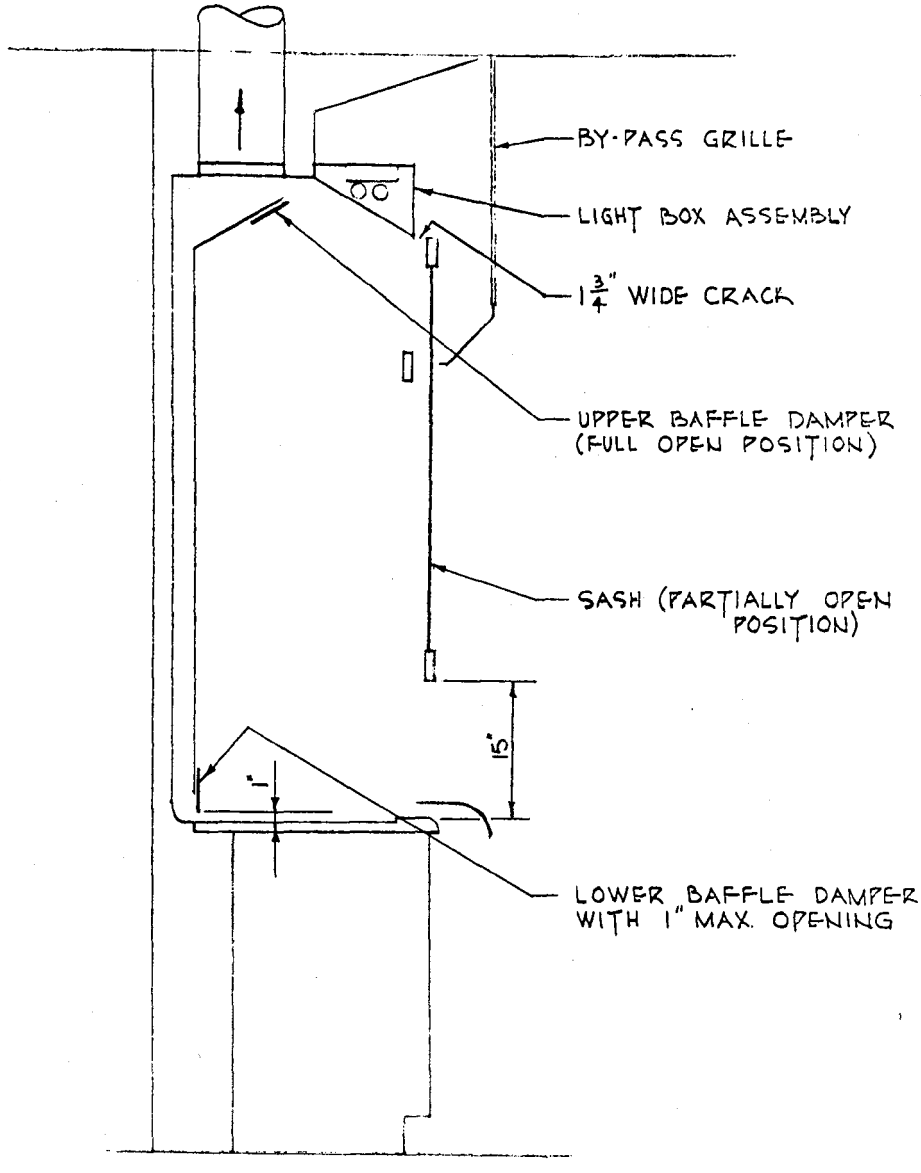
METALAB EQUIPMENT CO.

NO SCALE

SKETCH NO. 1

AIR HANDLING REVISIONS
BLDG 4500 SOUTH
WR A-0645-11D
R.H. FORDE—D.L. ANFINSON

8-62



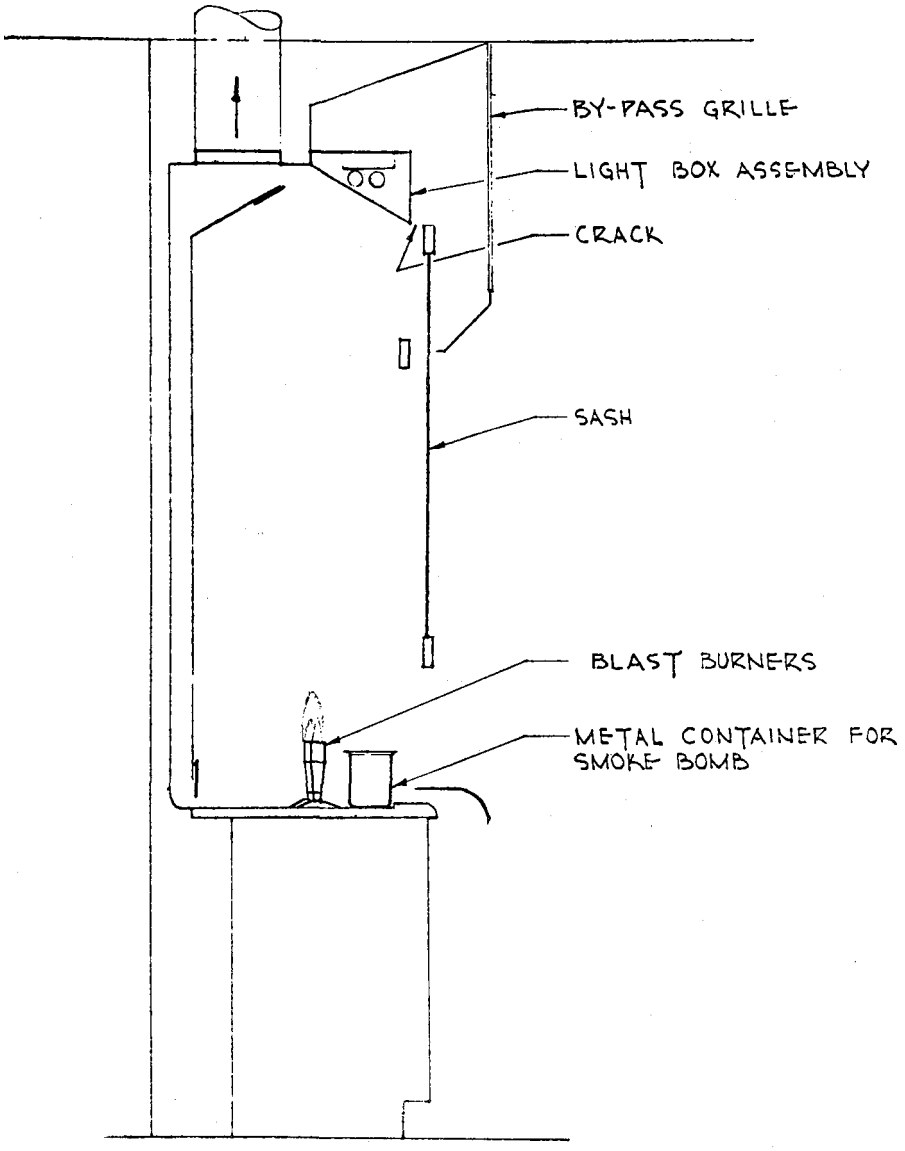
HOOD CROSS-SECTION

NO SCALE

SKETCH NO. 2

AIR HANDLING REVISIONS
BLDG 4500 SOUTH
W.R. A-06455-11D
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HOOD CROSS-SECTION

NO SCALE

SKETCH NO. 3

AIR HANDLING REVISIONS
BLDG 4500 SOUTH
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greater volume of air than the upper baffle opening could exhaust. An air pressure build-up resulted. The crack acting as a pressure relief port provided the route for the fume leakage out the hood bypass grille.

An additional series of tests was performed to determine the fume leakage boundary at various heat loads and air quantities. These tests are described later in this report.

HOOD MODIFICATIONS

Various types of panels were installed to deflect the air flow inside the hood and to contain the air at the increased pressure resulting from internal heat sources. As a temporary measure they were all constructed of blotting paper.

A support space deflection panel (Sketch No. 4) was installed. The blast burners were turned on, and a bomb produced smoke that flowed out of the hood through the space between the panel and the sash.

An angle panel was attached to the hood support member with the support space deflection panel remaining in position (Sketch No. 5). Smoke leakage was observed when the burners were in operation.

The disadvantage of the above two types of panels is that the bypass air path is closed. This causes undesirable high velocities across the work counter top at a low sash position.

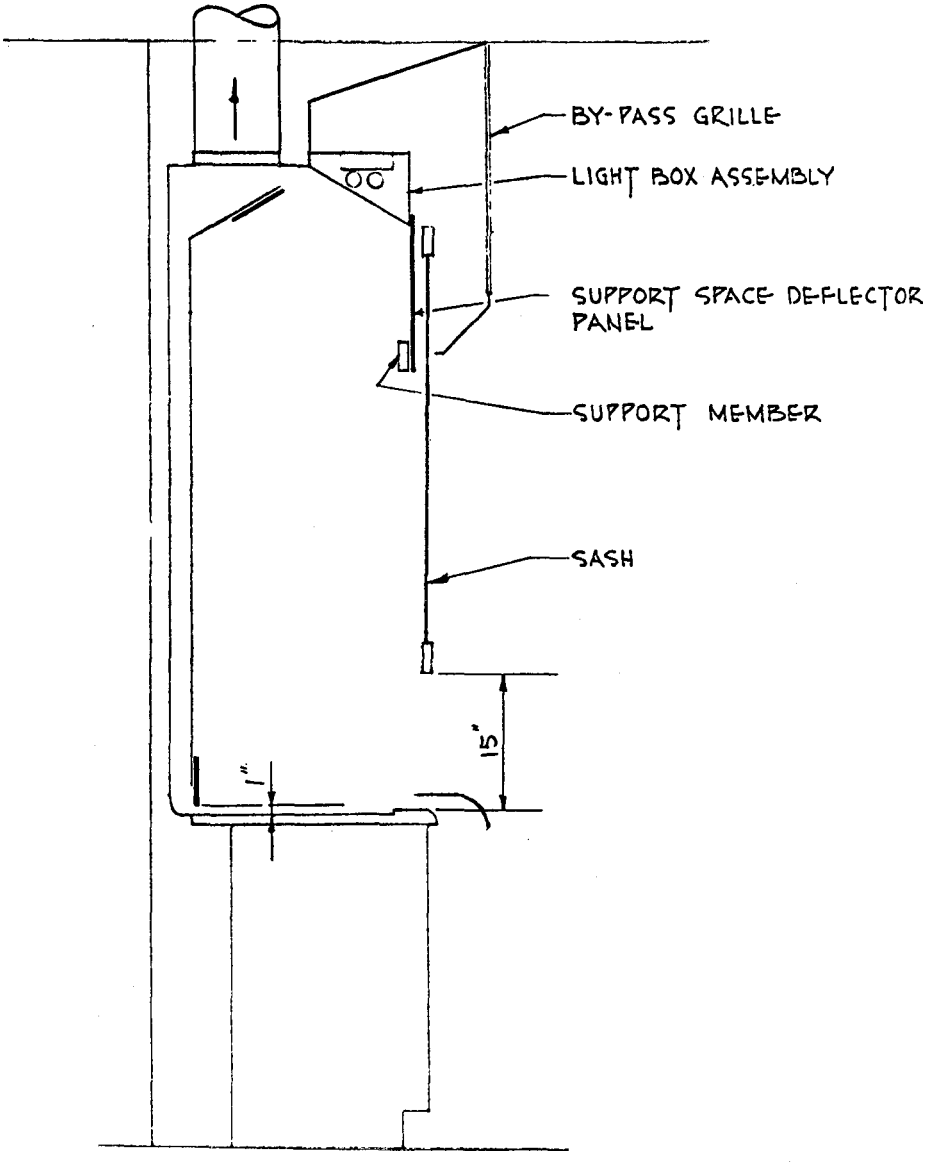
A third installation proved to be more successful. A panel was installed to totally block the bypass grille (Sketch No. 6). This panel did stop the outflow of smoke; however, it proved to have the same disadvantage as the first two panels--the function of the bypass is lost. The panel could be used as a temporary measure, providing the sash remained open; moreover, such modifications would mean some sash opening is mandatory at all times, which would negate the advantage of having the sash between work and worker.

A scraper-type panel was installed to block the crack (Sketch No. 7). Leakage was observed only where the end of the panel did not close against the side lining of the hood. A permanent panel constructed of a metal strip edged with neoprene on three sides, similar to a windshield wiper blade, would decrease the leakage. An added advantage of this panel was the increase of hood face velocity without a total flow increase. Further tests were conducted with metal and neoprene scraper-type panel at various air temperatures and hood face air velocity steps. Test procedure and detailed discussion are presented later in this report.

Excessive air turbulence was noticed near the lower corners of the fume hood face. A stream of air flowed out the opening in the face panel underneath the counter airfoil (Sketch No. 9). The fume hood exhaust fan pulls the air from the pipe chases. It flows through the space between the fume hood lining and side panels and out the face panel opening. The reversal of the air flowing out of this opening and into the face of the hood caused turbulence at the face.

Two closure plates (Sketch No. 10), one at each lower corner of the hood face, were used to block this air stream and stop the air turbulence.

A safety shield (Sketch No. 8) is another feature suitable to increase face velocity without increasing the exhaust air quantity. It consists of a panel that slides horizontally in front of the vertically moving sash. The safety shield blocks part of the face area and causes increased air velocity through



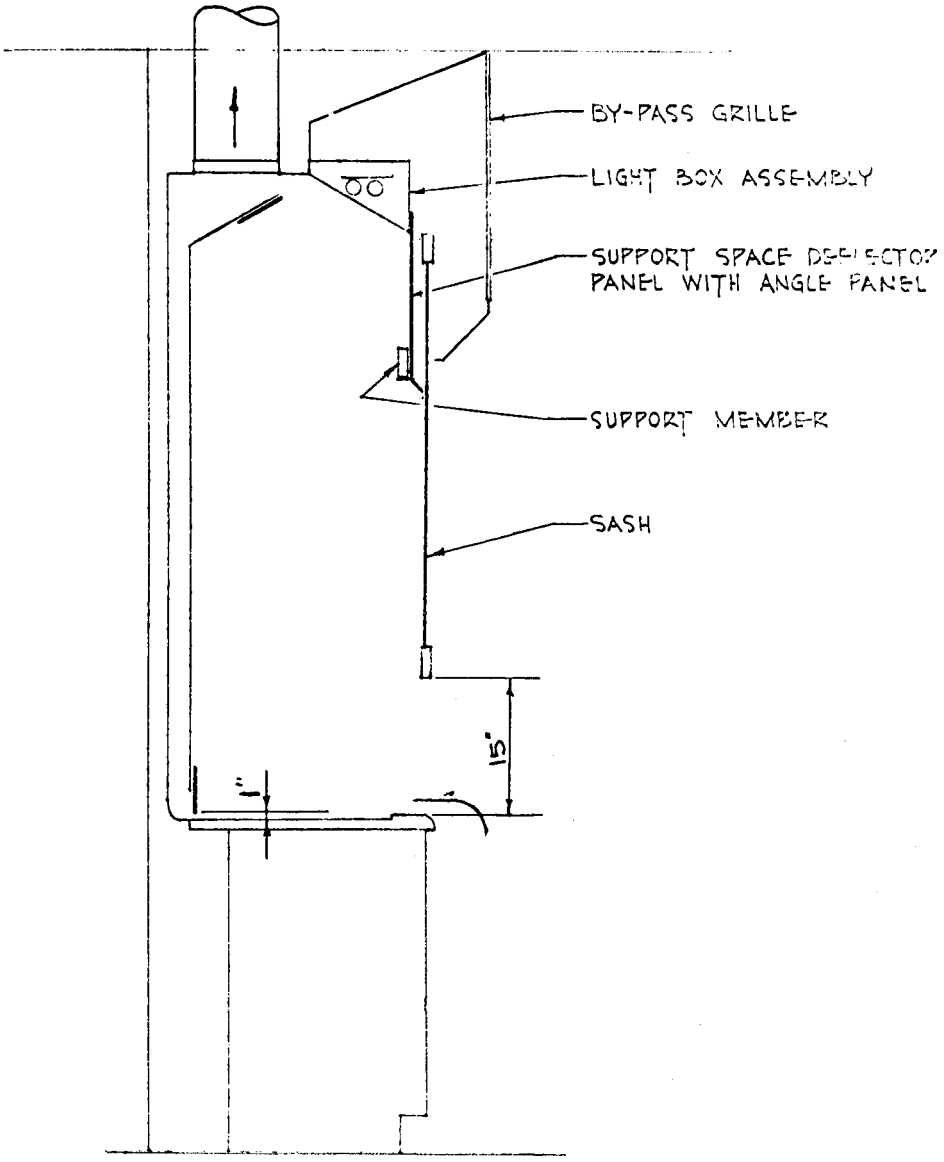
HOOD CROSS-SECTION

SHOWING SUPPORT SPACE DEFLECTOR PANEL

NO SCALE

SKETCH NO. 4

AIR HANDLING REVISIONS
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HOOD CROSS-SECTION

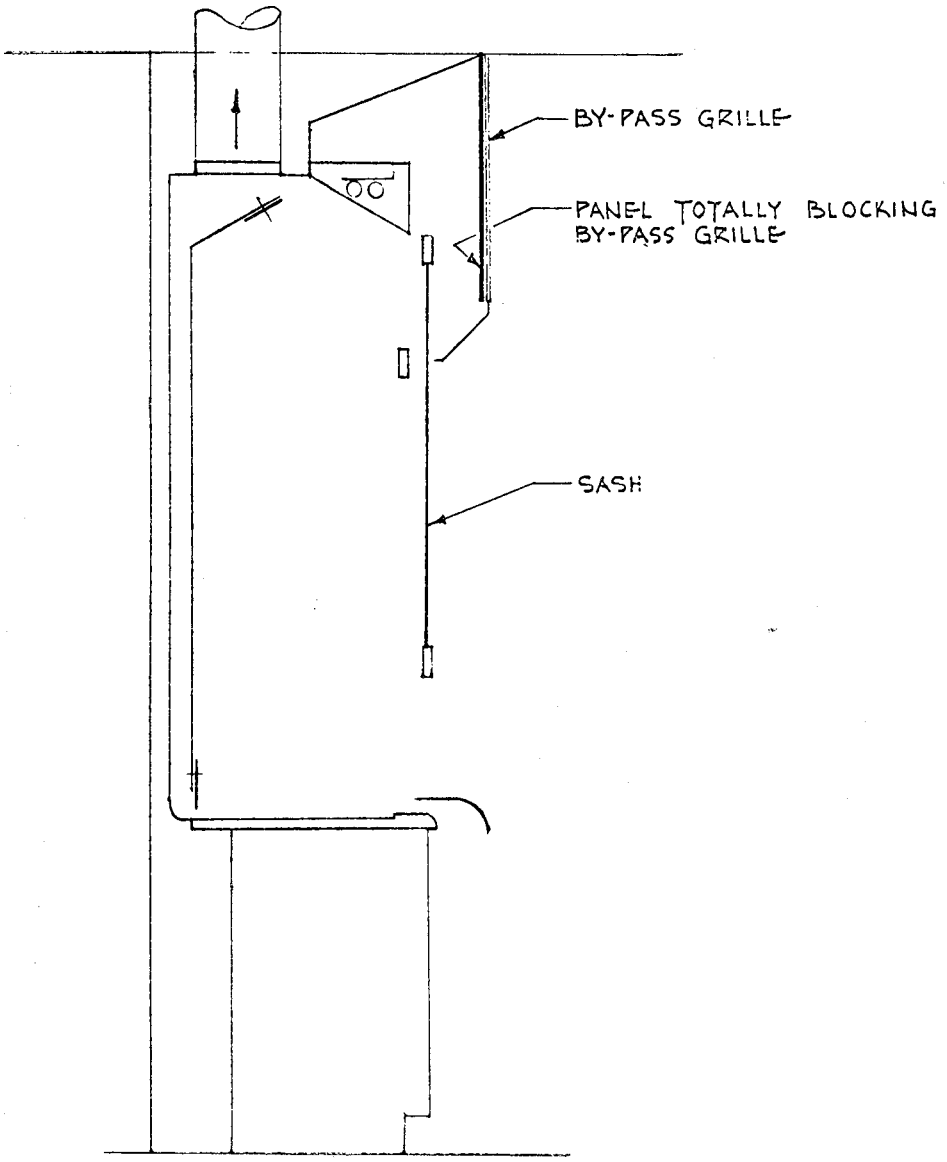
SHOWING SUPPORT SPACE DEFLECTOR PANEL WITH ANGLE ADDITION

NO SCALE

SKETCH NO. 5

AIR HANDLING REVISIONS
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HOOD CROSS-SECTION

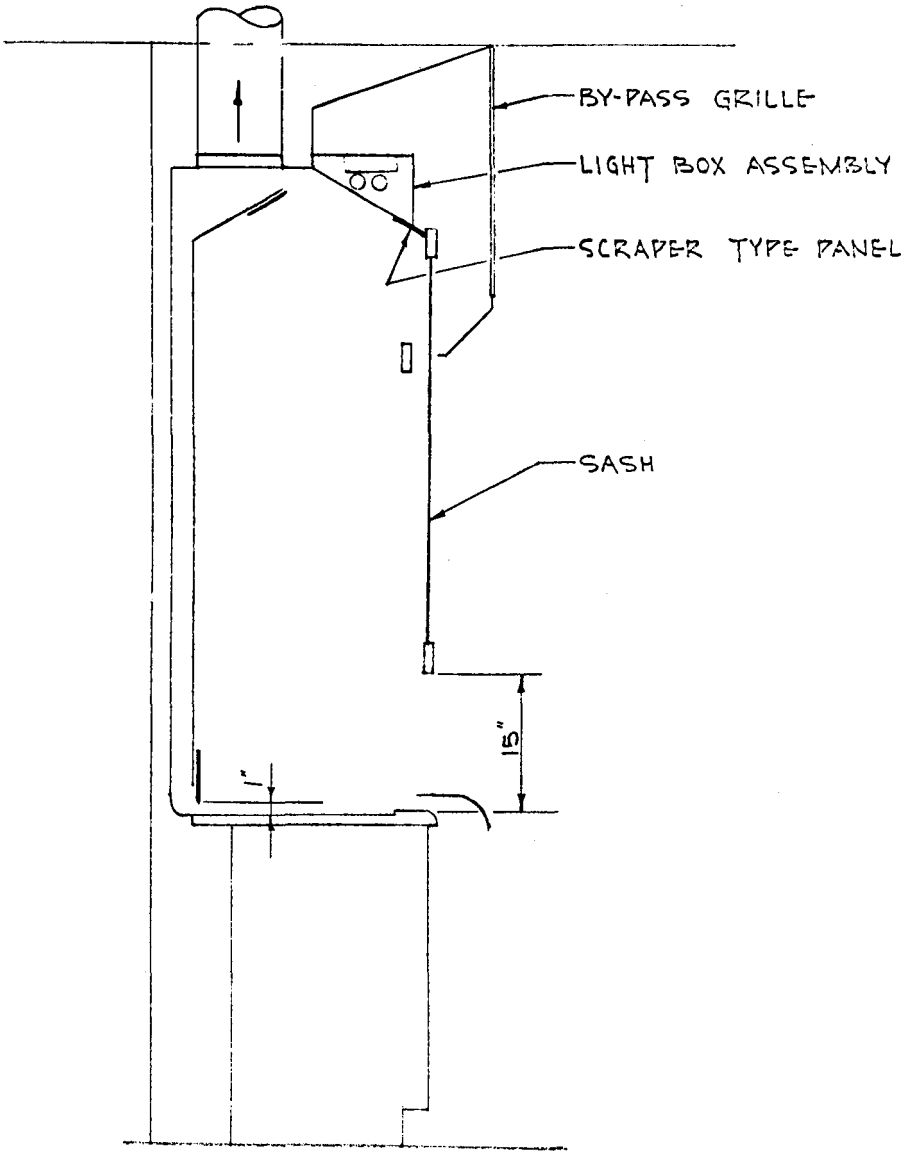
SHOWING PANEL TOTALLY BLOCKING THE BY-PASS GRILLE

