

## PROGRESS ON THE UNIVERSITY OF ILLINOIS CONTRACT

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The objective of the work at the University of Illinois is to study the properties and behavior of aerosol particles especially as they are related to problems in atmospheric pollution and gas cleaning connected with atomic energy operations. During the past two years attention has been given to the physical and chemical properties of solid aerosol particles as they occur in the air of industrial and urban communities. Two technical reports have been issued, as follows:

T.R. No. 15, (Serial No. COO-1017) "Electrostatic Effects in the Deposition of Aerosols on Cylindrical Shapes," March 15, 1958.

T.R. No. 16, (Serial No. COO-1018) "The Agglomeration of Solid Aerosol Particles," March 1, 1959.

Since copies of the reports were sent to AEC contractors and are generally available at the AEC Technical Information Service at Oak Ridge, Tennessee, only a brief summary of the work will be given here.

In T.R. No. 15 a fundamental study of the deposition of small particles on cylindrical collectors in the presence of electrostatic forces is described. Attention is given to three cases: (1) an uncharged cylinder is surrounded by an atmosphere of charged aerosol particles; (2) a charged cylinder is surrounded by an atmosphere of uncharged particles; (3) both the cylinder and the particles are charged. Mathematical equations were developed for the three cases and solved by the ILLIAC, an electronic digital computer. An experimental study was made of the efficiencies of collection of liquid aerosol particles on cylindrical collectors from a moving stream of gas under various electrostatic conditions. The experimental results agreed well with the theory and the results should be useful in the engineering design of aerosol collectors. An experimental study was also made of the effects of electrostatic charges on aerosol particles on the filtration efficiencies of glass fiber mats and tangled-wire dipole mats.

In T.R. No. 16, measurements are reported on the effective diameter, porosity, and uniformity of agglomerates formed from several species of aerosols. The studies were made by means of a Millikan Cell and the results were compared with electron micrographs of the agglomerates. The results show that:

- (1) When an agglomerate is composed of particles of uniform size and shape the void space is minimal and the effective density is close to that of the primary particles from which the agglomerate is formed.
- (2) When the primary particles are not uniform in size and shape there are wide variations in the density of the agglomerates and a plot of  $CD^2\rho$  versus mass differs considerably from the line calculated from the normal density of the substance.
- (3) When the primary particles have irregular shapes there is a difference between the drag diameter of the agglomerate determined from rising and falling velocities. This conclusion has practical significance in the efficiency of electrostatic precipitation of such aerosols.
- (4) The cascade impactor can be used for determining the size and size distribution of agglomerates when the Millikan Cell is used to provide supplementary information about the nature of the agglomerates.

The study of agglomerates is being extended to include the effects of humidity, the presence of organic vapors, and the presence of several species of aerosols on the nature of the agglomerated particles. The results of this work should give important information for engineering purposes and on the physiological effects of breathing air containing aerosols.

Studies have also been made on the rate of growth of aerosol particles that act as nuclei in the condensation of water to form fogs and clouds. In this work, two experimental methods were used. In one, a method for measuring the instantaneous rate of growth of nuclei within the first 50 milliseconds after the particles are exposed to moist air was developed. The results with sulfuric acid nuclei show that the rate of growth becomes constant within this interval of time. Measurements are now being made on sodium chloride nuclei, and on nuclei of molybdenum oxide, lead oxide, and other oxides and salts that are representative of fission products in air.

Studies were also made on the equilibrium composition of fogs formed in the presence of mixtures of two species of nuclei. The objective of this work is to find if there is a selective effect in the nucleation of clouds or fogs so that one species or size of nuclei is preferred as condensation nuclei. Measurements were made on the equilibrium composition of fogs. The relative amount of fog droplets nucleated by each of two species was measured by the chemical properties of the droplets. Manganese sulfate nuclei and sodium chloride nuclei were used. The former catalyze the absorption and oxidation of sulfur dioxide from air, whereas the latter produce only inert fog droplets. When sodium chloride nuclei are present in about equal concentration and in about the same size range as the chemically active nuclei the total activity of fogs for the reaction is reduced to less than half of that when only manganese sulfate nuclei are present, so that it appears that for this pair of substances sodium chloride nuclei would be selected in the condensation of water in high clouds that are formed by adiabatic expansion. It has been observed that droplets of fog are formed when the relative humidity is below 100% and these are much more active for the absorption-oxidation reaction than the larger unsaturated droplets normally present in fogs. This work is also being continued to study the effects of very small aerosol particles in the nucleation of other reactions.