NO SCALE

SKETCH NO. 6

AIR HANDLING RE-VISIONS
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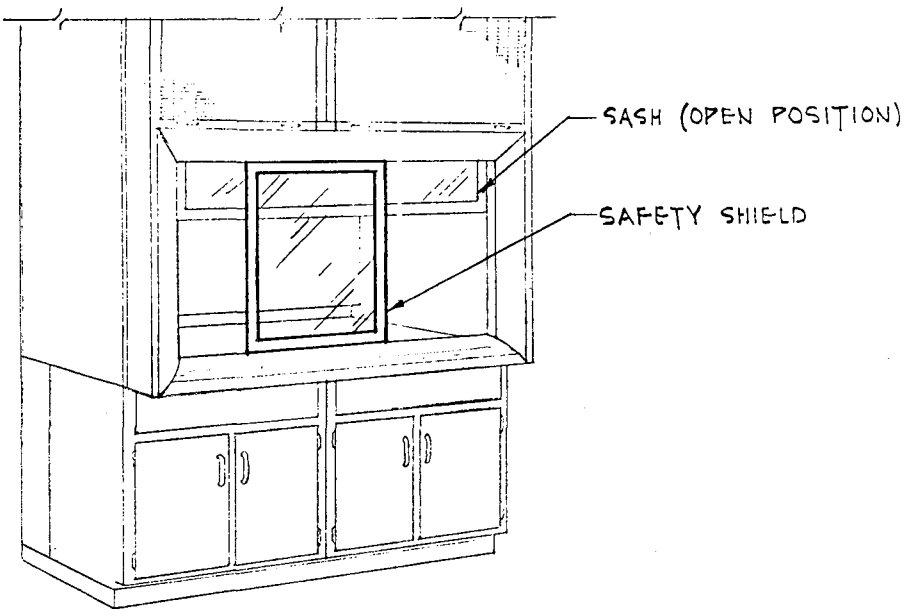


HOOD CROSS-SECTION
SHOWING SCRAPER TYPE PANEL

NO SCALE

SKETCH NO. 7
AIR HANDLING REVISIONS
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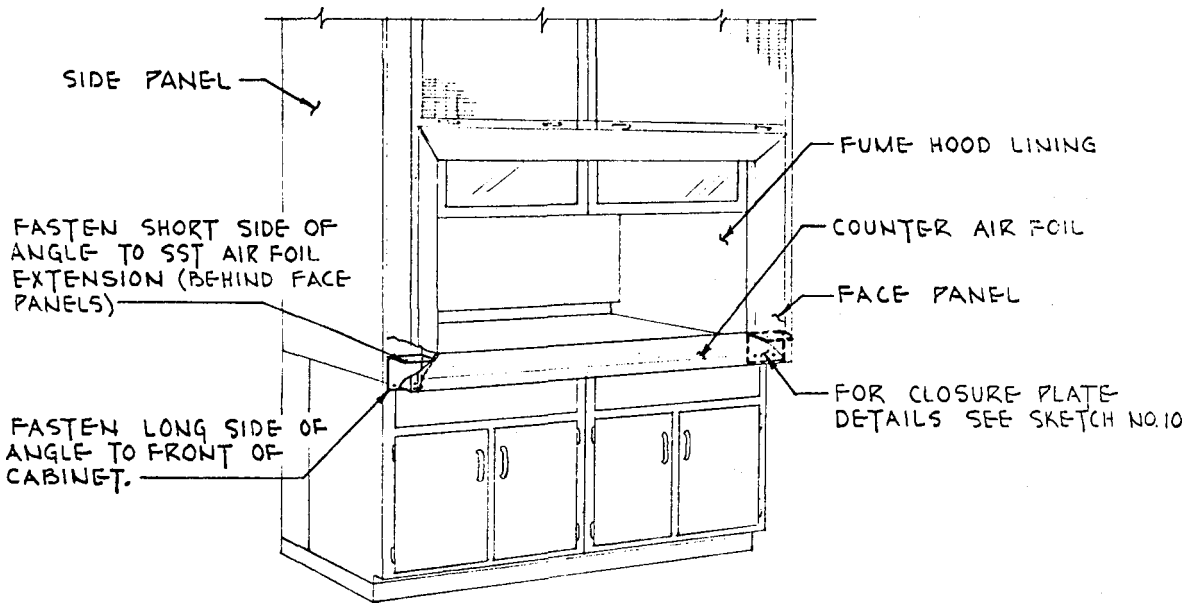


FUME HOOD WITH SAFETY SHIELD

NO SCALE

SKETCH NO. 8
AIR HANDLING REVISIONS
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8-62



TYPICAL LOCATION OF HOOD FACE PANEL CLOSURE PLATES

NO SCALE

NOTES:

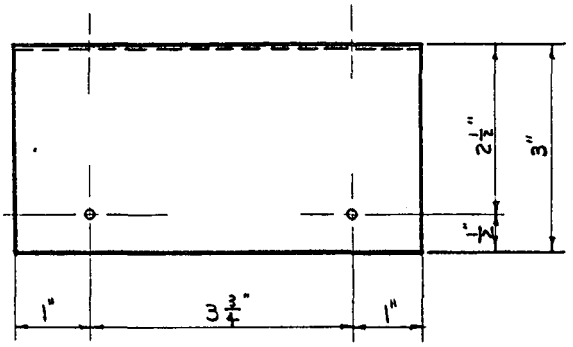
1. FASTEN CLOSURE PLATES TO HOOD WITH NO. 8, TYPE "A" SST SM SCREWS
2. CUT SLOTS IN SIDES OF CLOSURE PLATES WHERE COUNTER TOP INTERFERES WITH INSTALLATION. ALLOW MIN. CLEARANCE PROVIDING CLOSE FIT.
3. FIELD CHECK BEFORE DRILLING HOLES FOR ELECTRICAL CONDUIT, CABLE, OR JUNCTION BOXES HIDDEN BEHIND PANELS TO BE DRILLED.
4. AFTER INSTALLATION, CAULK CRACKS AROUND CLOSURE WITH AMERCOAT NO. 1043 SOFT PUTTY.

SKETCH NO. 9
AIR HANDLING REVISIONS
BLDG 4500 SOUTH
W.R. A-06455-11D
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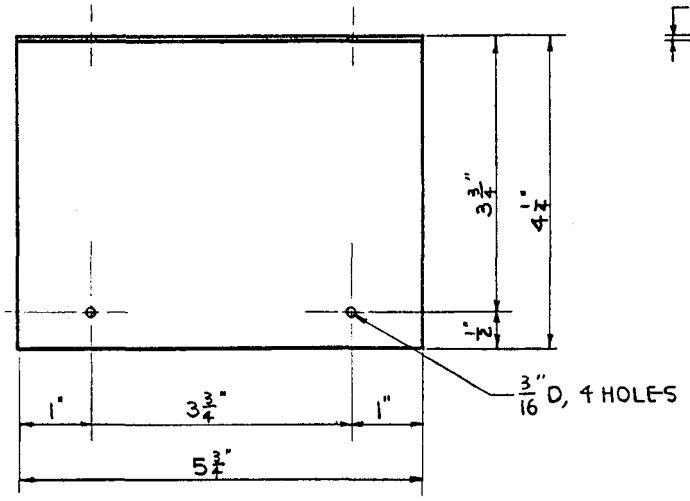
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NOTES

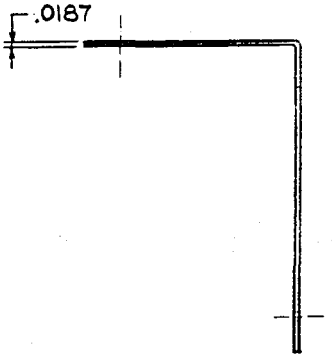
1. FABRICATE FROM 26 GA SST SHEET, TYPE 347.
2. REMOVE ALL BURRS & SHARP EDGES.
3. MODIFY IN FIELD AS REQUIRED TO FIT INTENDED LOCATION.
4. FOR INSTALLATION LOCATION SEE SKETCH NO. 9



TOP VIEW



FRONT VIEW



SIDE VIEW

CLOSURE PLATES FOR HOOD FACE PANELS

NO SCALE

SKETCH NO. 10
AIR HANDLING REVISIONS
BLDG 4500 SOUTH
WR. A-06455-11D
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the remainder of the opening. Naturally, the effectiveness of the safety shield is minimized when the bypass is open.

MAINTENANCE OF HOOD SYSTEMS

Routine maintenance of hood systems is required to assure designated hood face velocity; its maintenance involves attic filter fan operations, as well as laboratory air flow patterns. Both of these activities must be well coordinated to obtain optimum results.

It is characteristic of exhaust fans used for the fume hoods of Building 4500-South to handle a specific volume of air when at a constant speed and a set static pressure. The static pressure of an exhaust system with filtration increases as the filter loads with dirt. This increased static pressure or resistance reduces the air flow quantity unless compensations are made.

A damper is located in the filter box in order to adjust the static pressure (Sketch No. 11). When the filter is clean, the damper is partially closed to offer the resistance that dirt loading would produce. As the filter dirt load increases, the damper is opened to restore the original value of static pressure across the fan. This adjustment restores the air flow to the quantity necessary for the designated fume hood face velocity.

When the damper is fully open and the original set point of static pressure has been exceeded, the filter dirt loading causes excessive resistance. At this point the filter must be renewed to maintain designated hood face velocities. If the pressure is below the original set point at any time, the filter probably has ruptured and renewal is necessary.

Control of the air volume with the existing adjustable damper can be routinely maintained if a static pressure indicator is installed to indicate pressure created by the exhaust.

The purpose of the pressure-electric warning system is to send a signal to an alarm when an exhaust fan malfunctions. The alarm consists of a bell, horn, and red lights located in the operator's compartment in the basement of Building 4500-North. Additional red lights, one for each exhaust fan, are located in the attic of Building 4500-South.

THE EFFECT OF HEAT ON HOOD AIR FLOW

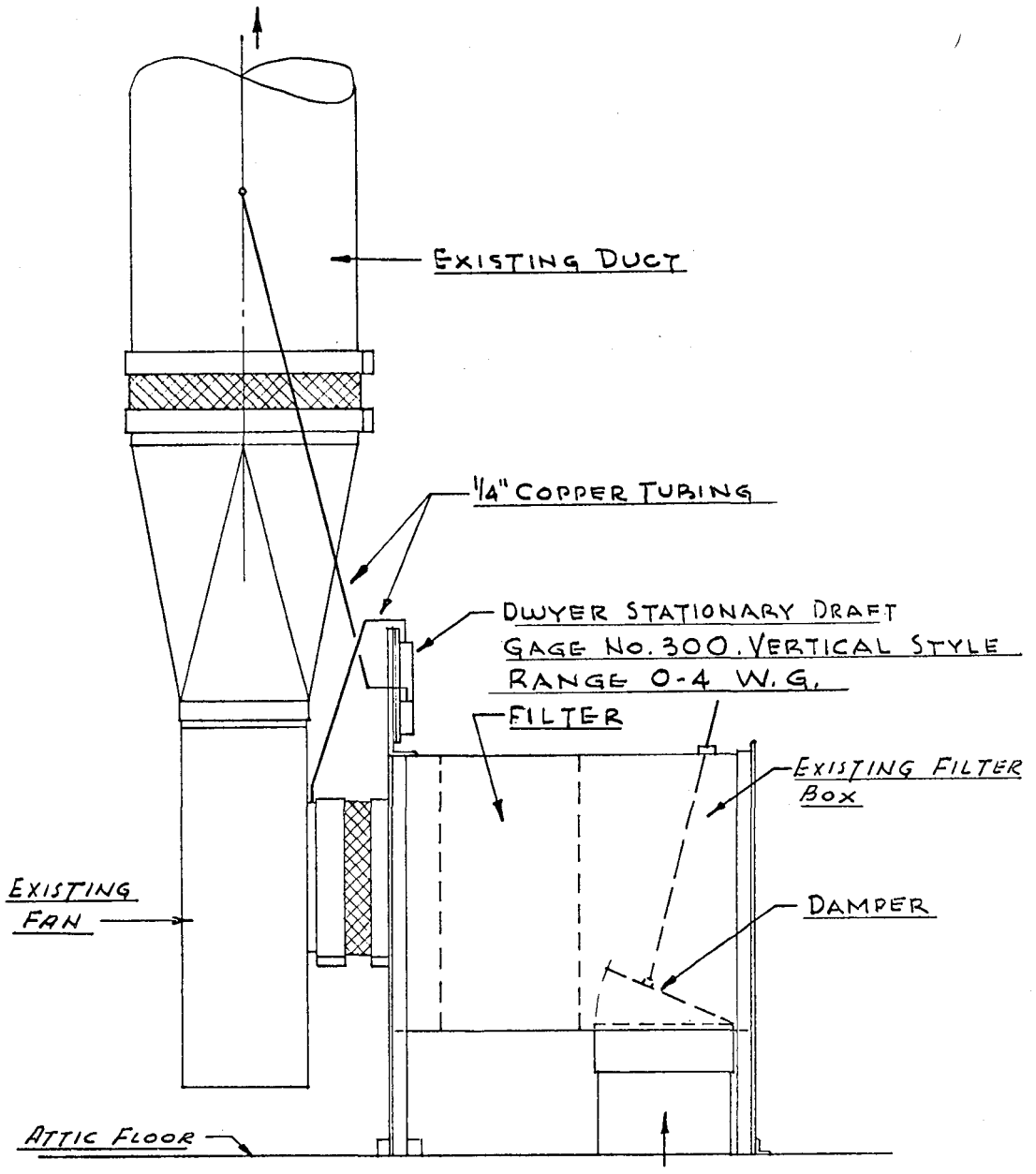
The purpose of this series of tests was to resolve how heated fumes can be contained safely in a fume hood and an exhaust system. Tests were conducted to determine the hood and ductwork modifications necessary to increase face velocity and prevent leakage of heated fumes while the hood utilizes a minimum air quantity.

Procedure

Equipment used was:

1. Fume hood - Metalab Equipment Company, Series H-200, 8-foot fume hood complete with services and exhaust system.

2. Centigrade pyrometer with four thermocouple leads of chromel-alumel (ext. res. 75 ohms); Assembly Products, Inc., SIM-PLY-TROL.



ELEVATION OF TYPICAL EXHAUST FAN

SKETCH NO. 11
AIR HANDLING REVISIONS
BLDG 4500 SOUTH
W.R. A-06455-11D
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9-62

3. Anemotherm air meter, Anemostat Corporation, Model 60.

4. Blast burners (2) complete with air and gas tubing connections, Fisher Scientific Company.

5. Smoke bombs - one minute white smoke - E. Vernon Hill & Company.

6. Container - open top, SST.

7. Centigrade thermometer.

8. Manometer - 0 to 3 inches of water scale with connecting tubing.

9. Magnehelic gage - 0 to 6 inches of water scale with connecting tubing. F. W. Dwyer Company.

10. Intercommunication system and wiring - battery-powered Monarch transistorized interphone.

11. Tachoscope - James G. Biddle Company.

12. Air pressure gage and orifice coupling.

13. Scraper-type panels.

Data recorded were:

1. Speed of fan (rpm).

2. Static pressure across fan (inches water gage).

3. Hood face velocity (fpm) of air at 15 inches or 25 inches.

4. Room temperature in degrees centigrade (°C).

5. Initial temperature inside hood at four thermocouple positions.

6. Natural gas pressure - inches of water.

7. Compressed air pressure - pounds per square inch (psi).

8. Temperature inside hood at the four thermocouple positions with heat added.

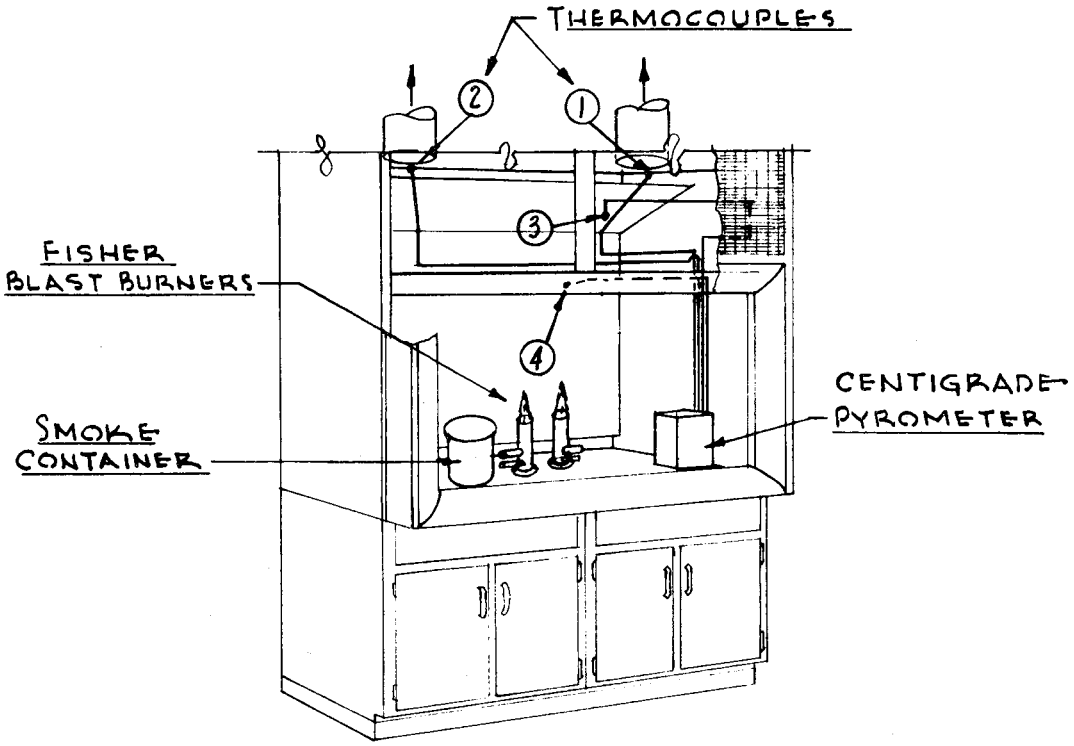
9. Visibility of smoke staying in hood or leaking out of hood.

Methods used were:

The exhaust fan serving the fume hood was set by adjusting the filter box damper to the desired air quantity. The air quantity was determined from hood face velocity readings measured with an anemotherm air meter. A nine-point traverse with the anemotherm consisted of three vertical readings at three points across the hood face.

Temperature in the room and at the four thermocouple points inside the hood were recorded. The four points, as shown in Sketch 12 and Sketch 13, were:

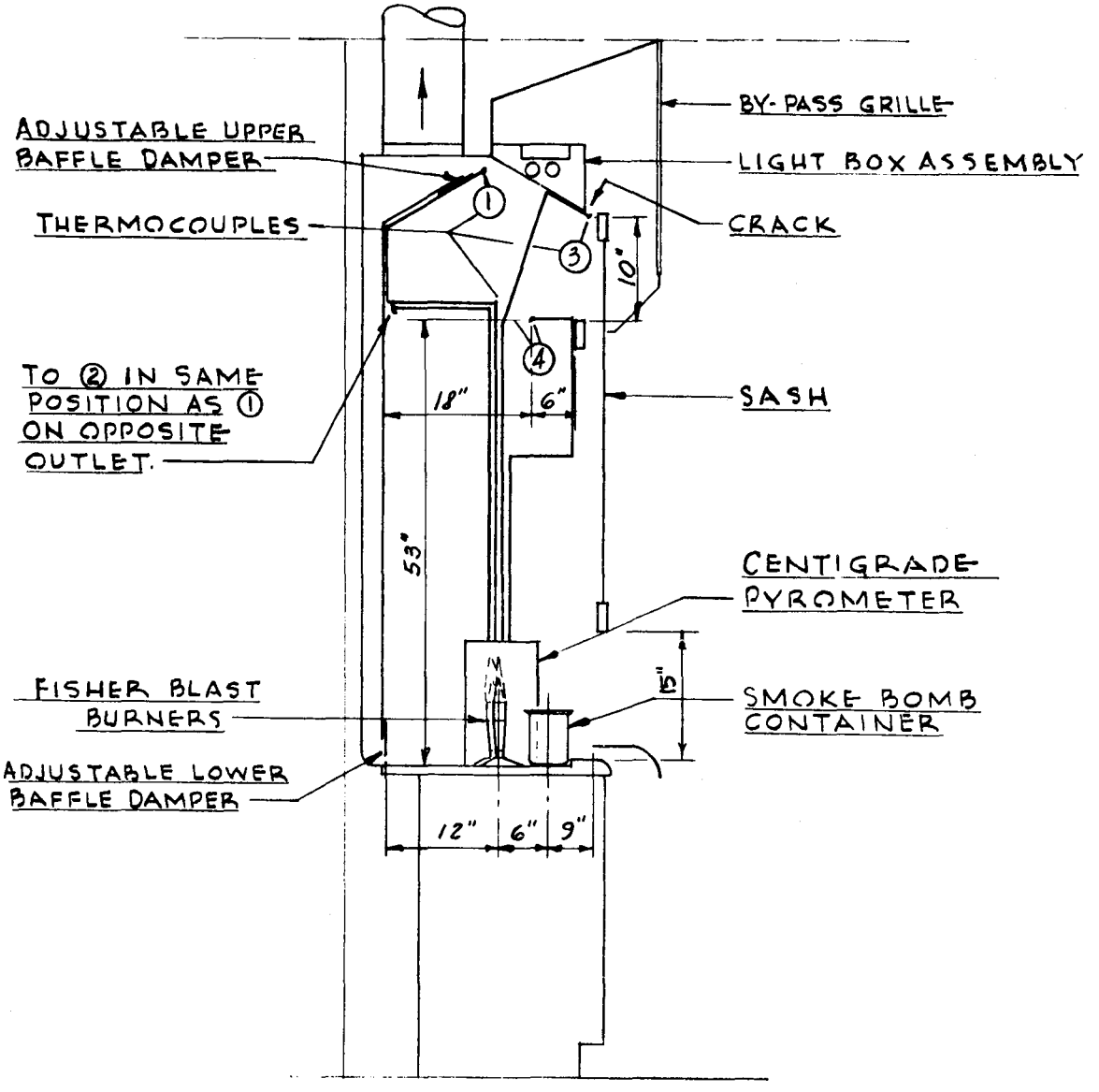
Point 1, right exhaust outlet of hood.
Point 2, left exhaust outlet of hood.
Point 3, center of hood in crack between light box assembly and sash.
Point 4, below point 3, 10 inches, and 6 inches into hood interior.



FRONT VIEW OF HOOD
SHOWING EQUIPMENT
NOT TO SCALE

METALAB EQUIP CO, H200 SERIES, 8 FT. FUME HOOD

SKETCH No. 12
HOOD AIR-FLOW STUDY
BLDG 4500 SOUTH
WR A-06926-11 D
R. H. FORDE - J. D. CLAPP



HOOD CROSS-SECTION

NOT TO SCALE

SKETCH NO 13

HOOD AIR-FLOW STUDY
BLDG-4500 SOUTH
W.R. A-06926-11D
R.H. FORDE - J.D. CLAPP

At the lower face velocities a smoke bomb was ignited in the metal open-top container. Close observation was made to detect any smoke outflow from the hood, particularly leakage through the crack between the light box assembly and the sash.

If no leakage occurred, a blast burner was ignited to add heat inside the hood. The heat output of the blast burner was standardized by installing an orifice plate in the compressed air supply. The orifice plate had an opening drilled with a No. 52 drill which was 0.0635 inches in diameter. After a ten-minute warm-up period, temperature readings were taken at each thermocouple position. The smoke test was performed, and the leakage or no leakage observation was recorded.

Temperature steps were varied until definite points of leakage or non-leakage of smoke were established.

The above procedure was followed for face velocities of 50, 75, 100, 125, 150, 175, and 200 feet per minute.

Scraper-type panels were installed in the hood to block the crack between the light box assembly and the sash. The entire test procedure was then repeated.

Effect of Air Flows and Air Pressures

Air flows and air pressures in surrounding spaces affect flow of air into a fume hood. Although each laboratory has a ducted air supply from the air-conditioning system, it is not sufficient to totally supply the exhaust system. Additional air is drawn through grilles mounted in the walls between the labs and corridors. Similar grilles are in walls between offices and corridors. Air directly supplied to offices flows from the office through grilles to the corridors, and then through grilles into the laboratories. A slight positive pressure in the offices, atmospheric pressure in the corridors, and negative pressure in the laboratories should result from this scheme of air flow.

A door opening or closing in an office, laboratory, or corridor, particularly to a stair well, causes a noticeable change in the pattern of hood face velocity. When air was flowing at points close to the velocity versus temperature curve, puffs of smoke were observed leaving the hood as the doors were used.

Air flows and pressures in service pipe chases between labs and under benches contribute to unstable air patterns of hood face velocity. The pipe chases have a direct air path to the attic through openings such as around piping, conduit, and ductwork. When one of the large attic exhaust fans switches on or off, the resultant change of air flow and air pressure is transmitted through the pipe chases to the laboratories. This contributes to the possibility of a puff of fume leakage from the hood.

Supply Air System to Laboratories

As formerly mentioned, a duct system directly supplies air to the laboratories. If the fan that moves air in this system cuts off, a change in the hood face velocity in both quantity and pattern takes place immediately. In the past, the fan has been cut off for emergency maintenance, automatic low temperature cut-off from steam failure, and electrical interruption. A fan shutdown, occurring twice during this experiment, was indicated as a change in air flow by an instant rise in pyrometer temperature readings.

If a heat source is being used in a fume hood, the temperature rise due to a decrease in air flow can cause fume leakage if the resultant temperature-velocity point is above the curve (see Curves 1 and 2).

As a safety measure, upon an interruption to the building air supply system, users of the fume hood must be cautioned to immediately close the hood sash. Heat must be turned off and preparations must be made to evacuate the laboratory.

Location of Hood in Laboratory

The location of a fume hood in the laboratory has a decided effect on the air face velocity pattern. The majority of hoods in 4500-South are located at right angles to the supply air stream from sidewall registers. The velocity of air passing the sash opening can create eddy currents that will spin fumes out of the hood.

Sidewall registers and ceiling diffusers supply air to the laboratory containing the experimental hood. At a low face velocity, under 100 fpm and particularly in the 50 to 75 fpm range, with the sash at the 15-inch position, disturbance caused by a passing air velocity can create a leakage of fumes from the hood--smoke in this case.

The hood is located with the left side against the rear wall of the laboratory. This position contributed to a decrease in the air velocity on the side of the hood face next to the wall.

Exhaust Ductwork

Exhaust ductwork leaving the hood caused an uneven pattern in the hood face air velocity. An attempt was made to increase the air quantity by increasing the fan speed. An increase in static pressure across the fan resulted, but the air velocity did not appreciably increase.

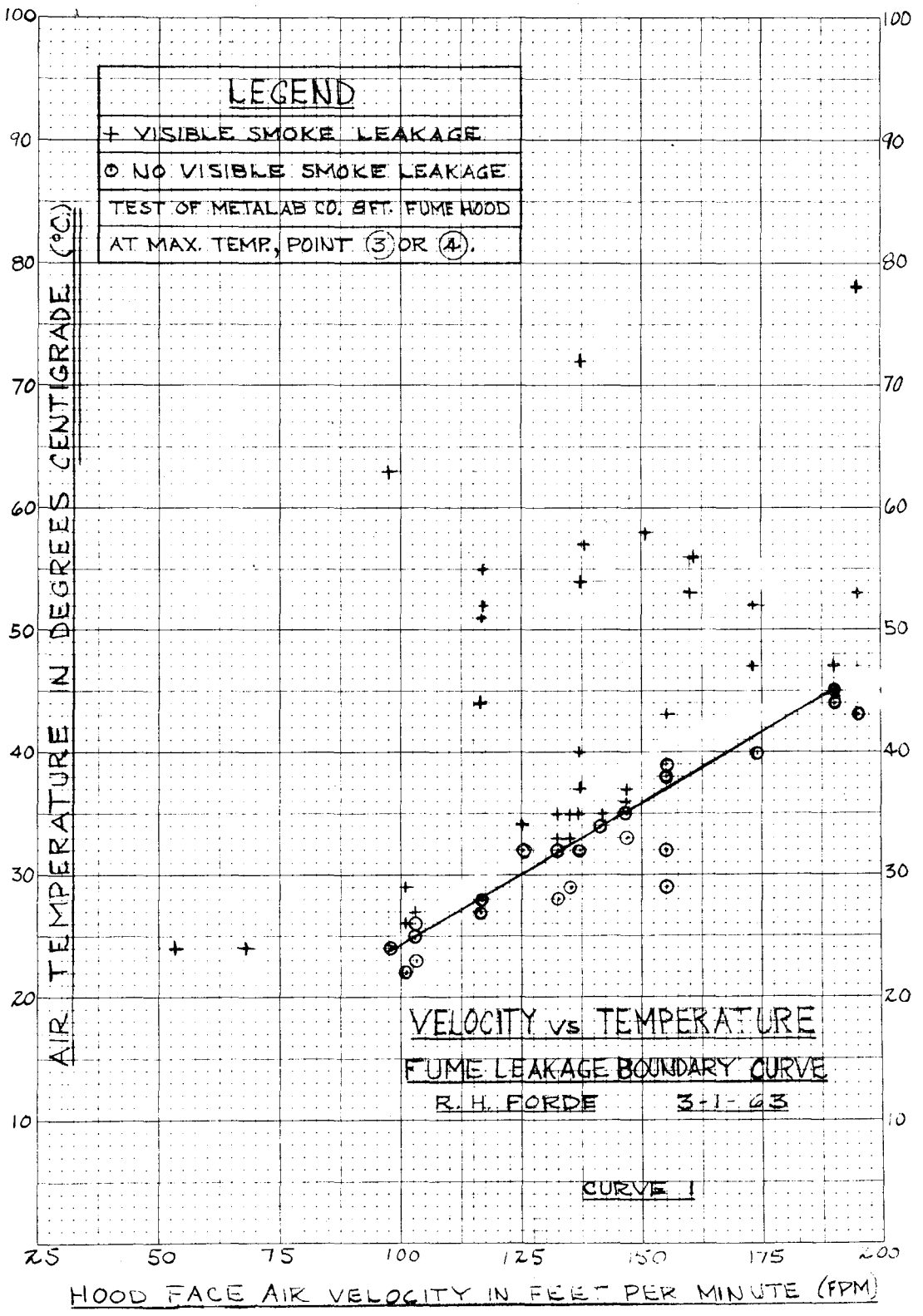
Above the laboratory ceiling near the top of the fume hood an inferior duct installation was discovered. The main exhaust duct had been connected at an angle to a cross header between the two hood exhaust outlets (see Sketch No. 14). The header created a direct collision between two air streams, and the angle connection caused a turbulence near the ductwork intersection. Both conditions caused a resistance that amplified to such an extent that very little increase in flow occurred as fan speed was increased.

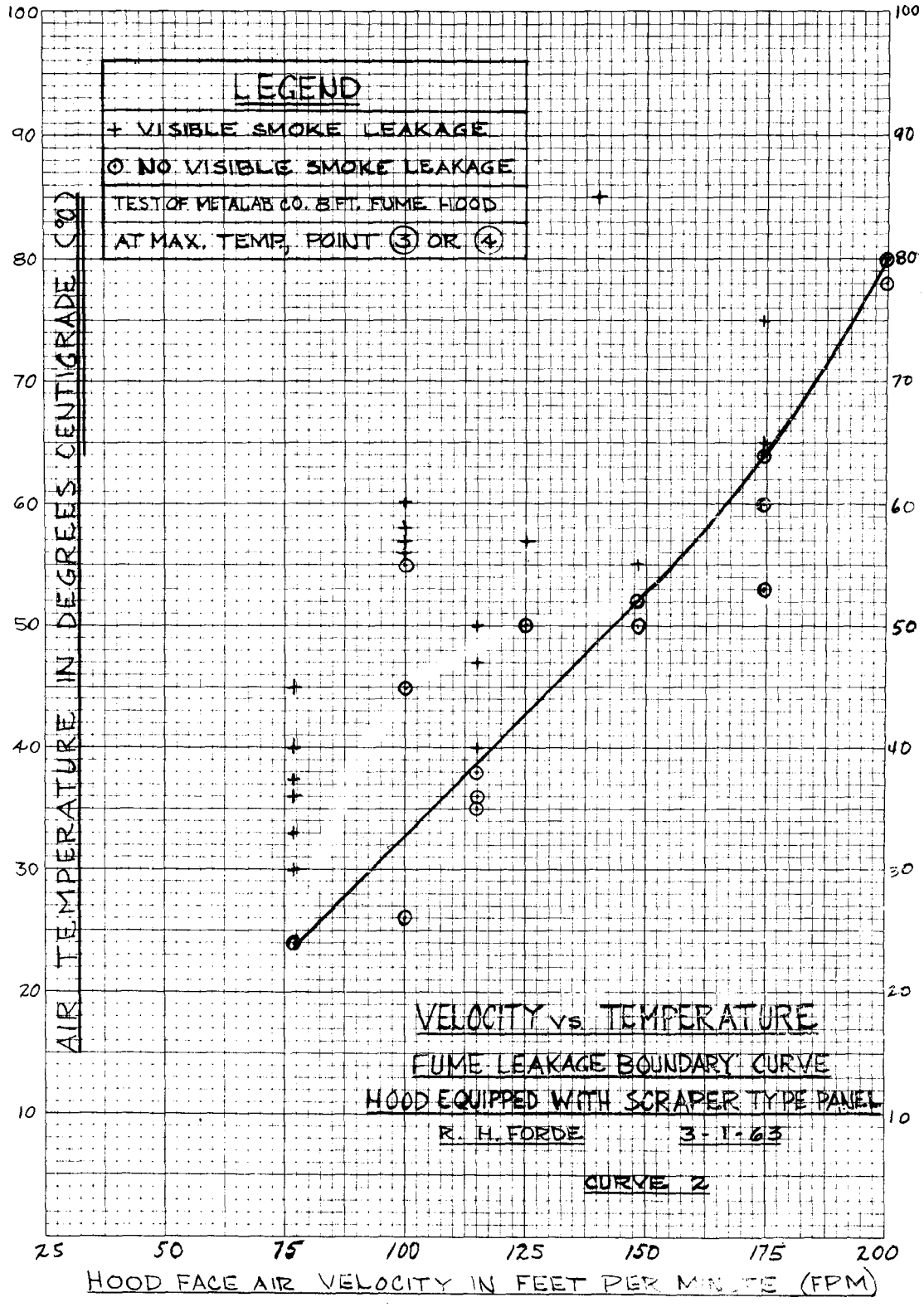
The header connection was replaced with a Y-type connection which reduced the resistance and removed its amplification. Sketch No. 14 shows a recommended ductwork alteration to replace header-type connections on other fume hoods in the building.

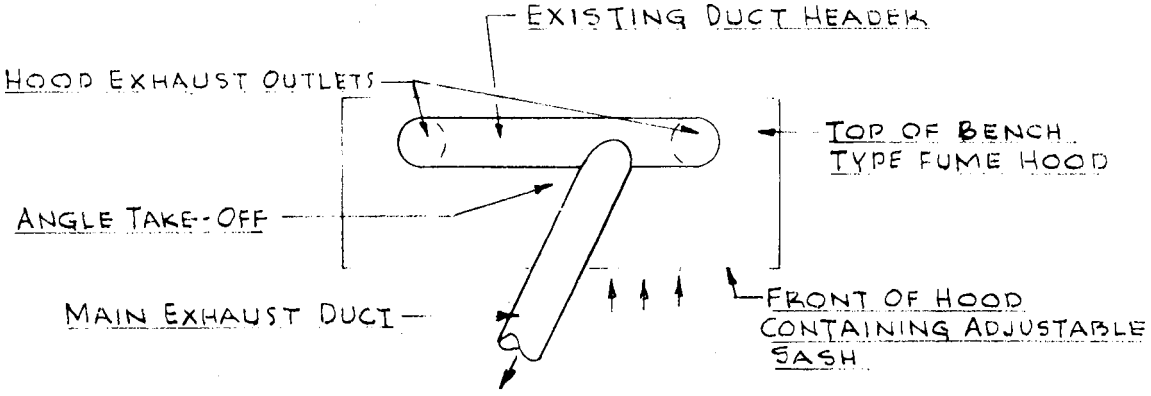
Exhaust Fan and Filter Installation

The exhaust fan is the most mechanically complicated part of the exhaust system. Variable forces are converted to a mechanical reaction at this point. Pressure indication, control devices, and maintenance operations must be concentrated in close propinquity.

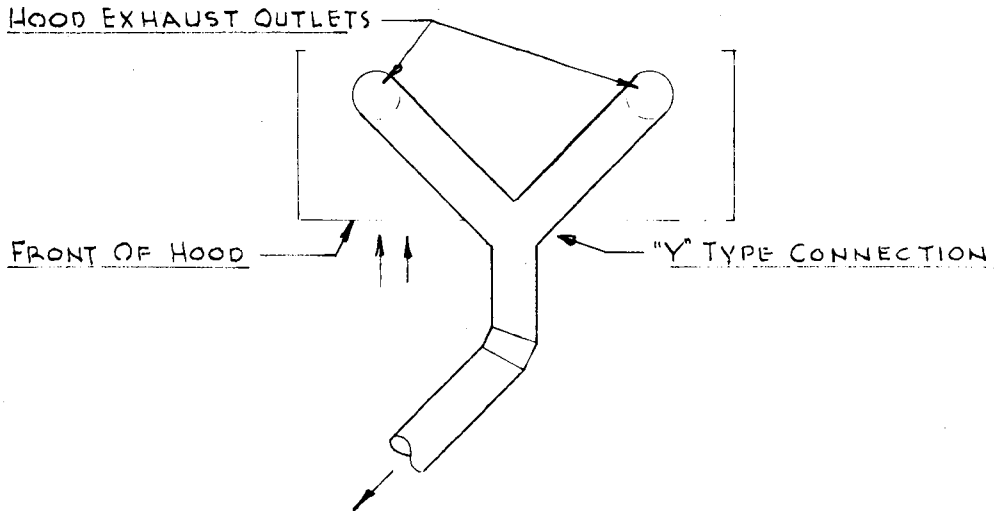
A manometer was placed in view for operating the control damper in the filter box. The manometer sensing tubes were inserted, one each, in the fan suction duct and in the fan discharge ductwork. A magnehelic gage tied into the same tubes was located in the laboratory three floors below the attic fan deck. The


LEGEND
+ VISIBLE SMOKE LEAKAGE
⊙ NO VISIBLE SMOKE LEAKAGE
TEST OF METALAB CO. 8FT. FUME HOOD
AT MAX. TEMP., POINT ③ OR ④.
AIR TEMPERATURE IN DEGREES CENTIGRADE (°C.)
100
90
80
70
60
50
40
30
20
10
25
50
75
100
125
150
175
200
VELOCITY vs TEMPERATURE
FUME LEAKAGE BOUNDARY CURVE
R. H. FORDE 3-1-63
CURVE 1
HOOD FACE AIR VELOCITY IN FEET PER MINUTE (FPM)


LEGEND
+ VISIBLE SMOKE LEAKAGE
⊙ NO VISIBLE SMOKE LEAKAGE
TEST OF METALAB CO. 8 FT. FUME HOOD
AT MAX. TEMP. POINT ③ OR ④
AIR TEMPERATURE IN DEGREES CENTIGRADE (°C)
100
90
80
70
60
50
40
30
20
10
25
50
75
100
125
150
175
200
HOOD FACE AIR VELOCITY IN FEET PER MINUTE (FPM)
VELOCITY vs. TEMPERATURE
FUME LEAKAGE BOUNDARY CURVE
HOOD EQUIPPED WITH SCRAPER TYPE PANEL
R. H. FORDE 3-1-63
CURVE 2



PLAN OF EXISTING HOOD EXHAUST DUCTWORK - NOT TO SCALE



PLAN OF RECOMENDED ALTERATION TO HOOD EXHAUST DUCTWORK NOT TO SCALE

SKETCH NO. 14
HOOD AIR FLOW STUDY
BLDG 4500 SOUTH
W.R. A-06926-WD
R.H. FORDE - J.D. CLAPP

intercommunications equipment provided oral contact between the man operating the control damper and the man determining the air quantity.

Removal of the high efficiency filter increased the control range of the damper. The air quantity of the exhaust fan increased to near 2000 cfm which produced a 200 fpm hood face velocity.

A higher horsepower motor and larger filter box are required if the face velocity of a fume hood, equipped with a scraper-type panel, is increased over 125 fpm. A hood face velocity of 125 fpm, with the sash at the 15-inch open position, represents an air quantity of 1100 cubic feet per minute.

The rated flow of a 24-inch-by-24-inch-by-12-inch high efficiency filter is 1100 cfm with a resistance, without dirt loading, of about 1.0 inch water gage. Any substantial increase of air quantity above 1100 to 2200 cfm must have an additional filter to reduce the initial resistance and allow reserve resistance for the dirt loading.

Since installation of a new larger duct would be difficult in most cases, the air velocity must be increased through the existing ductwork for a greater air quantity. A higher velocity in the duct increases the resistance to air flow. With both a greater air quantity and larger resistance, an electric motor with more horsepower will be required.

When the increased power demands of the exhaust fan to move the larger air quantities are satisfied, an increase in exhaust fan speed is required. Any increase in fan speed must be accompanied by amperage measurements to determine if a larger motor is necessary to maintain service.

Building Exterior Conditions

Exterior conditions, such as wind, atmospheric pressure, and temperature, affected the hood face velocity measurements. On gusty days the wind varied the discharge static pressure of the exhaust fan which caused slight fluctuations in velocity measurements.

A small increase in face velocity should be made to allow for any atmospheric pressure changes until the building air systems are balanced.

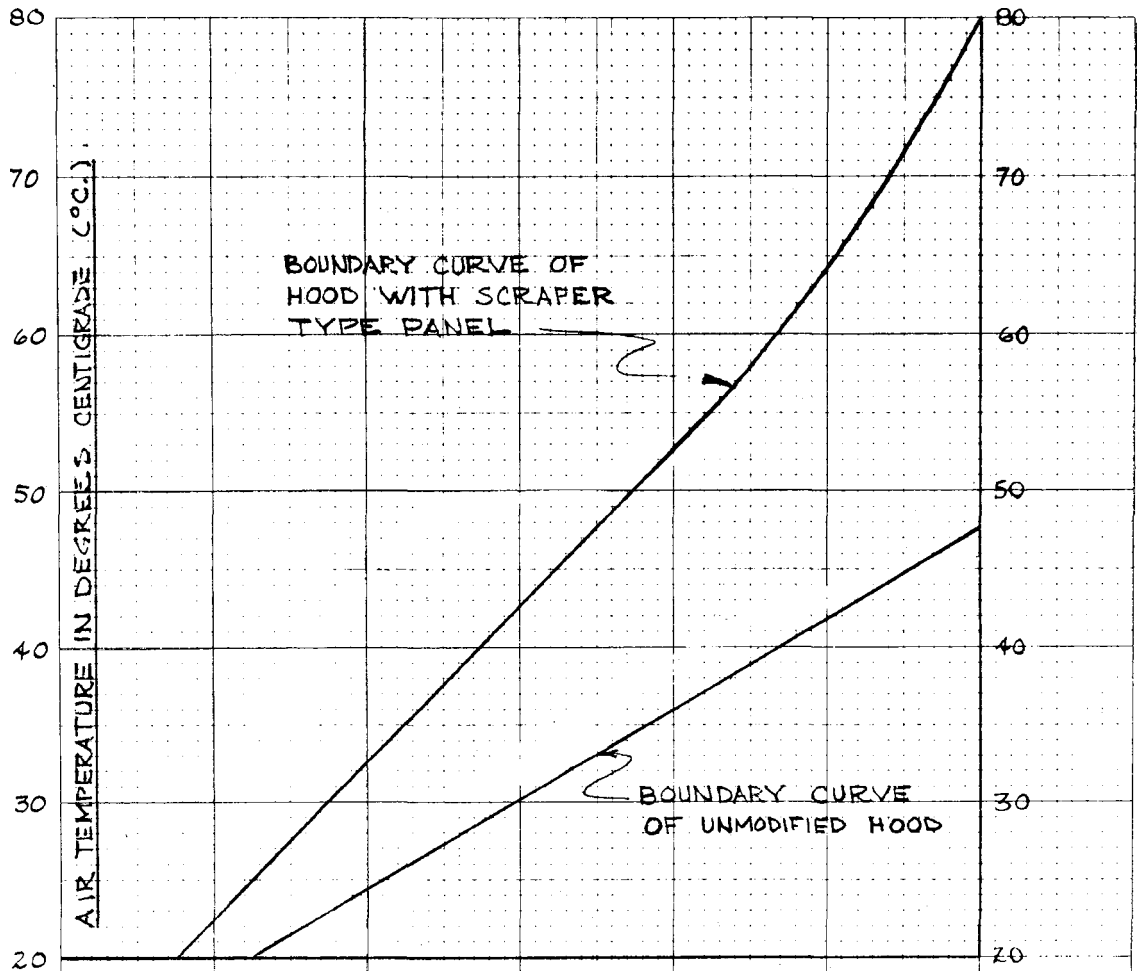
An air temperature below 40 degrees can cause a supply fan shutdown if there is an interruption in the air preheat system. Because a major decrease in face velocity occurs, the precautions stated before must be made.

Modified Hood

Tests were conducted on the hood equipped with scraper-type panels as described earlier in this report. As compared with the unmodified hood, the advantages are:

1. The scraper-type panel installation caused an increase in the hood face velocity of approximately 10 per cent. This increase of velocity was due to the same quantity of air being drawn through an area reduced by over 10 per cent at a 15-inch sash opening.

2. The hood equipped with the panels contained air, with no observed leakage, at temperatures 14 to 18 degrees Centigrade or 25 to 35 degrees Fahrenheit greater than the unmodified hood in the 100- to 175-foot-per-minute hood face velocity range (see Curve 3).



VELOCITY VS TEMPERATURE FUME LEAKAGE BOUNDARY CURVE COMPARISON OF UNMODIFIED HOOD AND HOOD WITH SCRAPER TYPE PANEL.

CURVE 3

R. H. FORDE, 3-5-63

3. With two blast burners at maximum heat, no leakage was observed at 200 fpm hood face velocity (15-inch sash opening) in the hood equipped with the scraper-type panel.

Velocity Measurements

In hood face velocity measurements taken with the anemotherm air meter, it was found that the reading taken in the center of the sash opening, vertically and horizontally, was the closest to average velocity. The variation of high velocity on the right and of low velocity on the left were, to a large extent, due to the hood location near the wall. Highest readings always were at the top of the open sash space and the lowest readings at the bottom. This pattern could be altered by changing the position of the baffle dampers inside the hood. (See Sketch No. 2)

Analysis of Curves

General

Three velocity versus temperature fume leakage boundary curves are presented with this report. Curve 1 shows the results of the test of an unmodified Metalab Company 8-foot bench-type fume hood. Curve 2 shows test results of the same fume hood modified by an addition of a scraper-type panel. Curve 3 is a comparison of Curve 1 and Curve 2.

On Curves 1 and 2 the plus symbol designates the velocity-temperature points at which smoke leakage was visible. In every case of leakage, smoke left the upper hood enclosure through the crack between the sash and the light box assembly. The circle symbol represents the velocity-temperature points where no smoke leakage was visible.

The abscissa of the curves represents hood face velocity. This air velocity was an average of a nine-point traverse consisting of three vertical and three horizontal measurements taken in the vertical plane of the sash opening.