## HARVARD AIR CLEANING RESEARCH ACTIVITIES 1957-1959

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My comments will serve to introduce the subsequent papers which will go into detail on the specific projects. I would like to indicate, however, that the description and discussion of Harvard activities as presented here are not solely Atomic Energy Commission supported contract work. The paper which Mr. Yoder will present on particle counting instrumentation, and the work Mr. Levenbaum will report, covering our pilot-plant studies on a high-temperature filter development and blast cleaning approaches, are supported by the American Iron and Steel Institute project at Harvard. In addition, I will mention briefly some work that is supported by our own University funds.

The major efforts since our Fifth Air Cleaning Conference at Harvard in 1957 have been devoted primarily to three particular items which will be described in detail in later papers. The first is the economic survey we are conducting on air and gas cleaning costs which will be presented by Mr. Fitzgerald. In our opinion, this is a most important project if atomic energy operations and applications are to be placed on a sound financial basis. For example, there is a need for some detailed evaluation and costs of air cleaning in proportion to the performance expected.

The next major project is the incineration study on which Mr. Dennis will report our progress and developments. I would like to

add that we hope to have the final device as a prototype unit for manufacture completed this calendar year. We are as anxious as the AEC to get this particular type of equipment into field applications where they are needed.

The third major item is the development of inexpensive efficient low resistance and long-lived operating devices for the removal of radioactive iodine and other halogens. I will present extended data later in the session indicating our progress.

Aside from these major developments, which will be covered by separate papers, I would like to mention six other projects on which some progress has been made since the 1957 presentations.

One project which was not discussed at the 1957 meeting is the containment scrubber. This project was the result of discussions with Oak Ridge National Laboratory Waste Disposal groups working on the aerosol and gas emanations from ceramic waste fixation studies on liquid waste disposal. It appeared to us that there was a possibility of developing a simple procedure which would collect the evolved fission gases and aerosols that would occur in a much simpler manner than the elaborate multi-stage filter that had been proposed. In this regard we proposed a closed-cycle, educator type scrubber similar to the S-K unit. This scrubber could be used with a caustic solution which would serve as an absorbent and reactant with effluent materials. The performance of the scrubber is not critical because the collection efficiency can be enhanced by multiple passes through the unit in a recirculating system. At the present time we have a small (less than 100 cfm) unit set up in the laboratory and are trying to determine open-cycle efficiencies of the educator scrubber under various conditions. Very little information of this type exists in the literature. Once this phase is complete, we plan to proceed with typical nitrate waste boiling reduction to

determine the kind of aerosol problem that would result. The final step would involve a closed circuit evaluation of such a system.

The second item on which we have continued further studies is that of the electrostatic fluidized bed and other approaches that were discussed at the Fifth Air Cleaning Conference. We have proceeded to develop this more completely in the way of actual design parameters and have now constructed a 100 cfm pilot plant to evaluate the principle on a much larger scale than the 1-2 cfm laboratory study. At the present time, we are having difficulty maintaining proper fluidization in this unit but we expect to overcome this by better gas distribution through the bed. In conjunction with the electrostatic project we have developed another approach in which single twisted fibers are charged by contact friction. These form the filtration targets within the gas stream. We have made a small laboratory scale unit for evaluating this procedure as well as a larger scale multiple fiber unit. The chief advantage of this system which appears promising at the present time is the fact that it offers practically no resistance to air flow and does not require an auxiliary charging system. However, actual performance data has not yet been obtained on the models constructed.