The ordinate of the curves is air temperature in Centigrade degrees at the maximum reading of the thermocouples in the four positions shown in Sketches No. 12 and No. 13. Thermocouples three or four always sensed the highest temperature, but thermocouples one and two sensed a closer approximation of the temperature of the air leaving the hood through the exhaust ductwork.

Heat quantities cannot be accurately calculated from the temperature measurements because, although total airflow is known, airflow from each exhaust port is not known. A large unknown percentage of the air flows through the lower baffle damper opening (see Sketch No. 2).

Curve 1

Curve 1 is the fume leakage boundary curve of an unmodified fume hood. This curve resembles a 30-degree line from horizontal when the ordinate increases in temperature 2 degrees Centigrade for every 5-foot-per-minute velocity increase of the abscissa.

Four points of no visible smoke leakage are located above the fume leakage boundary curve. The actual curve would have an irregular appearance if these points were included on the line. The irregularity can be caused by variables affecting fume hood air flow. Since the observed points were within 2 degrees Centigrade of uniformity, a straight line was selected to represent the recommended fume leakage boundary curve.

Curve 2

Curve 2 is the fume leakage boundary curve of a fume hood modified by the addition of a scraper-type panel. This curve resembles a 45-degree line from horizontal under the same conditions as Curve 1.

The efficiency of the scraper-type panel can be increased by a careful field fit of the neoprene wiper blade. The blade ends can be cut to fit closely into the irregular shapes created by cable and sash channels. This high efficiency was illustrated by points of no visible smoke leakage high above the boundary curve at velocities of 100 fpm and 125 fpm. These points were obtained by taping blotting paper at the end of the blade to conform to the shape of the irregular channels.

A loosely fitted blade, without blotting paper, produced the points (at 75 fpm, 115 fpm, 150 fpm, 175 fpm, and 200 fpm) that were used to define the boundary curve.

At a velocity of 200 fpm, the heat generated by two Fisher blast burners at maximum capacity did not produce visible smoke leakage. The maximum capacity of the blast burners was acquired with the following conditions: gas control valve full open with a line pressure of 13.5 inches of water, air control valve full open with a line pressure of 12.5 psi, and a No. 52 drill size orifice in the compressed air line.

Curve 3

Curve 3 indicates a comparison in fume leakage boundary curves between a hood that is unmodified and a hood that is equipped with scraper-type panels. The area between the curves illustrates the improvement gained from the addition of the scraper-type panels.

The Use of Activated Charcoal Iodine Monitors During and Following a Release of Fission Product Iodines*

Charles F. Foelix and L. Gemmell
Health Physics Division
Brookhaven National Laboratory

Description of Monitoring System

The present core of the Brookhaven Graphite Reactor consists of some 4900 highly enriched uranium fuel elements loaded in 615 horizontal fuel channels passing through a 25 foot cube of graphite moderator and reflector. The core is divided into two halves (north and south) by an 8 cm. wide vertical gap in the center of the graphite (Figure 1). The cooling air enters the reactor through inlet filters, at the rate of 270,000 CFM, passes into the central gap and flows bi-directionally through the north and south halves of the core. It then enters the collecting plenums and flows into the north and south ducts. The air is first monitored by the north and south exit air monitors located within the pile building. These are moving filter tape monitors with beta scintillation detectors. They are essentially operational monitors and are maintained by reactor operations. The air then passes through the exit air filters, heat exchanger, venturi and on to the fan house where the north and south ducts join. After the fan house the air is monitored for Argon-41 by a Kanne ion chamber system. Just before the air enters the base of the stack, the air is monitored for particulate activity and Iodine-131. The Health Physics Division maintains and operates these systems. The particulate monitor consists of a moving filter tape with a beta scintillation detector and is calibrated to measure the rate of release of particulate activity.

* Work done under the auspices of the Atomic Energy Commission

COOLING AIR SYSTEM
BROOKHAVEN PILE

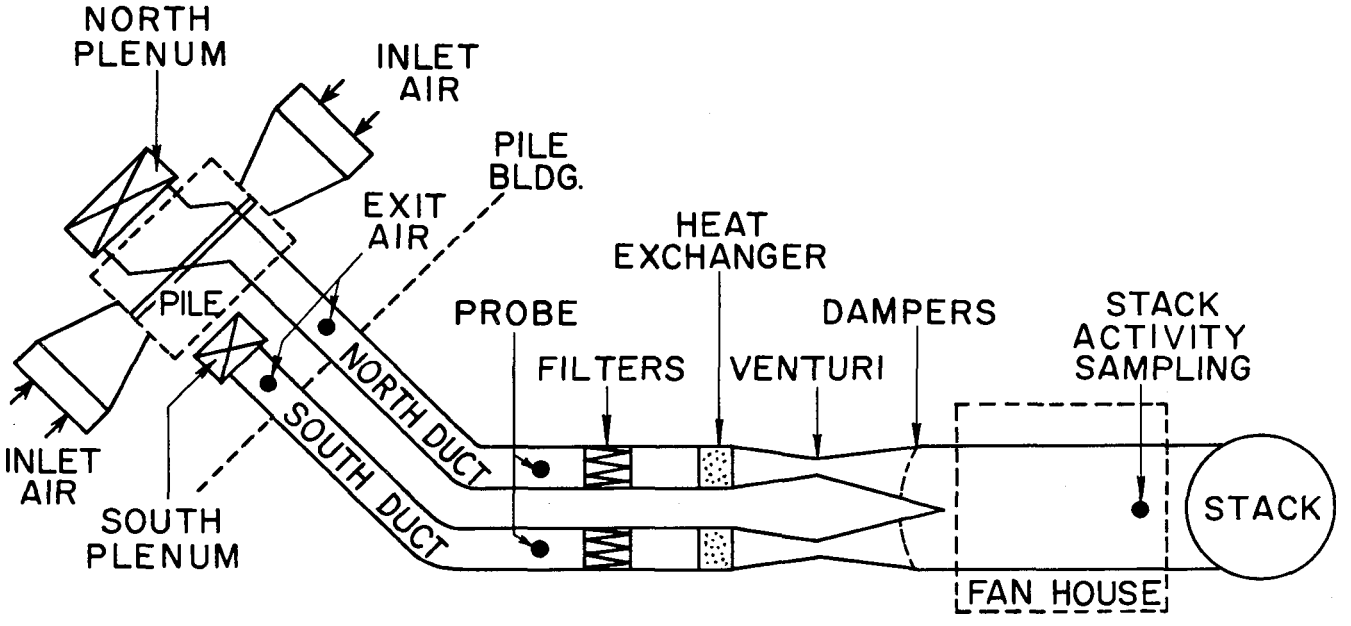


Figure 1

The release of I^{131} is monitored by continuously passing a measured volume of effluent air through a high efficiency filter and an activated charcoal trap[1] in series (Figure 2). The filter and trap are normally changed at 2 or 3 day intervals. The quantity of I^{131} on the filter and trap is determined by counting in a calibrated gamma spectrometer after sufficient time has elapsed to permit the decay of the shorter lived iodines. All necessary decay and sampling efficiency corrections are made and the total stack release of I^{131} is computed. This system of I^{131} monitoring was originally intended as an inventory monitor to accurately measure the total release of I^{131} but was not intended to act as an operational monitor.

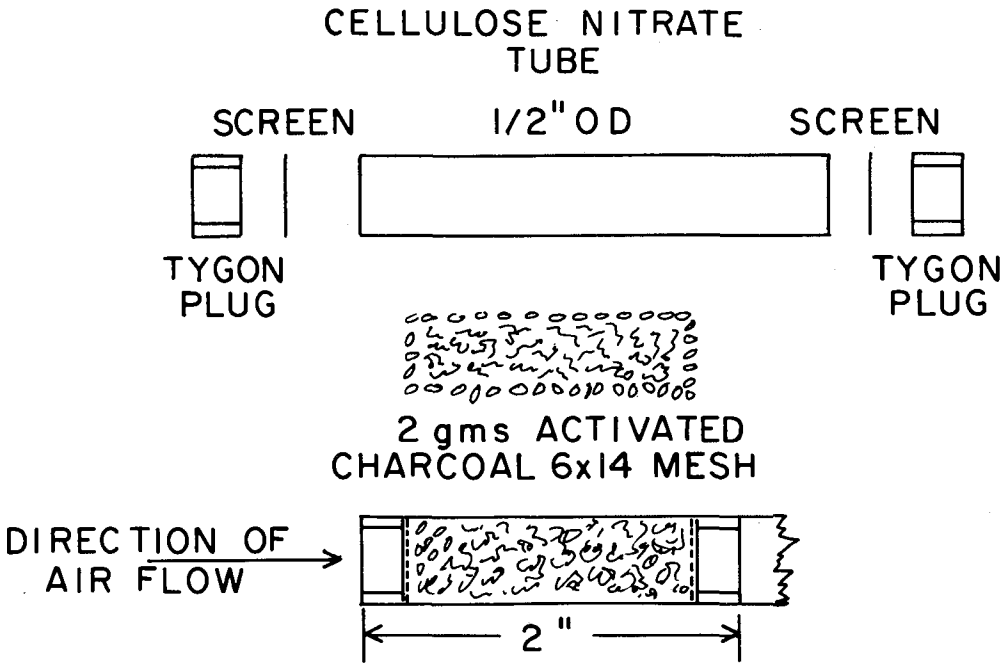
Releases of Radioactivity

During a two-day period in September of 1962 there were three distinct short term releases of activity which were the result of a partial cladding failure on one of the 6800 fuel elements. Although these releases were not of serious proportions, they did provide valuable experience in the area of reactor effluent monitoring under emergency conditions.

The three releases were characterized as follows on the operational monitors:

1. The north duct particulate monitor showed a peak which in itself was not large enough to cause concern except that there was no similar peak on the south duct monitor. When both monitors show a peak the presumption is that some material in the cooling air has been activated. The classic example is a vehicle or stationary engine operating near the air intakes and the exhaust fumes being sucked into the reactor. When only one duct monitor shows a peak it indicates that activity has been released in that half of the reactor.

2. The Kanne chamber monitor responded promptly to a full scale reading and returned to normal which indicated a short, concentrated



ACTIVATED CHARCOAL TRAP — FITS IN 5/8" NaI WELL CRYSTAL WITH COPPER LINER OR IN JIG FOR COUNTING WITH 3x3 NaI CRYSTAL

ACTIVATED CHARCOAL TRAP

Figure 2

release of gaseous activity.

3. The particulate monitor at the base of the stack showed a peak of modest proportions which again would not in itself be cause for alarm.

The first release occurred at 2100 hours on September 10, 1962. At 0845 the next morning the charcoal trap was taken from the sample line and placed in the gamma spectrometer within ten minutes after removal. It was immediately apparent from the display of the gamma spectrum on the 'scope of the analyzer that a release of equilibrium fission product iodines had occurred. The 0.365 MeV photo-electric peak of I^{131} was prominent and almost as large as the 0.53 MeV peak from I^{133}. Normally the I^{131} peak is almost entirely masked out and much smaller than the I^{133} peak. Under normal conditions the reactor will release about 8 mc of I^{131} per day. It was calculated that the first release totaled about 70 mc. The second and third releases contained 180 and 300 mc of I^{131} respectively.

Locating the Defective Fuel Elements

Needless to say, a great deal of effort was being expended to find the source of the releases but finding one or two damaged fuel elements out of 3400 elements is a difficult and time consuming task. Between the second and third releases the reactor was shut down and the elements in several suspected channels were inspected. These channels were suspected because of higher temperature readings on the thermocouples in these channels. The elements appeared normal so the reactor was brought up to a reduced power level, and shortly thereafter the third release occurred.

It was decided to reduce power level and to take air samples from each fuel channel. The samples were taken through the charcoal traps and the traps were monitored with a survey instrument. One fuel channel was found to be much higher than the rest. The reactor was shut down and the elements in this channel were removed and inspected. Two of the four elements appeared to be

damaged. One had a spotted appearance and the other was badly blistered. Subsequent hot cell inspections and testing of the elements proved that they were the source of the releases.

The reactor was again brought up to power and no further distinct releases occurred, but the stack samples showed that the I^{131} being released was much higher than normal, initially about 10 times higher and slowly tapering off to normal in about 20 days. It was theorized that some of the iodine from the elements had condensed or adsorbed on the duct work and exit air filters and was slowly subliming or exchanging off into the air stream. The analysis of additional air samples taken on charcoal at the north and south duct monitors and at the base of the stack supported this theory.

Table I shows the ratio of I^{133} activity to I^{131} activity in fresh and equilibrium fission products at various decay intervals.

Table I

Ratio of I^{133} to I^{131} Activity for Fresh and Equilibrium Conditions

Decay Time	Fresh	Equilibrium
0	21	2.3
1 hr	19	2.2
1 day	9.9	1.1
2 days	4.9	0.55
3 days	-	0.27
4 days	-	0.13

The ratio found in the effluent cooling air at the base of the stack under normal conditions is about 8, which corresponds to about 1-day-old fresh fission products. The sample taken during the time of the second release showed a ratio of 1.7 which is consistent with slightly aged equilibrium fission products.

On September 15, about 3 days after the last release, a set of 24-hour

samples was started with samples taken at the north and south duct monitor locations and at the stack. When these samples were analyzed the following information was obtained:

	South Duct	North Duct	Stack
Ratio $\frac{I^{133}}{I^{131}}$	8	1.4	1.2

The rate of release and the ratio found in the south duct was normal. The ratio in the north duct and stack samples was not as low as one would expect for 3-or-4-day old equilibrium fission products. However, if the sample results were corrected by subtracting the normal amount of I^{131} and I^{133}, the remaining activity shows a ratio of about 0.1 which corresponds to several day old equilibrium fission products. Also, it was found that the amount of I^{131} being released from the stack was almost twice the amount found in the duct samples indicating that about 50% of the I^{131} being released was coming off the filters.

These samples then, supported the theory that the idoine released from the fuel elements had adsorbed or condensed on the duct work and filters and was slowly subliming or exchanging off into the air stream. A subsequent experiment showed that the adsorption-exchange mechanism was the dominant one. In the course of trying to develop a new operational iodine monitor, stable I^{127} was released into the reactor to produce I^{128} to check the response of the new monitor. Each time this was done, the stack charcoal iodine monitor showed a significant increase in the amount of I^{131} released. The fact that when I^{127} is put in I^{131} comes out indicates that even under normal operating conditions there is iodine adsorbed in the reactor structure which exchanges off into the air stream. This knowledge of the behavior of iodine suggests a method of decontaminating reactors or other structures.[2,3]

Conclusions

The system of iodine monitoring in use at BNL has proved to be a satisfactory means of measuring the release of I^{131} to the environment under emergency conditions. Although the cooling air effluent is monitored by other means, which indicated that something had been released, only the system using activated charcoal traps and gamma spectrum analysis could reliably indicate that a release of equilibrium fission product iodines had occurred and accurately measure the amount released. Other media tested by BNL and others[4,5] do not have as consistently high collection efficiency as the charcoal traps. The system was also useful in locating the defective fuel elements and in explaining the behavior of iodine within the reactor structure.

BIBLIOGRAPHY

[1] C.W. Sill and J.K. Flygare, Jr., "Iodine Monitoring at National Reactor Testing Station", 1960, Health Physics, Vol. 2, No. 3, pp. 261-68

[2] W.J. Megaw and F.G. May, "The Behaviour of Iodine Released in Reactor Containers", 1962, Reactor Science and Technology, Vol. 16, pp. 427-36

[3] Robert E. Adams and William E. Browning, Jr., "Removal of Iodine From Gas Streams", 1961, TID-7627, pp. 242-60

[4] L. Silverman, R. Dennis, E. Kirstal and F. Stein, "Iodine Collection Studies", 1960, TID-7593, pp. 322-43

[5] Harry J. Ettinger, "Iodine Sampling with Silver Nitrate Impregnated Filter Paper", 1963, Presented at 8th Annual Meeting of Health Physics Society in New York. Abstracted in Health Physics, Vol. 9, No. 8 pp. 872

RESPIRATOR FILTER TESTING AT LOS ALAMOS*

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September 10, 1963
Los Alamos Scientific Laboratory
University of California
(Contract W-7405-ENG-36)
Los Alamos, New Mexico

I. Introduction

During the period 1960-1962, the Los Alamos Scientific Laboratory purchased approximately 23,000 high efficiency filter cartridges for half mask respirators and 1300 high efficiency filter cartridges for full face respirators at an approximate cost of $20,000. These are for use in work areas where plutonium or other radioactive materials are handled, although in many instances respirators are worn only as a precautionary measure and little or no radioactive material is deposited on the filter.

As of April 1963, we have issued 571 full face masks and 62 half masks to Los Alamos personnel on an individual basis, and several hundred more on a nonindividual basis. Respirators are sent to the respirator laundry at least once a month or when contaminated due to use.

Because of this usage record and because all filter cartridges on respirators received at the laundry were discarded although more than 75% had no detectable radioactive contamination, we considered reusing the uncontaminated filter cartridges. Before the filters could be reused, we had to make certain that the filter was intact

and still exhibited a high filtering efficiency. The most practical method of rapidly and accurately determining the filtering efficiency of such a large number of filters is to use the DOP respirator filter tester developed by the U. S. Army Chemical Corps.[1] We estimated that a respirator filter tester would pay for itself within a relatively short time period by permitting the reuse of filter cartridges.

II. DOP Tester

An investigation of possible manufacturers of a DOP respirator filter tester was initiated. Three manufacturers were willing to construct a tester based on design criteria for the U. S. Army Chemical Corps Model E-27 tester. Price quotations for these units ranged from $7,550 to $13,600. A tester was eventually purchased from T. D. Associates, Baltimore, Maryland, for $7,550. This tester included modification of the Army Chemical Corps' original design to permit the testing of six different commercial respirator cartridges. The original Army Chemical Corps' design only permitted testing of the Army M-11 ultra filter cartridge. The price quoted included a one-day checkout of the machine at Los Alamos by the manufacturer.

The tester operates by passing a 20 liters per minute (lpm) airstream through a preheater and then over the surface of liquid DOP which is maintained at 172° C in the smoke generator. An 80 lpm dilution airstream mixes with the DOP airstream leaving the smoke generator, thereby forming a liquid aerosol. The particle size of the DOP aerosol is controlled by adjusting the temperature of the dilution airstream. The aerosol passes into an aging chamber, where it is stabilized and exhausted to the test chuck containing the respirator filter cartridge being evaluated. The flow

through the filter being tested is 16 lpm. Samples of the DOP aerosol entering and passing through the respirator filter cartridge are directed through a forward light scattering chamber to determine per cent penetration of DOP aerosol. Particle size of the DOP aerosol is determined by passing an aliquot of the aerosol through an Owl which determines the degree of polarization of the scattered light beam and relates this to particle size.[2] Fig. 1 shows the DOP tester.

III. Test Program

Only high efficiency filter cartridges are considered for testing for reuse. Any cartridges with combination particulate filter and sorbent are discarded at the laundry when respirators are sent in for cleaning.

The filter cartridges are removed from the facepiece at the laundry and monitored. All filter cartridges that at contact have an alpha count of less than 100 counts per minute as measured with a 2π geometry, 60 sq cm, PeeWee probe and a beta-gamma count of less than 0.2 mr/hr as measured with an open shield GM tube are considered potentially available for reuse.

A preliminary pressure drop test is made on these cartridges. Table I gives the pressure drop range on new filters as received from the manufacturer. Any used filter that has a pressure drop within a range determined by tests on new cartridges is considered satisfactory for reuse. Any cartridge which has a pressure drop above the upper limit of this range is assumed to be partially plugged and is discarded. Pressure drop testing also provides a method of precluding contamination of the DOP tester. It was feared that radioactive contaminants on the cartridge might be pulled off during DOP testing. During pressure drop testing, the

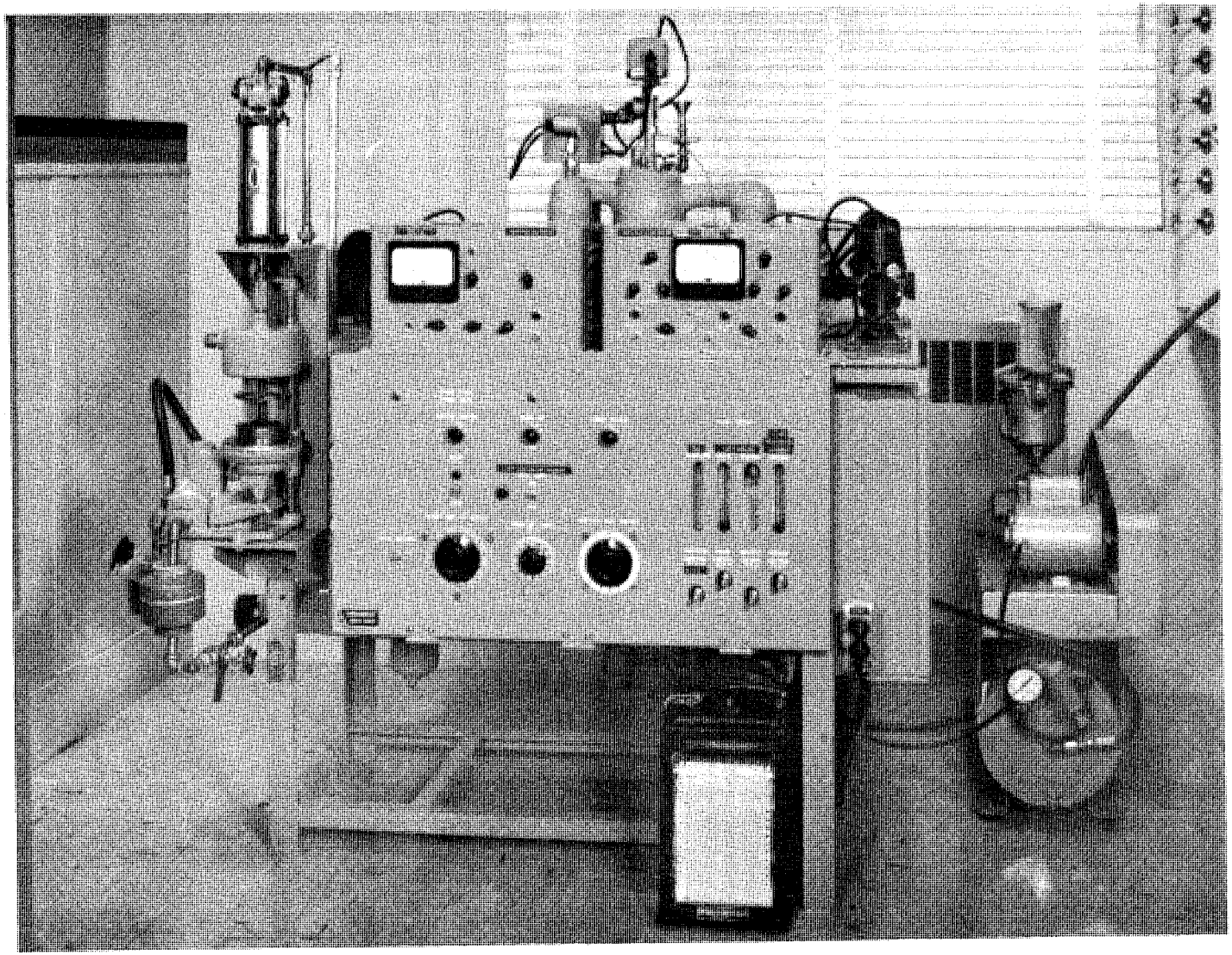


Fig. 1. DOP Respirator Cartridge Tester.

air exhausted through the respirator cartridge is filtered, and the filter alpha counted prior to DOP testing. If this filter shows a high radiation count, the respirator cartridges are screened to determine the source of contamination prior to DOP testing.

A maximum permissible penetration of 0.05% has been set, based on the proposed U. S. Bureau of Mines Schedule 21-B.[3] All cartridges which exhibit a DOP penetration greater than 0.05% are discarded. Fig. 2 shows the various commercial cartridges which have been tested using the DOP tester.

TABLE I. NEW FILTER TEST RESULTS

Full Face Mask

Type	Number Tested	Pressure Drop* mm H_2O at 85 lpm		Number with DOP Penetration > 0.05%
		Range	Median	
A	62	40-53	48	None
B	116	29-40	31	3
C	200	15-20	17	1

Half Mask

Type	Number Tested	Pressure Drop* mm H_2O at 42.5 lpm		Number with DOP Penetration > 0.05%
		Range	Median	
D	50	35-47	41	None
E	50	27-32	29	None
F	50	24-34	28	None

*Tested September 1963 at Los Alamos - altitude 7300 ft. No altitude correction made.

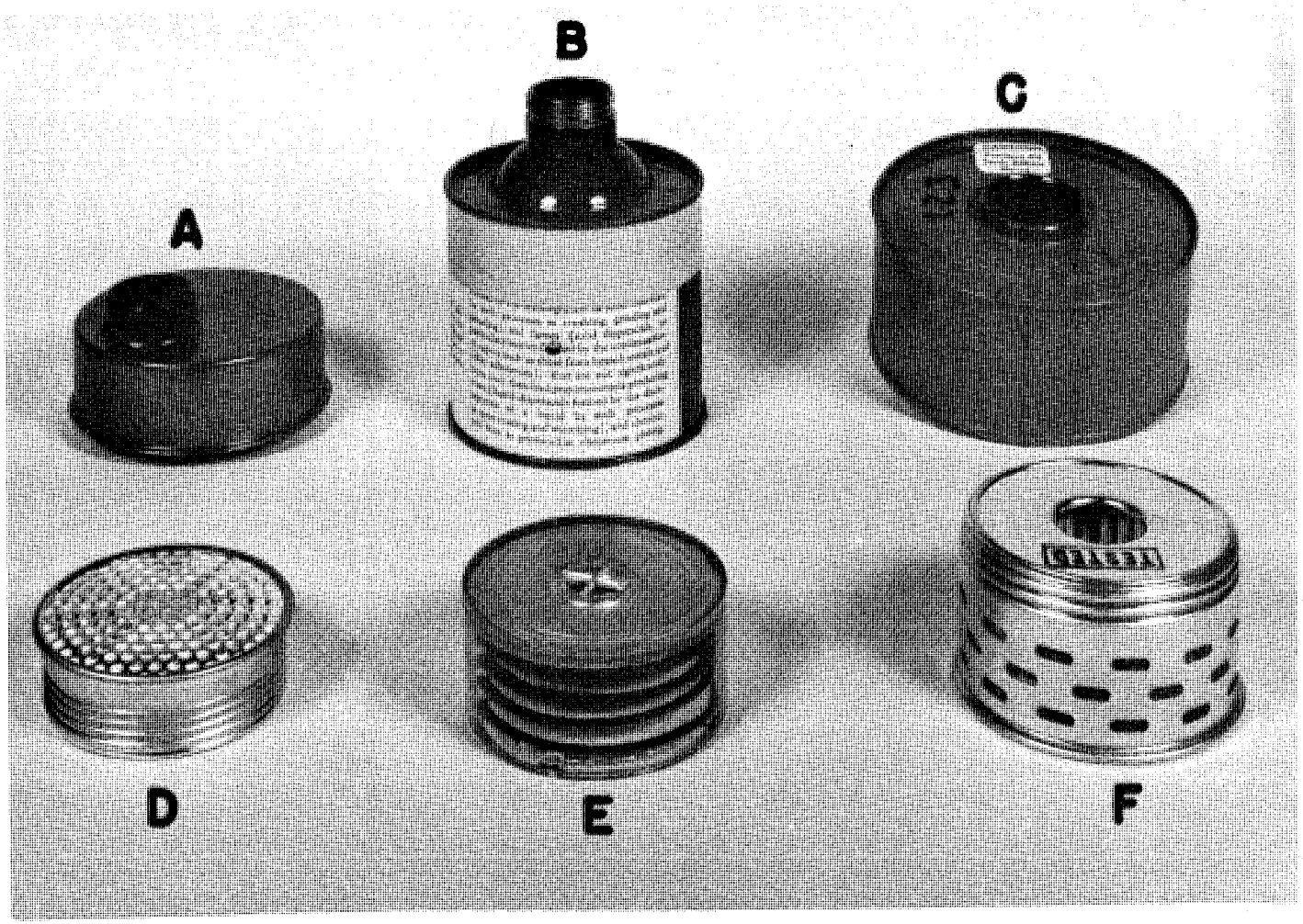


Fig. 2. Respirator Cartridges Tested at Los Alamos.

During the six month period since the installation of the tester, over 2100 high efficiency filter cartridges, both full face and half masks, have been tested. Of these, approximately 96% had a DOP penetration of less than 0.05% and were rated satisfactory and returned to the laundry for reuse. The type and number of filter cartridges tested is given in Table II.

TABLE II. USED FILTER TEST RESULTS

Type	Number Tested	Number with DOP Penetration ≥ 0.05%
Full Face Mask		
A	1070	16
B	441	57
C	None	--
Half Masks		
D	359	11
E	187	5
F	119	2

A considerable percentage of those cartridges which were rated unsatisfactory had bent or deformed casings which prevented adequate sealing in the cartridge holder during DOP testing. In some cases, these deformities might have prevented sealing when the cartridge was installed in the respirator facepiece. Rather than attempt to evaluate these cartridges, it was decided to discard them as unfit for reuse.

In addition to the direct cost saving achieved by the reuse of high efficiency filter cartridges, we have found the DOP tester to be a useful tool in evaluating the quality of commerical res-

pirator cartridges. Table I gives test results on new cartridges as received from the manufacturer. In the test program at Los Alamos, we have detected manufacturing defects in three different makes of filter cartridges.

The most serious defect found was the breaking of the filter media by rough handling or dropping of the cartridge, resulting in a DOP penetration of several per cent. The filter manufacturers were notified of our findings and without exception took immediate action to eliminate this structural weakness. DOP tests have shown that the modified filter cartridges are satisfactory.

It is planned to continue to use the DOP tester as a quality control on filter cartridges purchased routinely and for new models as they are introduced.

IV. Summary

Based on six month's usage of this equipment, it appears that within a two to three year period, the savings realized by reuse of high efficiency filter cartridges will more than equal the cost of the DOP tester. In addition, this unit will serve as a useful tool in quality control operations.

V. Acknowledgement

The authors wish to acknowledge the assistance of Darell A. Bevis who was responsible for operation of the DOP tester and provided the cost operation data.

BIBLIOGRAPHY

1. Filter Units, Protective Clothing, Gas Mask Components and Related Products. Performance Test Methods. (Mil-Std-282) U. S. Gov't. Printing Office, Washington, D. C., May 1956.
2. Handbook on Aerosols. U. S. Atomic Energy Commission. U. S. Gov't. Printing Office, Washington 25, D. C., 1950.
3. Proposed Revision, Bureau of Mines Schedule 21A, Respiratory Protective Apparatus Tests for Permissibility Fees. U. S. Dept. of Interior, Bureau of Mines, Washington, D. C., Dec. 20, 1962.

THE NUCLEAR SAFETY PILOT PLANT -- CAPABILITIES AND EXPERIMENTAL PROGRAM

by

L. F. Parsly, Jr.

Abstract

The Nuclear Safety Pilot Plant is a facility for investigating the behavior of fission products released into a containment vessel as a result of a core meltdown accident. The plant includes a furnace for melting irradiated UO_2 fuel elements, a 1350-ft^3 model containment vessel, and various auxiliary equipment for containment simulation, for mocking-up techniques which would reduce the radioactivity concentration within the containment vessel, and for experiment evaluation. Fuel elements containing up to 1000 curies of activity may be melted under a variety of accident conditions which would simulate those in various accidents. The initial experimental program directed toward the transport phenomena of iodine, and employing both stable and radioactive iodine, is described.

INTRODUCTION

The Nuclear Safety Pilot Plant (NSPP) is a facility in which to melt UO_2 fuel elements and to make observations of the behavior of gaseous, volatile, and particulate fission products entering a model containment vessel.[1,2,3,4] The plant is installed in a shielded underground cell and is capable of handling at least 1000 curies of beta-gamma activity. The design of the plant and the current concept of the experimental program are described in this paper.

DESIGN AND CAPABILITIES

The principal components of the pilot plant are a furnace for melting UO_2 slugs and a 1350-ft^3 model containment vessel, which is shown in Fig. 1. The furnace, shown in Fig. 2, is a horizontal semicircular trough in which a water-cooled boat containing the fuel element to be melted can be moved. A plasma torch mounted at the center of the furnace above the boat provides heat for melting. The design concept was based on the requirement of loading and unloading the furnace remotely and providing an ultimate capability of handling fuel elements up to 30 in. long, although the first furnace has been built to handle fuel specimens up to 6 in. long. Preliminary testing of the plasma torch indicates that UO_2 can be melted readily and that the particles evolved range from 0.005 to 0.4μ.[1] Such particles are in the general size observed in other out-of-pile melting experiments.

An inert gas is required for plasma generation -- helium, argon, or nitrogen can be used. Most of the preliminary testing has been done with helium, although one test was run with argon. The argon flame melts a narrow slice in the center of the pellet, while the helium flame melts the entire pellet and is therefore preferred.

It is possible to introduce two other gas streams into the furnace and thus vary the meltdown atmosphere. One stream enters tangentially at the torch nozzle so that it will essentially surround the flame. The other is a sweep or purge stream introduced into the furnace body. These can be used to produce either an oxidizing or an inert atmosphere surrounding the melt.

The model containment vessel is a 1350-ft^3 vertical stainless steel pressure vessel. It will be used for observations of the behavior and transport of fission products released into it, including removal by various natural and imposed phenomena, such as deposition in the vessel and on specimens of various materials. The containment vessel is provided with internal headers and the walls with decontaminating solutions. There are provisions for installing up to 144 deposition coupons. Air samplers are provided at 6 locations which will enable determination of airborne particulate matter as a function of time, and one fallout sampler is provided which will enable observations to be made of the fallout as a function of time.

Auxiliary facilities include a gas sampling train containing particulate filters and charcoal adsorbers for collecting iodine, xenon, and krypton, means for purging the vessel and cell through a filter system, and equipment for makeup and storage of decontaminating solution, and for obtaining inventory data.

FURNACE DEVELOPMENT

A development program was carried out to obtain information on proper operation of a plasma torch in the furnace.[1,3,5] The objectives were to determine

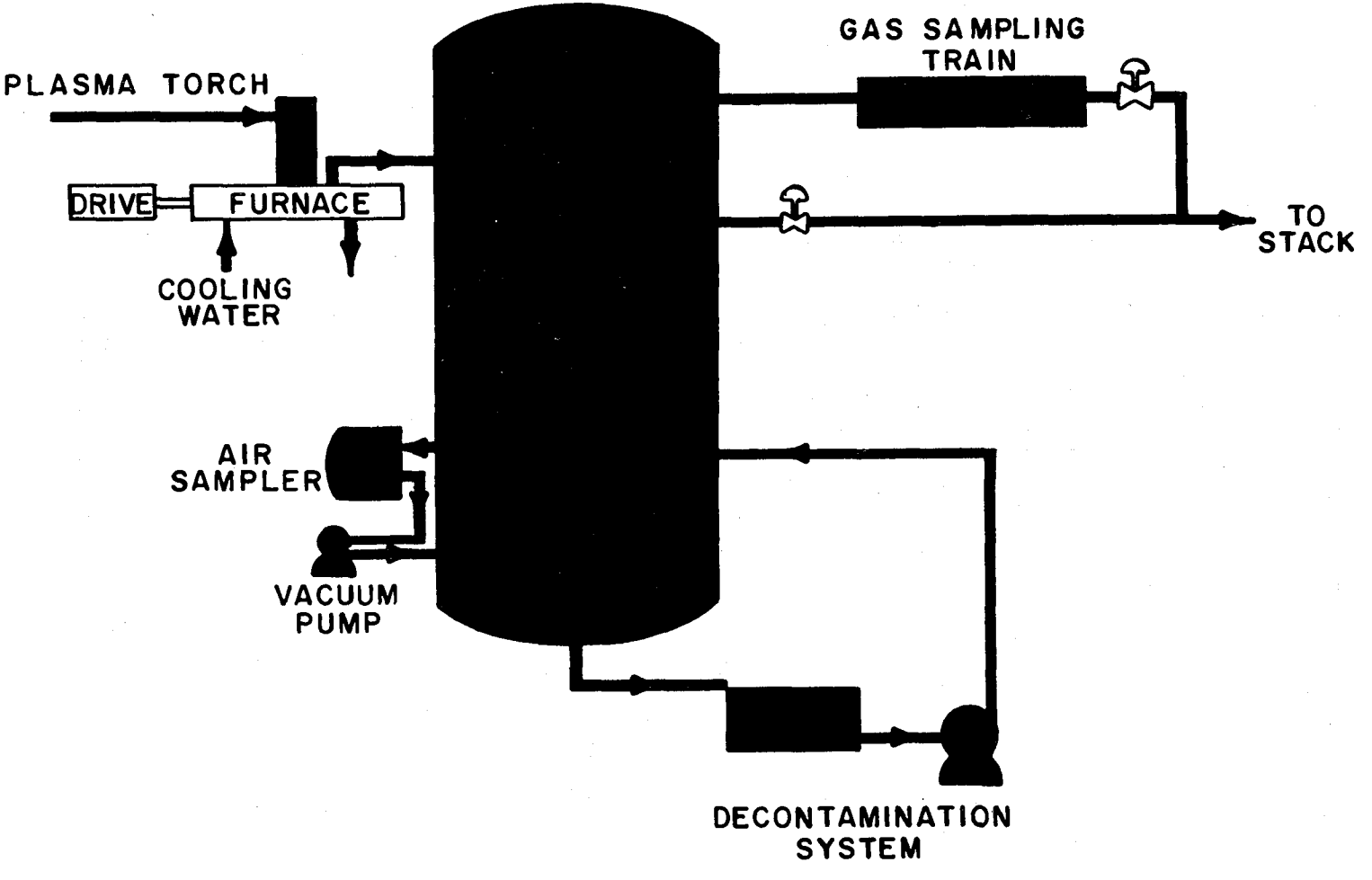
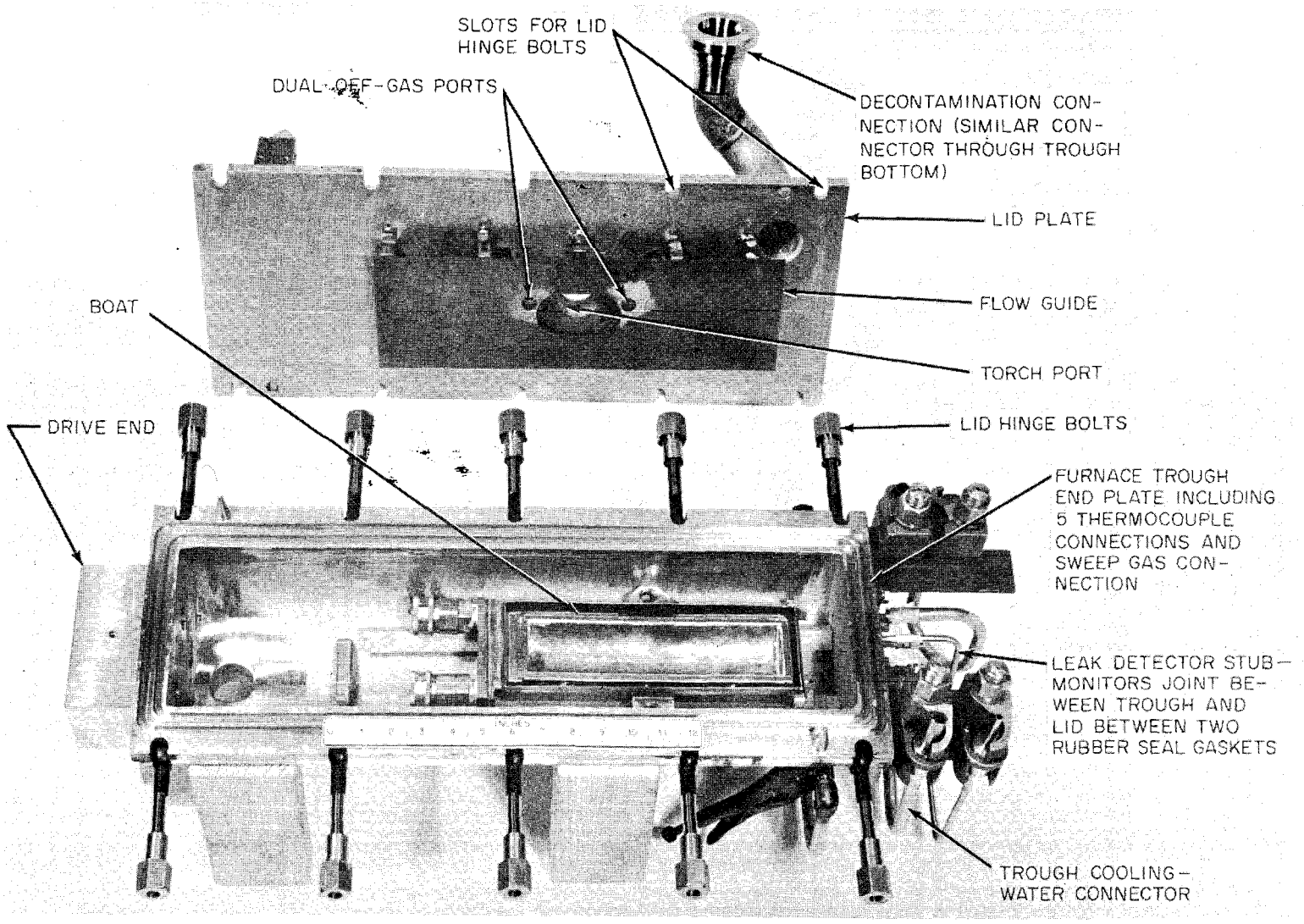

PLASMA TORCH
DRIVE
FURNACE
COOLING WATER
GAS SAMPLING TRAIN
TO STACK
AIR SAMPLER
VACUUM PUMP
DECONTAMINATION SYSTEM

Figure 1


SLOTS FOR LID HINGE BOLTS
DUAL OFF-GAS PORTS
DECONTAMINATION CONNECTION (SIMILAR CONNECTOR THROUGH TROUGH BOTTOM)
LID PLATE
FLOW GUIDE
BOAT
TORCH PORT
DRIVE END
LID HINGE BOLTS
FURNACE TROUGH END PLATE INCLUDING 5 THERMOCOUPLE CONNECTIONS AND SWEEP GAS CONNECTION
LEAK DETECTOR STUB—MONITORS JOINT BETWEEN TROUGH AND LID BETWEEN TWO RUBBER SEAL GASKETS
TROUGH COOLING—WATER CONNECTOR

suitable operating conditions to achieve essentially complete UO_2 melting, to find a suitable liner for the water-cooled copper melt boat, and to establish the configuration of the flow guide baffle placed above the boat to help channel vapors from the melt into the outlet off-gas pipes from the furnace. A great many interdependent variables affect the torch performance. One is the plasma gas; any inert gas can be used, but changing gases can affect such factors as flame shape and momentum. Torch current, rate of specimen feed under the flame, and spacing from the torch nozzle to the specimen all strongly influence the rate and degree of melting. A helium feed rate of 65 cfh, a spacing of 2 3/4 in., a current of 650 amp at 40-45 volts, and a feed rate of 2 in./min were chosen. Under these conditions, approximately 90% of the fuel pellet is melted rapidly and approximately 3% of the material is vaporized. A total of slightly over 7 hr of successful torch operation has been accumulated with no evidence of deterioration of the torch. (This is equivalent to at least 40 pilot plant runs.

The solution to the boat liner problem proved surprisingly simple. Originally it was proposed to use ceramic liners, and trial liners were prepared by the ceramics group of the Y-12 Technical Division. Both green and fired liners shattered under the severe temperature gradient produced by the plasma torch, and it was decided that ceramic liners were probably not suitable. A trough of tantalum sheet, separated from the boat by tantalum spacers, was then tried, and it worked satisfactorily.

The flow guide configuration also received attention during the development studies. The guide is a baffle designed to direct vapors leaving the melt to the outlet line from the furnace so that they will be conducted to the model containment vessel. The limitation imposed by the system was that it must not interfere with boat movement. A large central opening was required to provide access for the plasma torch and to leave an unobstructed view of the melt through two viewing ports. The flow guide preferably was to be simple and inexpensive enough to permit it to be destroyed during analysis after being used for one run, since a high degree of contamination was expected. The guide adopted is in the form of a simple hood made by bending down the sides and ends of a tantalum sheet and cutting openings for the torch and viewing ports. Stainless steel and Inconel guides were tried, but severe melting near the torch always occurred. Warping, cracking and embrittlement were encountered on some of the early tantalum flow guides, but it was found that a saw cut from the flame hole to the side of the guide allowed the guide to expand and contract without excessive restraint.

Furnace tests in the pilot plant will be required to obtain data on the effectiveness of transfer of fission products to the model containment vessel.

EXPERIMENTAL PROGRAM

The experimental program as presently conceived comprises three stages: stable iodine experiments, radioiodine experiments, and mixed fission product experiments.

In the first series of experiments stable iodine will be released in the presence of UO_2 by the following procedure: A simulated fuel element will be made by inserting several 3/4-in.-OD, 3/8-in.-ID, 1-in.-long, sintered UO_2 pellets in a tube of either type 304 stainless steel or Zircaloy-2. The cavity in the pellets will be packed with a mixture of UO_2 powder and iodine crystals containing the desired amount of iodine for the experiment to be performed. The fuel element will be sealed, placed in the furnace and melted with the plasma flame. The volatile materials from the melt will be directed into the model containment vessel. Samples to be collected will include the material

in a diffusion channel attached to the transfer line connecting the furnace and model containment vessel, coupons at several locations in the vessel, air taken at different times at one location in the vessel, and fallout taken at one location at different times. The diffusion channel samples will provide information on the size of the submicron particles with which iodine may be associated. Iodine will be determined by activation analysis. The residue in the melt boat, deposits in the furnace, and deposits in the transfer line will also be analyzed.

A series of experiments of this general type is planned. In these it is planned to investigate the effect of atmosphere surrounding the melt (helium, air, and steam), cladding material (stainless steel or Zircaloy), gas flow rates, containment vessel atmosphere, torch operating parameters (current and exposure time as influenced by rate of moving the fuel element under the flame), and location of release inside the model containment vessel (to be achieved by extending the transfer line inside the vessel to the point of concern). Subsequent runs will be more specifically concerned with the effectiveness of attenuation processes which may be introduced within the containment volume, such as water spray, steam spray, and recycle filtration, as well as various particle-agglomeration techniques.

The use of stable iodine appears to have several advantages and, of course, a few disadvantages. The greatest advantage is that no radiation problems will be encountered in runs of this type, which should expedite carrying out experiments and provide for frequent experiments. A second advantage is that relatively large quantities of iodine may be used, so that it will be possible to simulate the release of the entire iodine inventory of a large power reactor into its containment vessel.[1] The most obvious disadvantage is that there may be some radiation dependent phenomena which would affect the transport behavior of iodine. The form of the iodine entering the furnace is subject to question, as well as the possibility of leaving an iodine residue in the containment vessel that would influence the results of subsequent runs. (The vessel will be decontaminated as effectively as possible between runs.)

After completing work with stable iodine, it is planned to make a series of runs with I^{131}, both carrier free and containing varying amounts of I^{127} carrier. These runs will be intended primarily to investigate the effect of very low concentrations of iodine on its behavior. It will be possible to cover the range from the iodine inventory contained in a fairly low-level mixed fission-product experiment to the simulated release of the iodine inventory of a large power reactor core.