Under the program of evaluation of new approaches submitted to the Commission, we have continued to study the performance of the Pulverizing Machinery Company Mikro Pulsaire unit. We have tested this device as a large 500 cfm unit and have already completed studies with fly ash, iron oxide, and several other aerosols. It appears that cleaning is a function of the pressure level and is independent of the pulse duration. The cleaning of dusts  $> 0.5 \mu$  presents no problem using the pulse cleaning mechanism. However, the pulse effectiveness falls in performance if bag resistance is created by high resistance deposits such as extremely fine fume or aerosols. To date the equilibrium pressures with fly ash particulates produces relatively low resistances with equilibrium at reasonable values whereas those with finer aerosols result in

pressure loss values which consequently produce low capacities in the unit. In order to evaluate this device at higher temperatures, a small 70 cfm model was supplied by the company. This has been tested at 530°F on fly ash and iron oxide fume. It was found that at temperature the capacity is reduced and the resistance at equilibration on fume shows the same limitation as the larger unit. It appears that the pulse cleaning mechanism is better suited to coarser aerosols which do not permeate the felt.

We have continued to evaluate miscellaneous media for possible applications to AEC and in this connection have looked at a number of newer fabrics of glass-plastic combinations and synthetic foams which may have some value as prefilters or roughing filters.

In closing, I might mention one Harvard project which may be of some interest -- a study of the use of fluidized beds for gas removal. Some early studies have been made in this regard and we have been looking at the problem of trying to eliminate sulfur dioxide from power plant effluents by means of fluidizing activated carbon. These studies to date indicate about 1 per cent attrition per pass in a fluidized carbon bed. While greater throughput is possible, the performance falls off rapidly due to the streaming through the large voids. It had been hoped that the turbulent and eddy diffusion would enhance collection despite the voids. From this study some idea of the ways in which carbon can be used in a moving bed have been developed. It is possible that these may be applicable to processes such as iodine removal in dissolver and other processes which involve iodine in the off-gas.

## Discussion

- Q. (Stevens) Any summary data available on tests of pulsating units?
- A. (Silverman) We didn't bring it with us. We had thought originally of putting a complete paper on the program but it will be out as an AEC report during this year. I don't know if Dick has any data with him but I didn't bring anything but our progress reports. I tried to summarize this in terms of the load capacity in the high pressure drop of fine particulate. Do you have some comments on that?
- C. Yes, we are trying out one of the units we have in our plan, running some tests of some of the burnouts we have. We just installed them. We haven't quite started the thing yet. I was wondering just what information you have available because we got some of the production people and maintenance pushing, as they see the unit they know their overrigged blow rings. They have been unhappy for many years over blow rings like so many other maintenance people and we have to give them some kind of an answer.
- C. The difficulty we find with it is that while it works fine, coarse particulate to a CFM per square foot on fine particulates, the pressure drop builds up so that your capacity is down. In the air economy of 90 lb. air, multiple pulses is fairly critical. The thing we find is that it isn't the volume of air that does the cleaning, it is the flexing of the bag by the reverse pulse. So it is really sort of a snap cleaning and we have taken shock transducer measurements all over and we are pretty much convinced that air volumes are not critical but the pulse pressure is. The duration of the pulse pressure does not seem to be important.

## ECONOMIC SURVEY OF AIR AND GAS CLEANING OPERATIONS WITHIN THE AEC

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### Introduction

A preliminary survey of air and gas cleaning systems was initiated by personnel of the Harvard Air Cleaning Laboratory at the request of the Division of Reactor Development, U. S. Atomic Energy Commission. During the Fiscal Year 1959, eleven major AEC and subcontractor sites were visited for purposes of reviewing their air cleaning systems and to enlist their cooperation in the joint participation of a technical survey of air cleaning. Personnel and management at all sites have been very cooperative as indicated by the material compiled in the Appendices.

In the preliminary survey each site has analyzed its own air cleaning operations and prepared an analysis of the technical and economic aspects of air cleaning in a manner most appropriate for its own needs.

The cost and the effectiveness of air cleaning systems are important considerations. An economic survey of the air cleaning cost, however, is of little value unless we can integrate these costs together with the corresponding degrees of protection and radioactive decontamination that are achieved under stated conditions. Consequently, this study is essentially a technical air collection survey with the economics as an important but not the only factor considered in the total appraisal.

It should be clearly noted that at the present time it will continue to be difficult to compare the cost data from one site to the cost data from another since the conditions of collection and the requirements for air cleaning can and do vary considerably. Therefore, it shall be necessary in each instance to include significant qualifying remarks. No attempt in this report or in future reports will be made to compare data from individual sites. The data will be presented with qualifying remarks thus allowing individual comparisons. The differences in situations, however, may make the result of such comparison both unwise and unrealistic.