Ultimately, the pilot plant will be used to melt specially irradiated UO_2 fuel elements. It will be possible to work with fuel elements containing up to 1000 curies of fission products. It is expected that a similar sampling program to that outlined for iodine experiments will be followed. It is anticipated that the boat residues, the transfer line and diffusion channel, and the decontamination solutions originating in the furnace and model containment vessel will be analyzed for U, I, Te, Sr, Ba, Cs, Zr, Ru, and Ce. The deposition coupons, fallout samples, and airborne dust samples will probably be analyzed only for gross gamma activity. This decision is based both on economics and on the expectation that many of the samples will not contain enough material to permit a radiochemical analysis. Techniques for computer "unfolding" of gamma spectra are being investigated. If a suitable technique is found, gamma spectroscopy will be used to analyze many of the samples.

The mixed fission product runs have not been planned in detail as yet, but many sets of experimental conditions are being considered. It is expected that the iodine experiments will enable some of the variables to be eliminated and will also cause some of the sampling procedures to be modified. These

runs will be scheduled to get the most urgently needed data as soon as possible.

References

1. M. H. Fontana and C. G. Lawson, "NSPP Semiannual Progress Report, June 30, 1962", ORNL-3319, pp. 51-62.

2. M. H. Fontana and L. F. Parsly, "NSPP Semiannual Progress Report, December 31, 1962", ORNL-3401, pp. 57-60.

3. M. H. Fontana and C. G. Lawson, "NSPP Semiannual Progress Report, June 30, 1962", ORNL-3319, pp. 51-62.

4. L. F. Parsly, "NSPP Hazards Summary Report", ORNL-TM-683, (to be issued).

5. P. P. Holtz, "Plasma Torch Development", ORNL-TM-687, (to be issued).

THE TURBULENT TRANSPORT AND DEPOSITION OF PARTICLES WITHIN VERTICAL TUBES

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ABSTRACT

Theories are reviewed which predict particle deposition under turbulent flow conditions in vertical tubes. Theoretical predictions are compared with experimental deposition in 58-foot lengths of 1-1/4- and 3-inch-diameter tubing. Theories prove useful in predicting deposition; however, reentrainment must be considered as a separate factor when higher depositions are predicted. For 3-inch tubes deposition at low reduced stopping distances is higher than predicted. A possible explanation is that for these conditions a transition exists to a deposition mechanism not described by the postulated theory.

INTRODUCTION

The transport of airborne particles to and deposition on surfaces is of considerable importance in many systems in industry, meteorology, and in the life sciences. Deposition of radioactive particles in closed conduits, on structures, on vegetation and on terrain is of great significance in evaluating and predicting the radiological consequences at the point of interest. One special case is the deposition of particles in lung passages. Another is the plate-out of particulate material on reactor containment vessels and passages through reactor components during a serious reactor incident involving the release of fission products. Another case of significance is the deposition of particles in systems designed to transport waste gases containing radioactive particles, either to points of release to the atmosphere or to a sample collector. The deposition and retention of particles on exhaust ducts and sampling lines may materially influence the assessment of the radiological safety of the gaseous release.

To accurately determine the significance of particle deposition in a given circumstance requires knowledge of the many parameters which control the behavior of particles in an air stream. The important variables are the velocity of the carrying gas and its dynamic fluid properties, the friction of the surfaces, or walls in the case of closed conduit, and the inertial properties of the particles themselves.

Laminar, transition, and turbulent flow must be considered. Attention is restricted herein to turbulent flow because of the marked deposition resulting

for particles moving in a turbulent stream.

Theories have been proposed to predict the turbulent transport of particles to vertical walls. Friedlander and Johnstone[1] developed three equations to predict particulate deposition in vertical tubes. Each equation is applicable to particle sizes within a range of reduced stopping distances, S^+(*). Reasonable agreement between predicted and experimental deposition for particles from 0.8 to 2.6 microns in diameter in tubes from 0.5 to 2.5 cm in diameter were obtained for reduced stopping distances of 0.2 to 10.

In contrast, Owen[2] considered the general cases of particulate deposition from a turbulent air stream to all horizontal and vertical surfaces. Equations to predict deposition were developed which are independent of particle size. These two theories have been reviewed by Chamberlain[3] who obtained an order of magnitude agreement between predictions from Owen's equations and for micron size particle deposition on grass.

Direct measurements of aerosol deposition as a function of particle size have also been reported by Postma and Schwendiman[4,5] for 2-, 4-, and 30-micron-diameter particles in conduits 1.38 to 2.64 cm in diameter. The data were correlated reasonably well as one curve.

Since the correlation was based on pointwise deposition measurements within a tube, the applicability of the data to a long tube was subsequently measured by FitzPatrick, Nielson, and Schwendiman[6] who measured the total deposition of zinc sulfide particles (Radium Corporation No. 2210) in a 60-foot length of 1/2-inch-diameter tubing. The experimentally observed deposition agreed well with that predicted from Friedlander's and Johnstone's equations as well as with the correlations reported by Postma and Schwendiman. At depositions greater than 85 per cent, observed deposition was about 5 per cent less than predicted, presumably due to re-entrainment. The flow rates used corresponded to Reynold's numbers from 4000 to 10,000.

OBJECTIVE

The purpose of this study is to compare predicted with experimental total deposition for larger diameter tubes and for a greater range of Reynold's numbers than those previously reported. The turbulent deposition of zinc sulfide particles was measured in 58-foot (17.7 meters) long vertical tubes.

SUMMARY

The deposition of fluorescent zinc sulfide particles was measured in 1-1/4-inch- and 3-inch-diameter vertical tubes 58-feet long. The fraction deposited in the 1-1/4-inch tube ranged from 7 to 73 per cent over a Reynold's number range of from 6000 to 40,000. An average deposition of 6 per cent for the 3-inch tube was found with no significant variation within the experimental accuracy for flow rates from 4 to 35 cfm (Reynold's numbers of 1600 to 14,000).

All deposition data available are reviewed and compared with Friedlander's and Johnstone's theoretical relations. The values of the deposition ratio, K/V, are spread more widely when plotted against S^+ than when plotted against the correlation parameter used earlier by Postma and Schwendiman, but both curves have high correlation coefficients over most of the range of data.

Deposition in the 3-inch-diameter tube was significantly greater than predicted. This higher deposition is an indication of significant departure from a single deposition ratio for each low S^+ value for tubes of this diameter.

(*) All symbols are defined at end of report.

EXPERIMENTAL

The apparatus, shown schematically in Figure 1, consisted of 12-foot or shorter length of aluminum tubing held tightly together with short sections of rubber sleeves to form a continuous vertical tube. Two sizes of aluminum tubing were used: 1-1/4-inch-diameter with 0.049-inch wall (2.93 cm I.D.), and a 3-inch-diameter with 0.095-inch wall (9.68 cm I.D.). As shown, the particles were drawn through the tubes from a 50-gallon drum which served as a mixing chamber. A dust feeder[7] was used to introduce the particles into the mixing chamber at a constant rate.

Two samples were collected from the drum for each run. The first was a sample, C_o, collected immediately adjacent to the mixing chamber. Such a sample was collected to correspond to the quantity of aerosol drawn up into the long vertical tube. The second sample, C, was collected at the top end of the long vertical tube. For both cases, transitions on the filter holder permitted filtration of the entire air stream through 4-inch-diameter membrane filters.

The aerosol was zinc sulfide (Radium Corporation No. 2210) with a size distribution as sampled from the mixing chamber as shown in Figure 2. The lower end of this microscopically determined curve was extrapolated to data obtained from a Royco particle counter. Each run was approximately 20 minutes long with the particle feed rate controlled to yield a C_o filter collection of about 30 mg. The filters were dissolved in 14 ml acetone and the resulting mixture analyzed fluorometrically.

RESULTS

The deposition data obtained for the 1-1/4-inch tube are shown as a function of flow rates in Figure 3. Data for the 3-inch-diameter tube are not plotted since the total deposition was found to be 6 per cent and independent of flow rates for flows from 4 to 35 cfm. Although the latter deposition data were scattered, the deposition was significantly different from the average error of 1.7 per cent experienced in reproducing the C_o samples. For the 1-1/4-inch tube the Reynold's numbers were varied from approximately 6000 to 40,000; for the 3-inch tube, from approximately 1600 to 14,000.

DISCUSSION

The model used to describe turbulent particulate deposition is defined in terms of a deposition velocity.[1,4,5] For any particle size of a material, the deposition velocity is the quotient of the number of particles deposited per unit time per unit area of the wall divided by the volumetric average number of those particles per unit volume in the gas stream.

Friedlander and Johnstone[1] derived three expressions relating the deposition velocity, K, to S^+, the reduced stopping distance, the Fanning friction factor, f, and the average air velocity, V, in the tube. The three equations are for $S^+ \leq 5$,

$$\frac{K}{V} = \frac{f/2}{1 + \sqrt{f/2}\left(\frac{1565}{S^{+2}} - 50.6\right)}, \qquad (1)$$

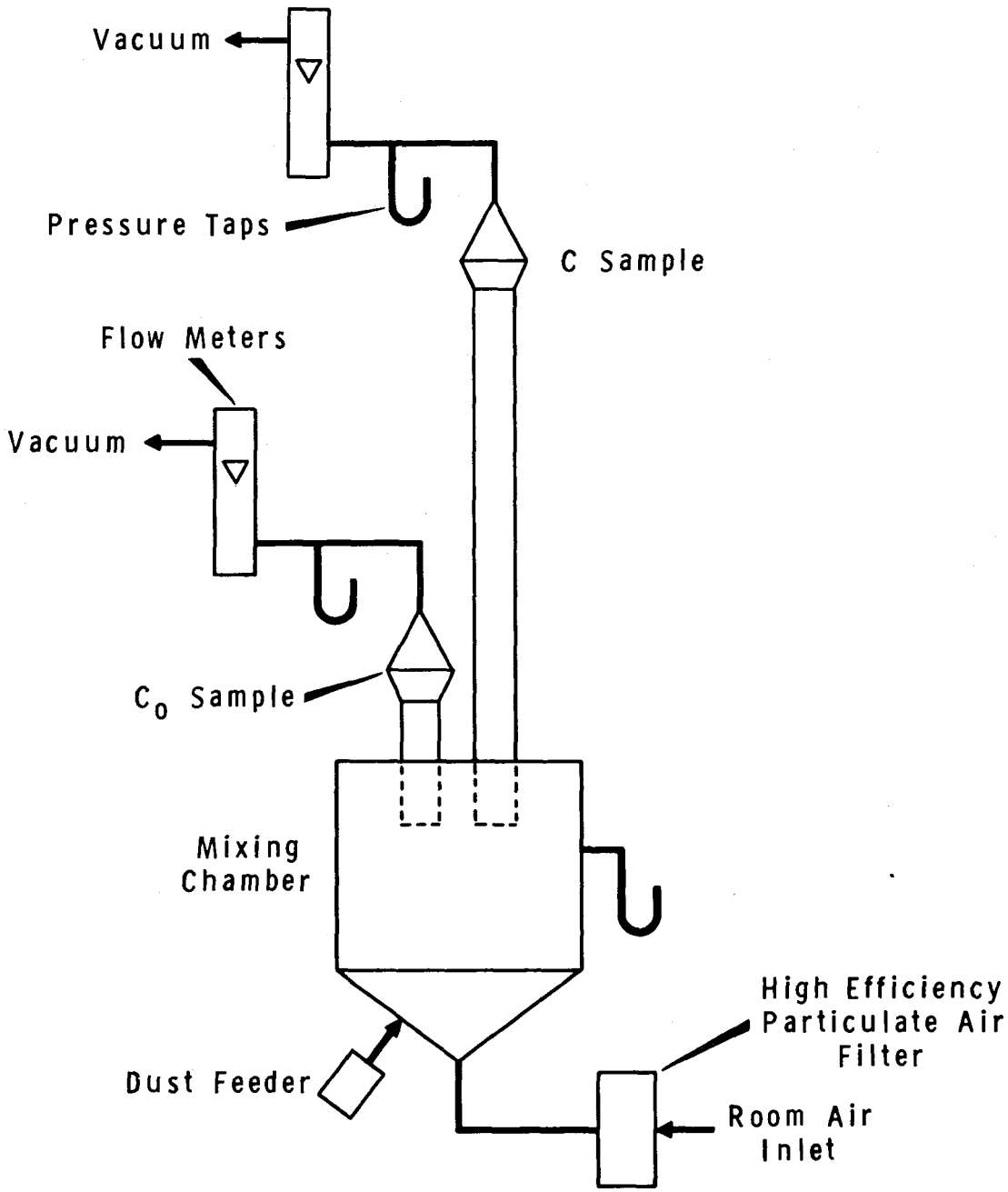


FIGURE 1: FLOW CHART OF DEPOSITION SYSTEM

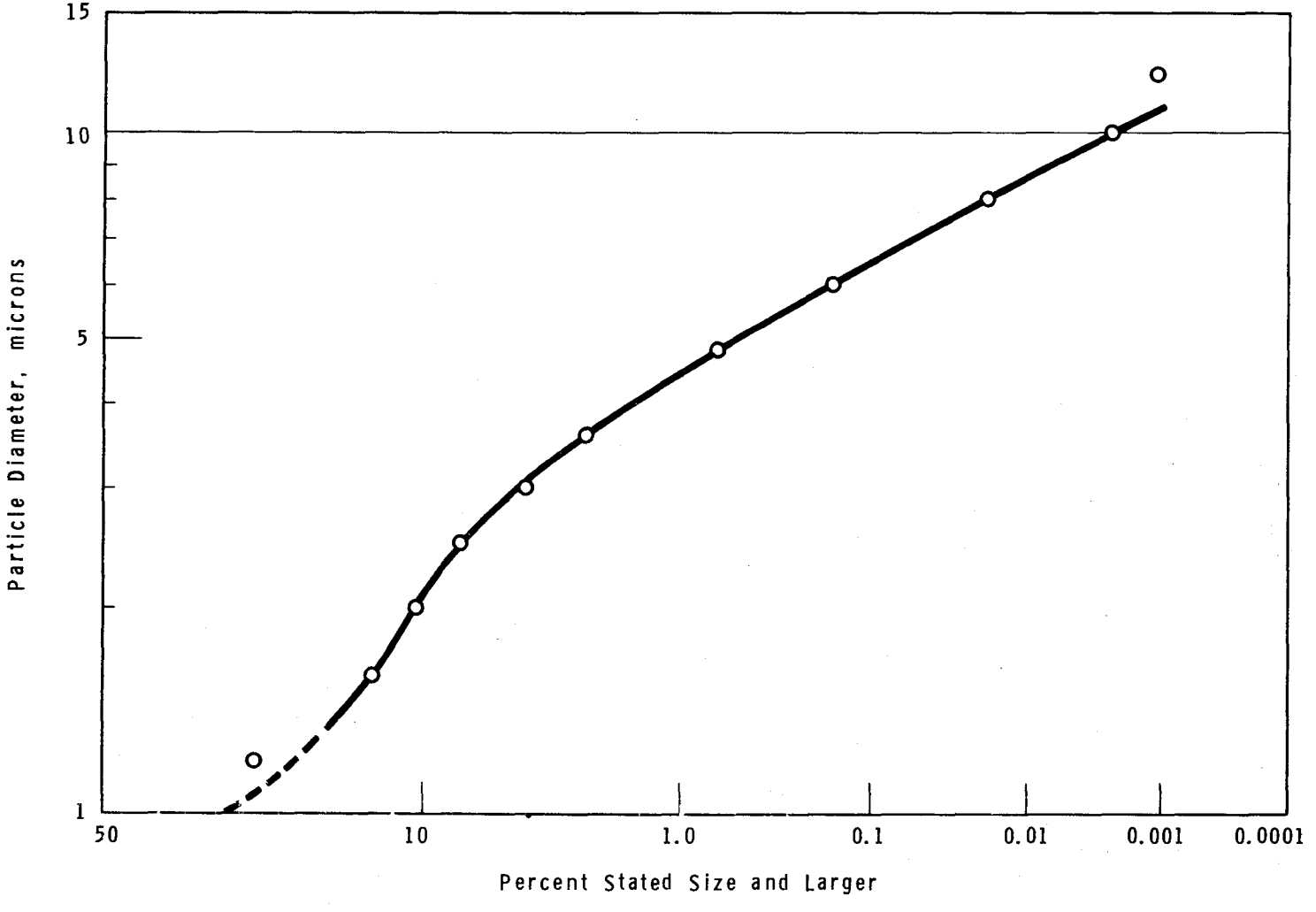


FIGURE 2: PARTICLE SIZE DISTRIBUTION ENTERING VERTICAL TUBE

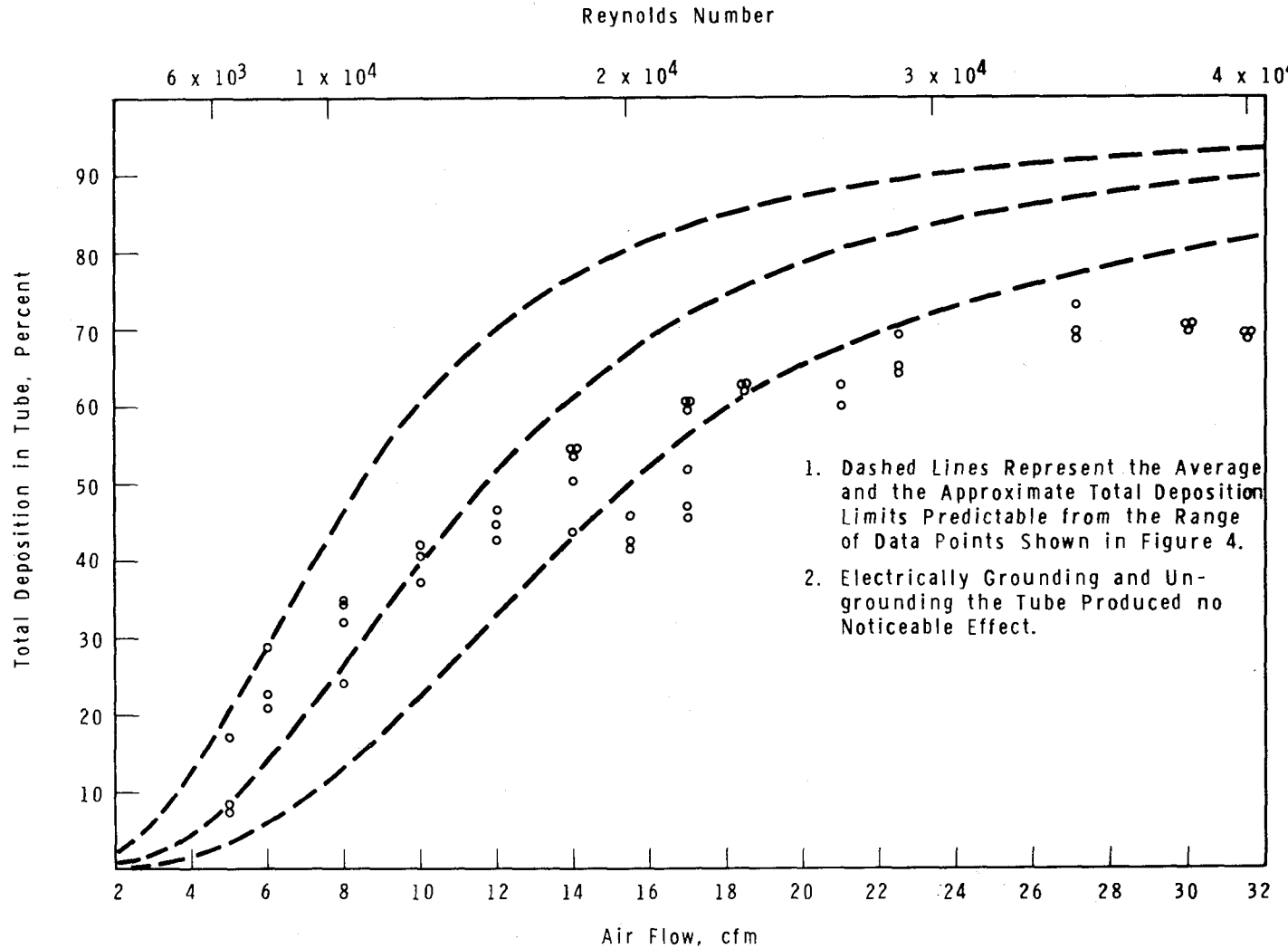


FIGURE 3: PERCENT DEPOSITION OF ZnS PARTICLES IN A 17.7 METER (58 Foot) LENGTH OF 2.93 cm I.D. (1-1/4 Inch O.D.) TUBING

for $5 < S^+ < 30$,

$$\frac{K}{V} = \frac{f/2}{1 + \sqrt{f/2}\left[5 \ln\left(\frac{5.04}{S^+/5 - 0.959}\right) - 13.73\right]} \tag{2}$$

and for $S^+ > 30$,

$$\frac{K}{V} = \frac{f}{2} \tag{3}$$

Friedlander and Johnstone chose as the independent variable the dimensionless deposition ratio, K/V.

The data for deposition in tubes available to date have been plotted in Figure 3. The solid line is a plot of Equation (1) for average flow and particle conditions ($S^+ < 5$) selected to best fit the bulk of the data.

For S^+ between 5 and 30 the experimental K/V falls about a factor of two higher than the values predicted by Equation (2).

For S^+ greater than 30, for the few experimental points in this range, Equation (3) predicts much lower values than observed. Equation (3) predicts a decreasing K/V with increasing S^+ in this range, yet the experimental data show no indication of a lower K/V. By modifying Equation (3) empirically to

$$\frac{K}{V} = \frac{f}{2}\left(\frac{S^+}{30}\right), \tag{4}$$

a reasonable fit was obtained for points at $S^+ = 30$ and greater.

The expected fractional deposition of the polydisperse zinc sulfide aerosol in the 1-1/4- and the 3-inch tubes was calculated with an IBM 7090 computer from Equations (1) and (2), and from the empirically modified Equation (3), the particle size frequency in Figure 2, and by using the deposition equation[4,5]

$$\frac{C}{C_o} = e^{-4\left(\frac{K}{V}\right)\left(\frac{L}{D}\right)} \tag{5}$$

The deposition observed in the 1-1/4-inch tube is shown in Figure 3. The predicted total deposition using a range of 0.3, 1.0, and 3.5 times the K/V values from Equations (1), (2) and (4) are shown as the three dashed lines. At the higher flow rates the calculated fractional deposition is greater than the experimental fractional deposition. Below a flow rate of approximately 10 cfm, the experimental total deposition is within the range that is predicted from the deposition velocity data shown in Figure 4. The most probable explanation of these differences is that particle re-entrainment becomes appreciable at the higher flow rates.

For the 3-inch-diameter tube, the predicted total deposition is a fraction of 1 per cent. In contrast, the experimental deposition was much greater, being constant at 6 per cent. This constancy may be interpreted to mean that within experimental accuracy the deposition ratio, K/V, is constant for all S^+

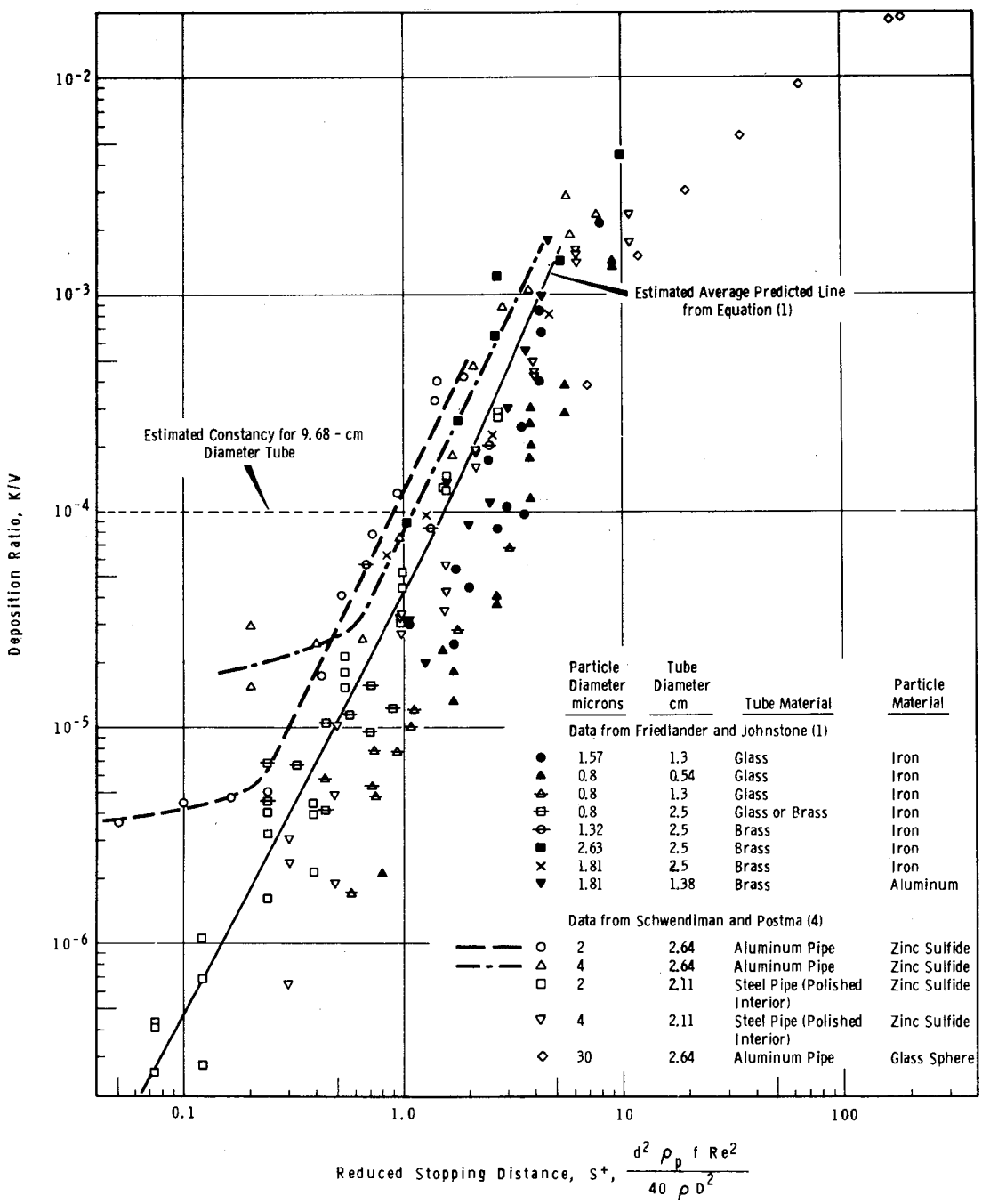


FIGURE 4: DEPOSITION RATIO AS A FUNCTION OF THE REDUCED STOPPING DISTANCE

values in this flow range for the 3-inch tube. Using Equation (5), K/V is calculated to be constant at 1×10^{-4} for the 3-inch-diameter tube for S^+ values between approximately 0.02 to 1.0. This conclusion is shown as the horizontal dashed line in Figure 4.

This conclusion is significant when considered together with Postma's and Schwendiman's data[4] for 2- and 4-micron-diameter zinc sulfide particles in a 2.64-cm-diameter tube. The data for these particles are represented in Figure 4 by the open triangles and circles, and the data are approximated by the two curved dashed lines. These dashed lines are indicative of the tendency for the deposition ratio, K/V, to be constant as S^+ decreases. This tendency supports the conclusion that was made for the 3-inch-diameter tube.

In addition, when the deposition of 0.004-micron-diameter particles[8] and the retention of iodine vapor[8,9,10] in tubes are considered, the conclusion is reasonable. Although the mechanism for deposition of these substances is different than for micron sized particles, the concentration gradient of these substances along the tube wall may be assumed to be approximated by a single exponential function. In this case, Equation (5) can be used to calculate an order of magnitude "pseudo" deposition ratio, K/V. The resulting range for the "pseudo" K/V is approximately 10^{-4} to 1. Also, these substances would have reduced stopping distances approximately 10^{-8} and smaller. These "pseudo" K/V values are considerably greater than the K/V observed for values of S^+ ranging from about 0.1 to 1. This is indicative of the fact that for some range of S^+ values, the value of K/V must increase as S^+ decreases. The data for the 2- and 4-micron-diameter tube are an indication that in this range of S^+ values, K/V is trending toward higher values than predicted by the overall correlation of the data.

CONCLUSIONS

Deposition in vertical tubes may be reasonably well predicted from correlations of Friedlander and Johnstone, and Postma and Schwendiman, for 1- to 10-micron-diameter particles for tubes with diameters of the order of 1/2-inch. If the predicted deposition is greater than approximately 85 per cent, re-entrainment will probably produce a lower than predicted total deposition. For larger diameter tubes, deposition can be predicted, but with less accuracy. The predicted deposition for 1-1/4-inch tubes should be adjusted using Figure 3 as a guide in estimating re-entrainment. Deposition in 3-inch tubes will be appreciably greater than predicted, although still a relatively small fraction for many particles and velocities and reasonable lengths of tubes.

The data suggest that for some tube diameters and for quite low S^+ values, K/V approaches a constant value or at least decreases at a much slower rate with decreasing S^+ than the correlations would predict. This divergence has not been satisfactorily explained but may show a transition to a deposition mechanism not accounted for in the turbulence theory used by Friedlander and Johnstone.

Should the transition be one from lower to higher deposition with decreasing S^+, after passing through a minimum this transition would be consistent with a postulate of a particle of sub-micron size which is least effectively removed in high-efficiency filters.[11,12,13]

NOMENCLATURE

C = volumetric average concentration, particles of a particular size and material per cc downstream in the tube

C_o = volumetric average concentration, particles of a particular size and material per cc upstream in the tube

d = particle diameter, assuming spherical shape, cm

D = tube diameter, cm

f = Fanning friction factor, dimensionless

K = deposition velocity, cm/min

L = distance from upstream to downstream points of interest in the tube, cm

m = mass of particle, gm

S = stopping distance, $\frac{m\ v_o}{3\pi\mu d}$, cm (Ref. 1)

S^+ = reduced stopping distance, $\frac{SV\rho}{\mu}\sqrt{f/2}$, dimensionless

T = gas temperature assumed to be constant at 70 F for all data

v_o = assumed equal to root mean square of the radial component of the fluctuating gas velocity, taken as $0.9\ V\sqrt{f/2}$ (Ref. 1)

V = average gas velocity, cm/min

μ = gas viscosity, poises

ρ = gas density, grams per cc

ρ_d = particle density, grams per cc

REFERENCES

(1) S.K. Friedlander, H.F. Johnstone. "Deposition of Suspended Particles from Turbulent Gas Streams," Ind. Eng. Chem., vol. 49, p. 1151, 1957.

(2) P.R. Owen. "Dust Deposition from a Turbulent Airstream," Int. J. Air Water Pollution, vol. 3, p. 8. 1960.

(3) A.C. Chamberlain. Transport of Particles Across Boundary Layers, AERE-M-1122, Great Britain, November 1962.

(4) A.K. Postma, L.C. Schwendiman. Studies in Micromeritics -- Particle Deposition in Conduits as a Source of Error in Aerosol Sampling, HW-65308, May 12, 1960.

(5) L.C. Schwendiman, A.K. Postma. Turbulent Deposition in Sampling Lines, HW-SA-2286, September 27, 1961 and TID-7627, pp. 127-136. October 1961.

(6) V.F. FitzPatrick, S.M. Nielson, L.C. Schwendiman. Particle Deposition in a One-Half Inch Conduit, HW-73404, June 8, 1962.

(7) B.M. Wright. "A New Dust-Feed Mechanism," J. Sci. Inst., vol. 27, p. 12. 1950.

(8) W.E. Browning, Jr., R.D. Ackley. "Particle Size Distribution of Radioactive Aerosols by Diffusion Coefficient Measurements," Nuclear Safety Program Semiannual Progress Report for Period Ending June 30, 1962, ORNL-3319, pp. 44-50. August 1962.

(9) J.D. McCormack, Unpublished Data, General Electric Company, Hanford Atomic Products Operation, 1963. (Personal Communication).

(10) M.N. Ozisik. An Analytical Model for Fission-Product Transport and Deposition from Gas Streams, ORNL-3379. Oak Ridge National Laboratory, August 1963.

(11) J.J. Fitzgerald, C.G. Detwiler. "Optimum Particle Size for Penetration through the Millipore Filter," Arch. Ind. Health, vol. 15, p. 3. 1957.

(12) W.J. Megaw, R.D. Wiffin. The Efficiency of Membrane Filters, AERE-R-4211, Great Britain, January 1963.

(13) W.E. Browning, Jr., R.D. Ackley. "Diffusional Characterization of Millimicron Radioactive Aerosols with their Removal from Reactor Gases," Nuclear Safety Semiannual Progress Report for Period Ending December 31, 1962, ORNL-3401, pp. 44-49. March 1963.

THE VALIDITY AND USE OF SUTTON'S EQUATION AS APPLIED TO STACK EFFLUENTS

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ABSTRACT

A simple determination of the maximum ground level concentrations of radioactive stack gases can be made by using the basic Sutton equation. Using simple assumptions, a correlation coefficient of 0.72 at a 95% confidence level was found between the calculations and sample results.

INTRODUCTION

In the gaseous diffusion process, a point is reached where the desired UF_6 is separated from light gaseous contaminants which have been introduced into the system either intentionally or unintentionally. These gaseous contaminants, commonly referred to as "lights," can be separated in the same manner as are the UF_6 isotopes. The contaminating "lights" all have molecular weights lower than that of UF_6 and are consequently separated more readily than are the UF_6 isotopes. An additional purge cascade is utilized beyond the UF_6 withdrawal point to further separate the "lights" from any UF_6 that might be carried along beyond this point. The "lights" include such gases as nitrogen, dry air, freon, etc. The "lights" pass from the purge cascade through alumina traps to remove the remaining traces of UF_6 and are finally exhausted to the atmosphere.

These alumina traps must be replaced periodically to recover the sorbed UF_6 and to restore the trapping system efficiency which degenerates in normal use due to plugging and depletion of the trapping chemicals.

In 1960, a study was made to determine the cost of frequent trap changes versus the value of the recovered enriched uranium. The study indicated that estimated annual savings in excess of $30,000 could be realized if the traps were changed only when the UF_6 concentration beyond the traps exceeded a fixed value. Health physics considerations presented the only potential objection to this proposal. As a result, health physics and meteorological studies relating to the hazards of this proposal were made.

HEALTH PHYSICS CONSIDERATIONS

A preliminary calculation of the uranium concentration in the stack gases indicated it would be on the order of 10^5 times the permissible level as indicated by the uranium

alpha activity for continuous off-site conditions. The allowable concentrations are 20×10^{-12} $\mu c/cc$ on site and 2×10^{-12} $\mu c/cc$ off site. Because of this high stack concentration, more detailed calculations were made to estimate the effects of atmospheric dilution.

The maximum "fall-out" concentration was calculated from Sutton's equation to occur from 485 to 4480 feet from the vent stack, assuming a constant wind velocity of 5.37 mph (the average wind velocity on plant site). The 4480-foot distance practically coincides with the perimeter road in the prevailing wind direction and is within the plant boundaries in all the other usual wind directions. Data previously collected for other considerations indicate that the maximum long-range effective "fall-out" distance agrees with the 485-foot value. Of significant consideration is the fact that at this 485-foot distance, the maximum permissible concentration is ten times higher than that for "off-site."

Calculations indicate the maximum uranium alpha activity to be approximately 14% of the off-site limits. A study of the past weather records shows that the wind is in the prevailing direction about 20% of the time; this is a safety factor not considered.

METHOD OF CALCULATION

All calculations were made from the basic Sutton equation for gases diffusing in the atmosphere. It was assumed that the stack effluent is, for all practical purposes, a gas.

The Sutton equation[1] used in the computation is given by:

$$\chi = \left(\frac{2Q}{\pi C^2 \bar{u} x^{(2-n)}} \right) e^{-H^2/C^2 x^{(2-n)}}$$

where: χ = ground level concentration (in grams per cubic meter)

Q = emission rate (in grams per second)

H = stack height (in meters)

x = distance downwind from stack (in meters)

C = diffusion coefficient dependent on wind velocity and stability parameter

$\bar{u}$ = average wind velocity (in meters per second)

n = stability parameter

The stability parameter, n, has the following general values:

Stability Condition and Temperature Profile	n
Unstable. Generally during sunny days; "Looping" plumes.	0.20
Neutral. "Coning" plumes.	0.25
Stable. Mild to strong inversion; "Fanning" plumes. Generally happens at night or early autumn mornings.	0.33

The distance (in meters) corresponding to the maximum concentration, using the Sutton equation, is expressed as follows:

1. Meteorology and Atomic Energy. Washington, D.C., U.S.G.P.O. 1955. p. 47.

$$x_{max} = \left(\frac{H^2}{C^2}\right)^{1/(2-n)}$$

Calculations were made as to the effect of varying stack height and wind velocity. The following tables show these effects:

Table I

EFFECT OF STACK HEIGHT ON MAXIMUM CONCENTRATION
(CONSTANT WIND VELOCITY OF 5.37 MPH)

	Percent of Maximum Allowable Concentration at Location of Maximum "Fall-Out"	
Stack Height	On-Site	Off-Site
81.4 feet (24.8 meters) (present height)	1.4	14
91.8 feet (28.0 meters)	1.0	10
105.0 feet (32.0 meters)	0.8	8
114.7 feet (35.0 meters)	0.7	7

Table II

EFFECT OF WIND VELOCITY ON MAXIMUM CONCENTRATION
(STACK HEIGHT OF 81.4 FEET)

	Percent of Maximum Allowable Concentration at Location of Maximum "Fall-Out"	
Wind Velocity (mph)	On-Site	Off-Site
3.35	2.2	22
5.37 (actual average)	1.4	14
11.18	0.7	7
20.00	0.4	4

The results shown in Table I indicate that an apparent advantage would be gained if the stack height were increased. However, an increased stack height would tend to bring the location of the maximum concentration off plant site, thus decreasing the maximum allowable concentration by a factor of ten. Therefore, because of this situation there would be no advantage to increasing the stack height.

Included in this paper are curves illustrating the effect of stack height and wind velocity on the maximum uranium alpha concentration (Figure 1), and, for different stability parameters, the relationship of stack height and wind velocity to the location of maximum fall-out (Figure 2).

From health physics considerations the computations showed that frequent alumina trap changes could be eliminated with a reasonable safety margin. However, due to the uncertainties of meteorological and operational conditions, it was obvious that special particulate samples should be collected and studied as an additional safeguard against excessive fall-out.

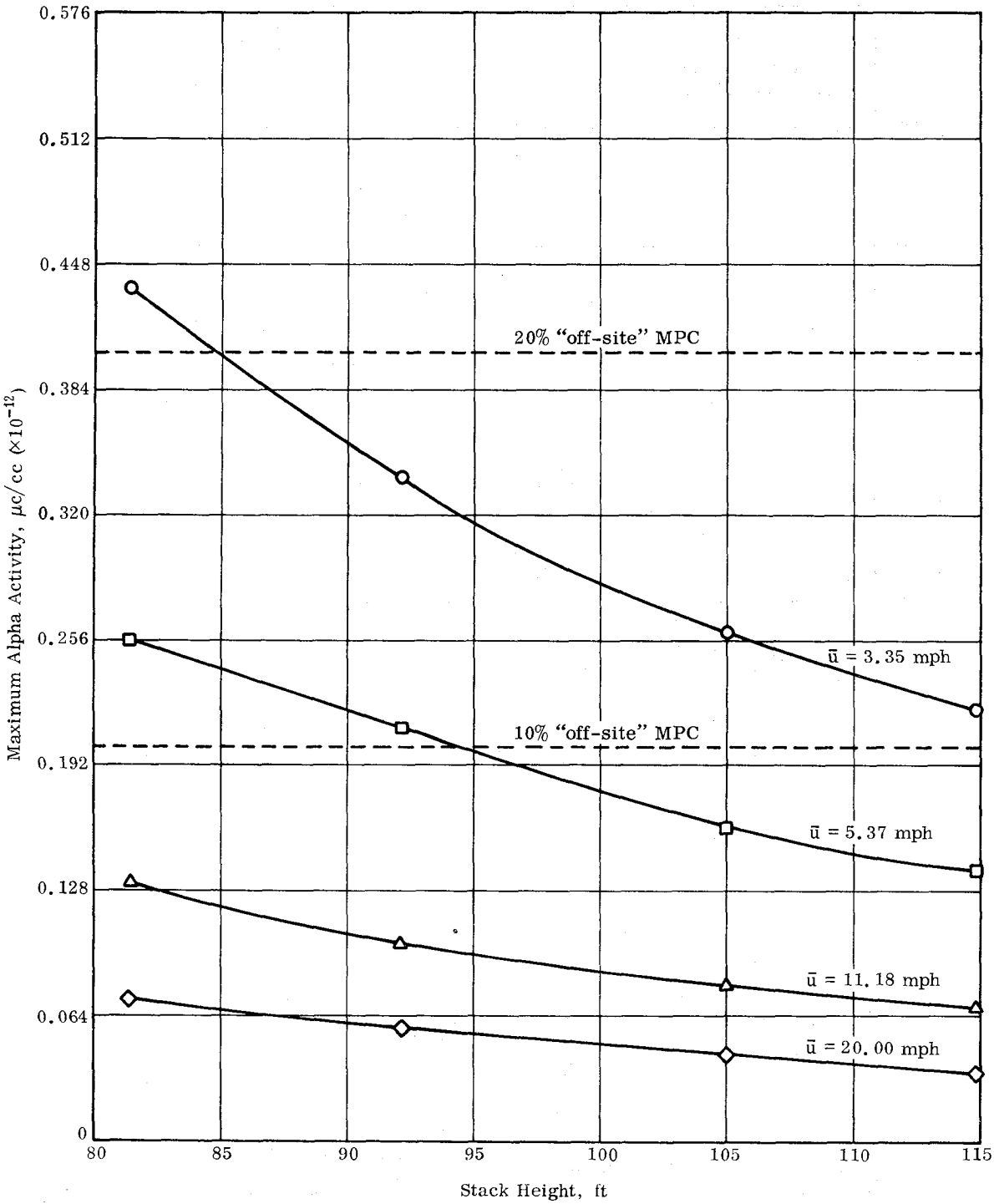


FIG. 1. EFFECTS OF STACK HEIGHT AND WIND VELOCITY

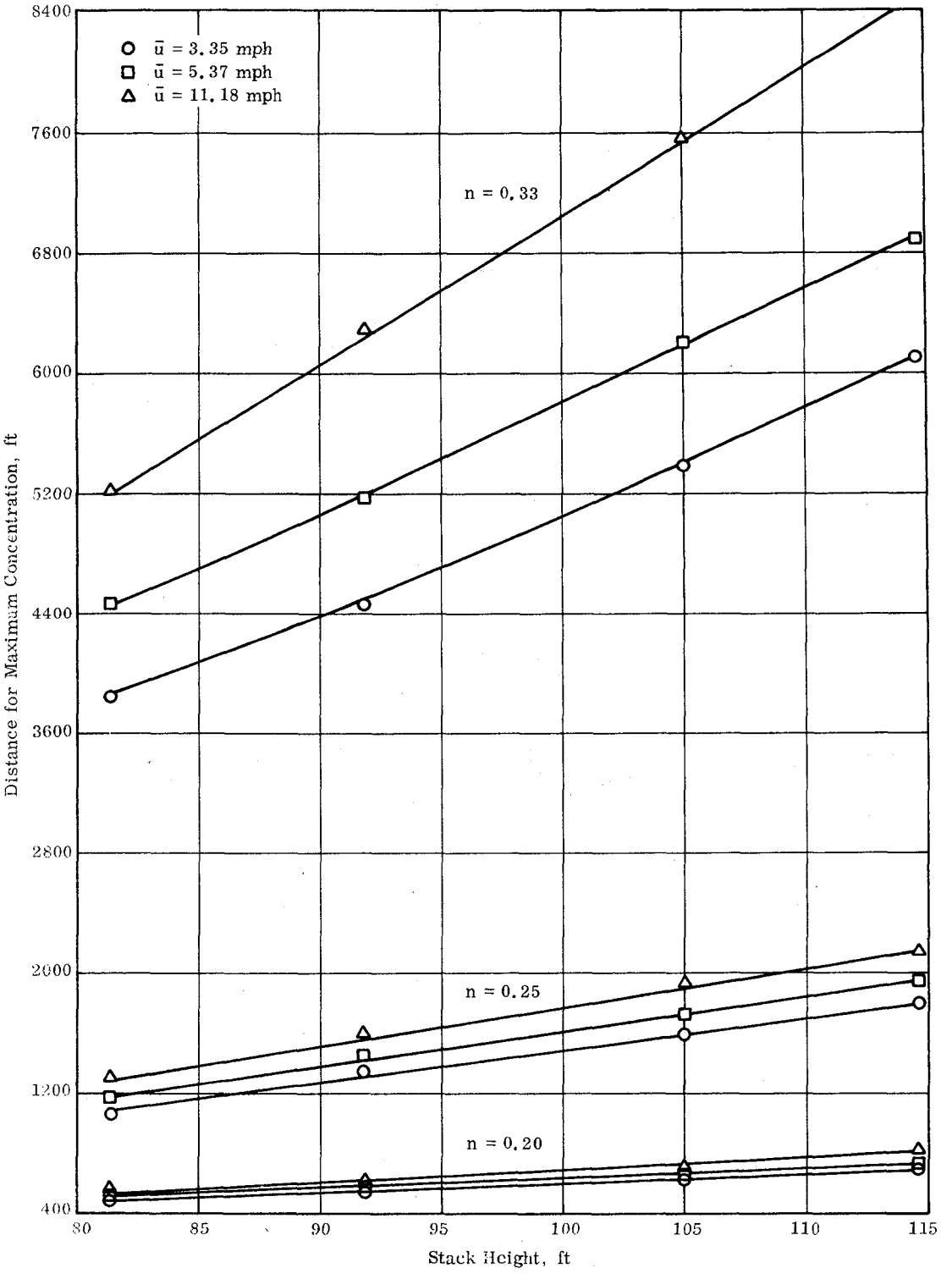


FIG. 2. EFFECTS OF STACK HEIGHT, WIND VELOCITY, AND STABILITY PARAMETER ON DISTANCE FOR MAXIMUM CONCENTRATION

SAMPLING

SAMPLING PROGRAM

A daily sample was collected on each scheduled workday from September 14, 1960, to the end of that year. For the month of January, 1961, the sampling frequency was changed to twice a week. During the study 85 samples were collected. The data are presented in Table III. The samples were collected in the approximate vicinity of the expected maximum concentration based on the prevailing weather condition at the time of sampling.

SAMPLING RESULTS

The individual results were compared to the value of the maximum concentration calculated using the appropriate wind velocity and stability parameter at the time of sampling. The sample results were placed in groups of ten consecutive samples. A plot of the average of groups of ten measured results versus the corresponding average calculated values is included as Figure 3. The coefficient of correlation was 0.72 ± 0.16 at the 95% confidence limit.

There are several factors that contribute to a low correlation coefficient; these are:

1. The limits of error and sensitivity were poor at the low measured counting rates.
2. The stack discharge was not continuous at a constant rate but fluctuated under wide values, as indicated by the space recorder charts. Also, there was no significant correlation between individual space recorder readings and uranium alpha activity collected on the samples at the corresponding times.
3. The calculations assumed that all the alpha activity originated from one vent stack. Consideration was given to determine the collective assay of all samples to determine the source of the uranium, but the amount of uranium collected on the filter papers was insufficient to make such an analysis.

Of the 85 samples collected, none exceeded maximum permissible concentrations at the sample location. All of the statistics and data refer only to the locations of maximum concentrations.

The statistical results are as follows:

1. The highest individual sample was 4.5×10^{-12} μc/cc. This is about 22% of the continuous "on-site" value.
2. The average measured value was 0.45×10^{-12} μc/cc or about 2.2% of the continuous "on-site" value. The average calculated value was 0.57×10^{-12} μc/cc, equivalent to 2.9% of the continuous "on-site" limit.

CONCLUSIONS

It is to be noted that the sampling program was carried out during the autumn and winter seasons (the samples were usually collected in the early morning); these seasons are probably the most unfavorable for venting due to the high frequency of inversion conditions during early morning hours. However, the over-all environmental air-borne alpha average, after the elimination of frequent alumina trap changes, was essentially the same as that prior to the new procedure. From the time of the initial studies through July, 1963, nearly 1000 routine particulate air samples have been collected both on-site

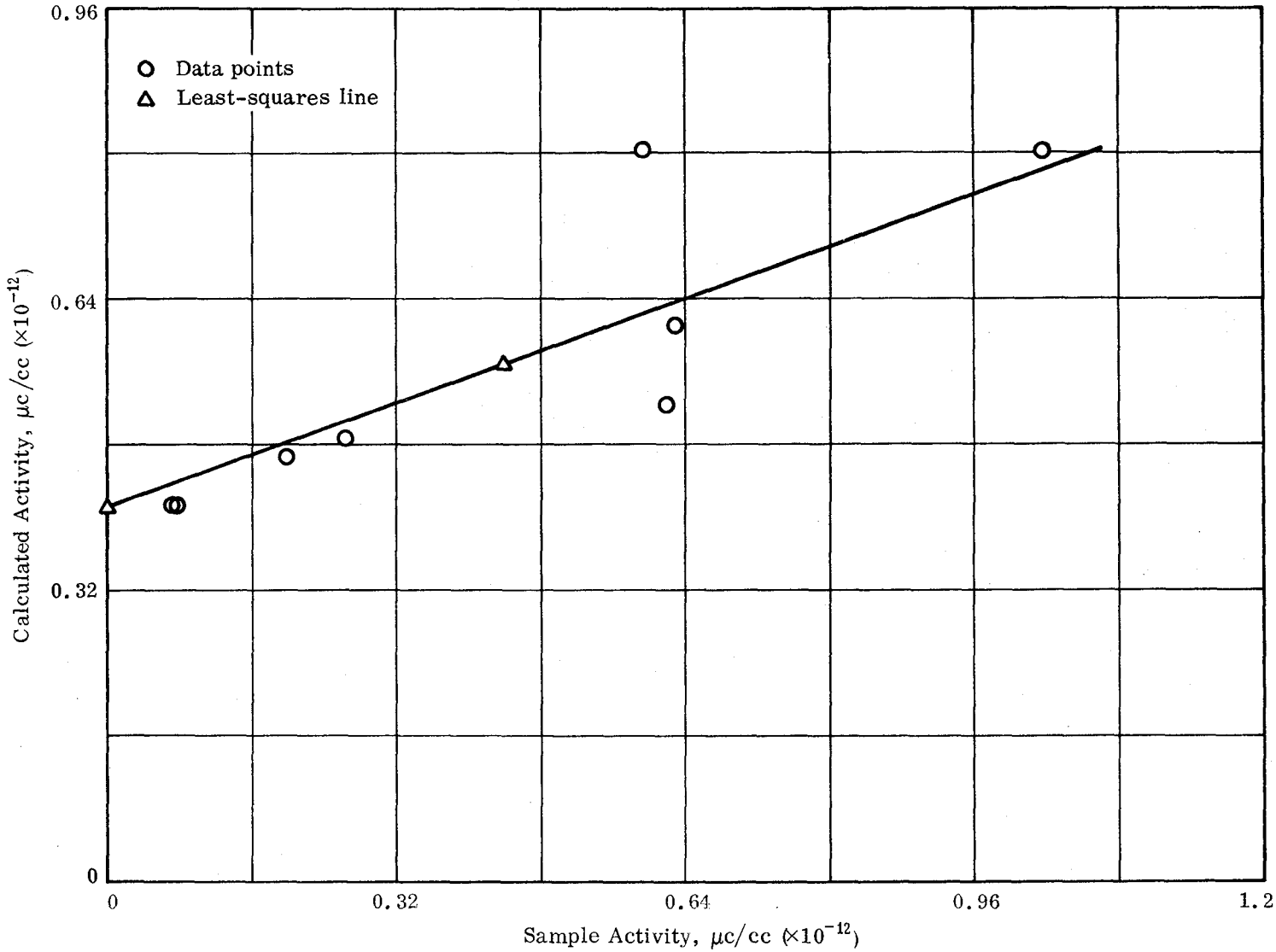


FIG. 3. COMPARISON OF CALCULATED AND SAMPLE RESULTS FOR 8 GROUPS OF 10

and off-site, with an average on the order of 1×10^{-13} μc/cc. Not one of these samples has exceeded the MPC of 2×10^{-11} and 2×10^{-12} μc/cc, respectively. Based on the calculated values and laboratory results, the reduction in frequency of the top purge alumina trap changes indicates that there is no significant health physics problem except under very unusual meteorological or operating conditions.

It is concluded that the basic Sutton equation can be used as a valid method for determining the ground-level concentrations of radioactive stack gases without the involvement of time-consuming air sampling procedures.

Table III

SAMPLING PROGRAM DATA

Date	Wind Velocity (mph)	Weather†	n	Results‡		Average for Prior Ten Values‡	
				Lab.	Calc.	Lab.	Calc.
9-14-60	1	69	0.25	0.544	1.456		
9-15-60	2	69	0.25	1.920	0.736		
9-16-60	1	69	0.25	0.560	1.456		
9-19-60	3	34	0.33	0.240	0.480		
9-20-60	5	34	0.20	0.528	0.288		
9-21-60	4	34	0.33	0.240	0.368		
9-21-60	4	34	0.33	0.336	0.368		
9-22-60	2	49	0.25	0.160	0.736		
9-23-60	1	69	0.20	0.080	1.456		
9-26-60	2	69	0.33	1.328	0.736	0.592	0.816
9-27-60	2	39	0.33	0.336	0.736		
9-28-60	7	39	0.20	0.768	0.208		
9-29-60	2	49	0.33	1.152	0.736		
9-30-60	4	79	0.33	0.704	0.368		
10-3-60	8	69	0.33	0.608	0.176		
10-4-60	*	39	0.33	0.128	0.288		
10-5-60	1	49	0.33	0.656	1.456		
10-6-60	6	39	0.33	0	0.240		
10-7-60	5	69	0.20	0.944	0.288		
10-8-60	2	69	0.20	0.912	0.736	0.624	0.528
10-11-60	2	69	0.20	1.072	0.736		
10-12-60	1	49	0.25	1.810	1.456		
10-13-60	1	49	0.25	2.030	1.456		
10-14-60	2	49	0.33	0	0.736		
10-17-60	3	69	0.25	0.480	0.480		
10-18-60	4	79	0.25	0.160	0.368		
10-19-60	6	29	0.33	0.640	0.240		
10-20-60	15	68	0.20	0.064	0.096		
10-21-60	3	68	0.20	0	0.480		
10-24-60	12	68	0.20	0.064	0.013	0.640	0.624
10-25-60	1	69	0.33	0.960	1.456		
10-26-60	1	39	0.33	1.104	1.456		
10-27-60	3	39	0.33	0	0.480		
10-28-60	4	49	0.33	0.032	0.368		
10-31-60	13	29	0.33	0	0.011		
11-1-60	10	78	0.20	0.192	0.144		
11-2-60	7	78	0.20	0.256	0.208		
11-3-60	14	88	0.25	0.064	0.112		
11-4-60	5	39	0.33	0	0.288		
11-7-60	6	78	0.20	0.016	0.240	0.262	0.488
11-8-60	1	69	0.20	0	1.456		
11-9-60	10	28	0.33	1.580	0.144		
11-10-60	8	78	0.25	4.480	0.176		
11-11-60	1	49	0.33	2.880	1.456		
11-14-60	1	79	0.33	0.320	1.456		

Table III (Cont'd.)

SAMPLING PROGRAM DATA

Date	Wind Velocity (mph)	Weather†	n	Results‡		Average for Prior Ten Values‡	
				Lab.	Calc.	Lab.	Calc.
11-15-60	11	78	0.25	0.112	0.128		
11-16-60	11	28	0.25	0.352	0.048		
11-17-60	9	69	0.33	0.256	0.160		
11-18-60	1	69	0.33	0.064	1.456		
11-21-60	1	49	0.33	0.304	1.456	1.0352	0.804
11-22-60	1	79	0.33	0.720	1.456		
11-23-60	12	38	0.20	0.016	0.128		
11-25-60	7	69	0.20	0.384	0.208		
11-25-60	7	69	0.33	0.112	0.208		
11-28-60	8	38	0.25	0.048	0.176		
11-29-60	20	78	0.20	0.480	0.080		
11-30-60	17	78	0.25	0	0.080		
12-1-60	10	78	0.25	0	0.144		
12-2-60	2	69	0.33	0.128	0.736		
12-5-60	1	79	0.33	0.064	1.456	0.197	0.467
12-7-60	10	78	0.25	0.128	0.144		
12-8-60	5	79	0.33	0.160	0.288		
12-9-60	2	69	0.33	0	0.736		
12-12-60	13	78	0.20	0.176	0.112		
12-13-60	2	69	0.33	0.032	0.736		
12-14-60	6	68	0.20	0.064	0.240		
12-15-60	11	38	0.20	0.160	0.128		
12-16-60	12	38	0.25	0.064	0.128		
12-19-60	7	79	0.33	0	0.208		
12-20-60	1	39	0.33	0	1.456	0.0784	0.416
12-21-60	12	78	0.25	0.080	0.128		
12-22-60	14	68	0.33	0.032	0.112		
12-23-60	7	69	0.33	0.016	0.208		
12-27-60	14	38	0.25	0.110	0.112		
12-28-60	5	69	0.33	0.144	0.288		
12-29-60	2	39	0.25	0.176	0.736		
12-30-60	7	39	0.25	0	0.208		
1-3-61	7	38	0.25	0.048	0.208		
1-5-61	2	69	0.20	0	0.736		
1-10-61	1	69	0.20	0.144	1.456	0.0752	0.416
1-12-61	1	69	0.20	0	1.456		
1-17-61	10	38	0.25	2.510	0.144		
1-19-61	5	58	0.25	0	0.288		
1-24-61	15	58	0.25	0.160	0.096		
1-31-61	1	79	0.25	0.208	1.456		

*Instrument failure; assumed wind velocity of 5 mph.

†Weather Code: 1 - Clear 2 - Rain 3 - Overcast 4 - Fog 5 - Snow 6 - Sunny
7 - Partly Cloudy 8 - Windy 9 - Calm

‡All values are reported in terms of 10^{-12} μc/cc.

INCINERATION OF WASTE CONTAMINATED OIL

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ABSTRACT

The accumulation of various organic liquid wastes contaminated with uranium is a problem at the National Lead Company of Ohio because of the potential of ground contamination and the high cost of maintaining these materials in storage. Of the various disposal methods investigated, incineration has proven to be the most successful. An oil burner is now operating on site capable of disposing of 400 to 700 fifty-five gallon drums of mineral oils and emulsions monthly. Uranium recovery from this process is virtually complete, and air contamination is held to acceptable levels.

INTRODUCTION

The Feed Materials Production Center (FMPC) located near Cincinnati, Ohio, and operated by the National Lead Company of Ohio for the AEC generates many types of uranium-bearing scrap. Most of this scrap is recycled to other parts of the process or is converted to a usable feed for other plants by the FMPC Scrap Recovery Plant. Until oil burning was developed, a method to dispose of waste organic liquids was not available. Hence, increasing quantities of these drummed materials accumulated on site. In addition to the hazard of fire from the flammable materials, the possibility of ground contamination from these uranium-contaminated wastes was also apparent. The drums containing these materials rust in the weather, acids in the wastes corrode the drums from within, and water in the drums sometimes freezes, causing many of these drums to leak. Redrumming is necessary as soon as possible after leakage is noticed to prevent contaminated wastes from washing into the storm sewer system and contaminating the small creek which runs through the site. The redrumming process was becoming increasingly costly, and was contributing, along with weathering, to losing the identification of the materials. It became necessary, therefore, to find a method to dispose of this backlog.

TYPES OF WASTE CONTAMINATED ORGANIC LIQUID

Although there are about 100 different classes of waste liquid organic materials stored at the FMPC, they can be divided into the following four principle types:

1. Mineral Oils

The typical contaminated mineral oil contains 2 g/l to 4 g/l of uranium, and is accompanied by a water phase which is usually lower in uranium content. Sludges which have settled to the bottom of some of these drums range from 5% to 30% uranium.

2. Emulsions

Uranium levels of 5 g/l to 10 g/l are typical for emulsions and for any accompanying water phase below the emulsion.

3. Waste Extraction Solvent

Uranium levels of 2 g/l to 4 g/l in the TBP-kerosene solvents are typical.

4. Wastes Rich in Chlorinated Hydrocarbon Solvents

This class of materials is not amenable to disposal by incineration since they would have to be carefully blended with other organic liquids before burning, and the decomposition products would be highly toxic.

EXPERIMENTAL WORK

Several attempts were made to adapt the Scrap Recovery Plant to burn contaminated oils with conventional burners or in existing plant equipment. However, the resulting process difficulties, high air dust levels, and the expense of required additional dust collection equipment made other approaches to a solution of the problem look more promising.

After several other methods of treatment were tried unsuccessfully, further investigation was made of the incineration of organic wastes. Mineral oil from which the water and sludge had been removed with a centrifuge was burned in a small pot to see if the ash could be retained in the pot and air contamination could be held to acceptable levels. It was shown that uranium recovery was virtually complete and air contamination was held to acceptable levels when the forced draft was controlled to assure visibly clean burning. Subsequent tests showed that the organic phase of emulsions broken with heat could be burned with the same results.

OPERATION OF THE OIL BURNER

The foregoing oil burning tests looked promising enough to justify the construction, early in 1962, of the oil burner presently in use (see Figure 1). Procedures for feed preparations and burning conditions were developed in the next few months, and additional feed preparation equipment found necessary to keep the burner supplied with burnable oil was installed.

The oil burner was started as a production unit operating 24 hours per day, five days per week in January, 1963. The process consists of four steps:

1. Cold or warm feed preparation

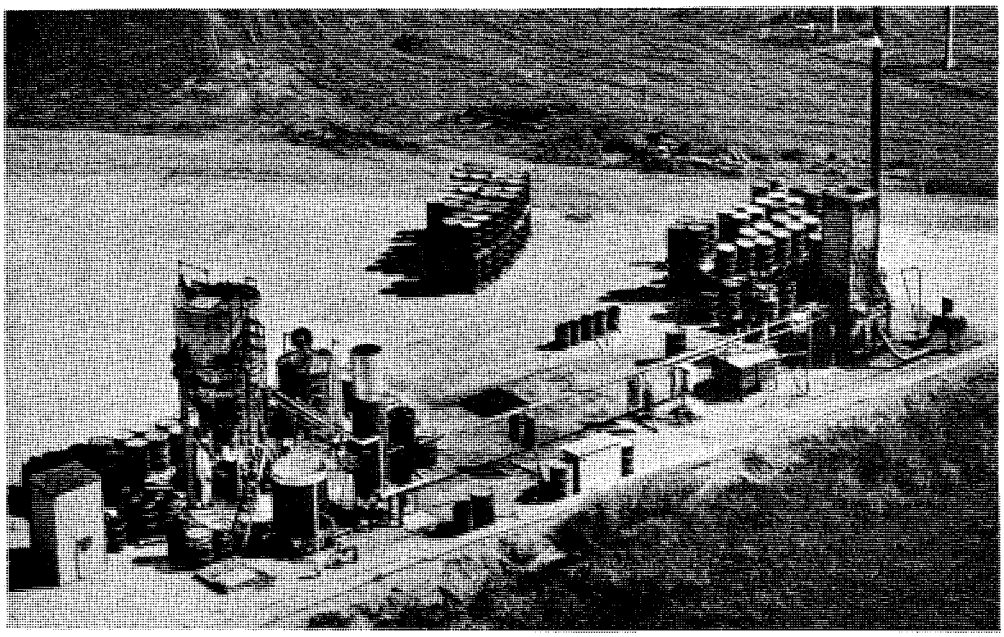


Figure 1 Photograph of Oil Burning Facility

BURNING WASTE CONTAMINATED OIL

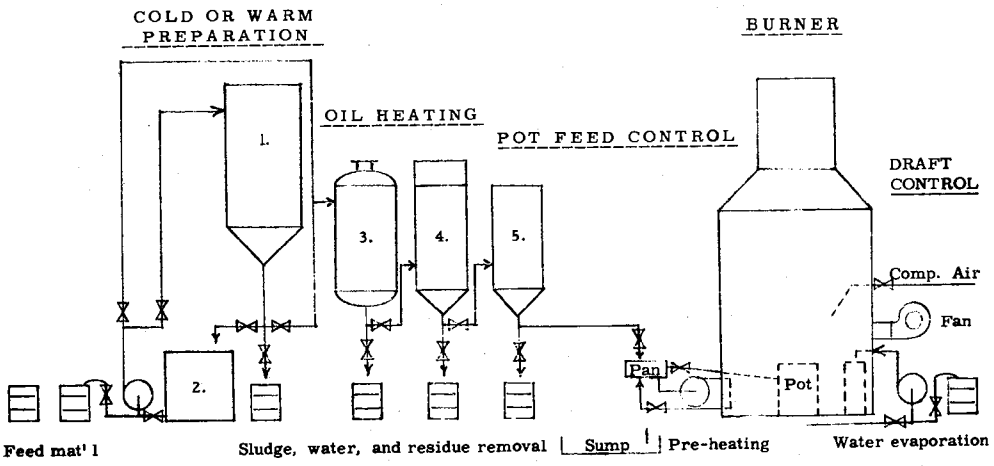


Figure 2 Schematic Drawing of Oil Burning Facility

2. Oil heating
3. Pot feeding
4. Oil burning

Each of the four steps will be discussed in relation to Figure 2, a schematic drawing of the facility.

COLD OR WARM FEED PREPARATION

Mineral Oils and Extraction Solvents:

Mineral oils are pumped from the feed drum to Tank 1, the receiving tank. Heavy sludges which would be difficult to pump are left in the bottom of the drum. Tank 1, with a capacity of 2700 gallons, serves as a surge tank and permits the blending of different feeds to supply a more consistent oil mixture to the burner. The tank is usually kept at ambient temperature; however, in winter, it is warmed to prevent freezing. Sludge and water are removed from the bottom of the tank and drummed separately. The oil is then ready for gravity feed through the rest of the system (bypassing Tank 2).

Emulsions:

Emulsions are also received in Tank 1. Any sludge or water is drained into drums as was described above. In these feeds, much of the water remains as an emulsion at this point in the process. The emulsion is then drained into Tank 2 and the pH is adjusted to 10 to 10.5 with Na_2CO_3 since it has been found that considerably more water is removed on subsequent heating if the material is slightly alkaline. The emulsion is then heated to nearly 212°F, and the effect of first heating is observed. If Tank 3 is nearly full, Tank 2 is pumped back to Tank 1 to again have separated water removed from the emulsion, and then be slowly fed into the hot oil in Tank 3. If Tank 3 has the capacity and is not above 212°F, the contents of Tank 2 may be pumped directly into Tank 3 from which tank the water is withdrawn. Cool or warm (less than 212°F) feeds are always fed slowly into hotter oil to prevent flashing of the water and more volatile organics into vapor which produces spattering.

OIL HEATING

Tanks 3 and 4 are the heating tanks which allow the temperature of the material to be raised slowly. Small amounts of sludge or residue, but very little water, are withdrawn from the bottom of Tanks 3 and 4 with mineral oil feed. The heat lowers the viscosity allowing more rapid settling of the sludges and residues. When emulsions are being fed to the heating tanks, the increased heat finishes breaking the emulsion, and some water is removed from the bottom of Tank 3. However, much of the water, along with more volatile organics, is vaporized in the heating process. Feed between tanks is slow and intermittent, allowing settled material to be withdrawn from the bottom before feeding is resumed. Liquid levels in the heating tanks are allowed to vary, but oil heating is still considered a semicontinuous process. Unless kerosene is a major component of the feed, the temperature of the oil in Tanks 4 and 5 is maintained at about 280°F.

POT FEEDING

The feed rate to the burner is controlled by the valve above the feed pan (Figure 2) to about 20 or 30 gallons per hour. This is about half of the volume of material delivered to the feed preparation system for processing; the other half is removed from the burnable oil in the feed preparation and oil heating steps. An effort is made to maintain the oil in Tank 5 at a reasonably constant level so that a stable feed rate to the feed pan can be maintained. The feed pan prevents rapid changes in pot feed rate when adjustments are made to the feed rate valve. This pan also is a safeguard against over-filling the burning pot, since the oil level in the feed pan is only slightly higher than the normal level in the burning pot. It has been found that some oils must be heated to over 300°F before burning to prevent the more volatile components from flashing when they reach the burning pot and extinguishing the flame. For this reason, oil is preheated in the feed pan to 325°F to 350°F by recycling oil from the pan through the burner and back to the pan.

OIL BURNING

The burning of the oil takes place within a stainless steel pot centered in a refractory brick incinerator. The high pressure draft system is supplied by compressed air (Figure 2). The low pressure draft system is supplied by a fan. Both systems are adjustable both in location and direction of air input to keep the off-gas clean. Experience has shown that some high pressure draft is necessary for clean burning.

Burning normally takes place with little or no smoke except when starting up or shutting down the burner. At these times a few minutes of heavy smoking and about a half hour of light smoking are expected. Heavy smoke, flame coming out of the stack, and entrained ash in the flue gas must all be avoided if contamination of the air is to be avoided. Average uranium levels sampled in the flue gas 5 to 10 feet downwind from the top of the stack are as follows:

Properly controlled burning	0.05 mg/m^3
Light smoke being emitted from stack	0.2 mg/m^3
Entrained ash visible above pot	0.4 mg/m^3
Flame coming out of stack	0.8 mg/m^3
Heavy smoke being emitted from stack	1.9 mg/m^3

The conditions which result in higher uranium levels are all obvious to the operator of the burner, and can be corrected by his adjusting the pot feed rate or the draft systems.

A smaller stainless steel pot, located in one corner of the burner, is used to boil off water removed from the preparation tanks or from the sump. Residue from this evaporation is added to the ash which remains in the burning pot after oil is burned. Three to six drums of ash, each weighing 400 to 500 pounds and assaying 15% to 30% uranium are removed from the burner each month. Although the major purpose of the burner is to dispose of waste organic liquids, the recovery of several hundred pounds of uranium per month which can be used as feed material for the FMPC Scrap Recovery Plant is a worthwhile adjunct to this disposal process.

Waste extraction solvent can not be continuously burned in the same manner as the heavier oils. The ash from this feed has more bulk, a uranium content of only 3% to 4%, and tends to form a crust over the liquid surface in the burning pot which extinguishes the flame. The flame of burning kerosene near the top of the burning pot has been found to be more destructive to the pot than the flame from heavier oils. Also, the crusted phosphate ash formed in this manner has been sintered at high heat, and has been found to give poorer uranium yields in subsequent recovery processes.

The most successful method to date for burning extraction solvent has been to use the pot as a boiler, adjust the draft to keep the burning vapor well above the liquid surface, and remove the pot from the burner before the ash has sintered. This method has not been fully developed with the present oil burner due to limitations of pot heating control and draft control. However, it is quite probable that the problems in burning extraction solvent in production quantities can be solved by further development work involving specialized equipment and capital expense.

CONCLUSIONS

1. Incineration has proven to be the only practical method yet developed to dispose of waste contaminated oil and other organic wastes at the FMPC.

2. The problems inherent in burning extraction solvent can probably be solved by further development work.

3. Nearly all organic wastes need some preparation to serve as burnable feed for a burner. Heating to progressively higher temperatures, along with phase separation, has proved successful in preparing all types of organic wastes for burning.

4. Burning contaminated organic wastes can take place with virtually complete uranium recovery and acceptably low uranium discharge to the air. Careful control of the burner feed rate and draft is necessary for successful operation.

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