For an essentially complete analysis of the Economic Survey Program, it seems appropriate that we set forth the following questions for discussion, with respect to the purposes, status and plans of the Program.

What is the purpose of the program?

What progress has been made in the furtherance of this program?

What are the future plans?

### Purpose of the Survey

The primary purpose of this survey is to provide appropriate and (physically and economically) efficient air cleaning systems. The prime mover of this survey is the Division of Reactor Development, U.S. Atomic Energy Commission. In the final analysis, however, good administrative and managerial practices in any technical operation require an analysis of the cost and effective use of air cleaning systems.

The methods and the schedules to fulfill the stated objective are listed in Table 1 below.

TABLE 1

<u>Statement of Goal</u>	<u>Scheduled Completion Data</u>	<u>Comments</u>
1. Establish Preliminary Criteria	1956	Criteria set forth on pages 95 to 97 in TID-7551
2. Promulgate the Criteria	1957	Announcement formally made at Fifth AEC Air Cleaning Conference (See TID-7551)
3. Make Preliminary Survey	1959	Eleven sites visited in 1959. See next section on Status of Survey
4. Evaluate Preliminary Data	1959	Preliminary evaluation of survey reported at Sixth AEC Air Cleaning Conference
5. Initiate Final Survey	1959	Includes the development of improved criteria and submission of the criteria to additional sites for completion
6. Integrate Data	1960	Involves the compilation of all the data into an appropriate form for the most effective use by all concerned.
7. Recommend Appropriate Research	1960	On the basis of the survey, a recommendation will be made with respect to the research required to further the primary objective to provide appropriate and effective air cleaning systems.

- |   |      |   |
|---|------|---|
| 8. Communicate Final Findings to Participating Groups | 1960 | Make available the basic data to the participating groups and obtain their comments and ultimately their acceptance of the material to be submitted in the future for general distribution. |
| 9. Present Data at the Next Air Cleaning Seminar      | 1961 | Make available reviewed data for general discussion and distribution.   |
| 10. Compile a Manual                                  | 1962 | On the basis of the data compiled, draw up a manual on "Air Cleaning Management" for broad use in the Nuclear Industry.   |

The compilation of data from this survey will aid all sites in the beneficial and economical use of air cleaning systems. Such analysis and discussions have already been proven to be successful in the integration of available data on air cleaning systems. It is also evident that such analyses will indicate the need and type of research that will be most beneficial and effective. The need for a manual on air cleaning systems, their effectiveness and costs with respect to the growing nuclear industry is evident. This survey will serve as the basis for the compilation of an adequate manual that may be effectively used in the nuclear industry.

#### Status of the Survey

During 1959, eleven major AEC installations were visited wherein the Economic Survey was discussed. These surveyed installations included the Brookhaven National Laboratory, the Savannah River Plant, Oak Ridge National Laboratory, National Lead Company (Fernald, Ohio), the Connecticut Aircraft Nuclear Experimental Laboratory, the Knolls Atomic Power Laboratory, Aircraft Nuclear Propulsion Department, (G.E.), Argonne National Laboratory, Hanford Atomic Products Operations, University of California Radiation Laboratory (Berkeley and Livermore), and the Los Alamos Scientific Laboratory.

The preliminary economical survey criteria as set forth in TID-7551 were discussed. The preliminary data as compiled by the responsible personnel at the corresponding sites are presented in the Appendix. In each instance, the basic objectives of the survey were discussed and the individuals were given complete freedom as to the expression of their physical and economical air cleaning data. Consequently, there has been at this time no attempt made to standardize the data since significant data could have been omitted as a result of such standardization. In addition, the use of qualifying statements was encouraged to assure a more realistic analysis of the air cleaning costs and the effectiveness of these systems with respect to the basic requirements.

In addition, to the material compiled in the Appendix, the personnel of General Electric Atomic Nuclear Propulsion Department in Ohio, have compiled considerable economical data on their air cleaning activities which has not at this time been reduced to tabular form.

Data on air cleaning specifications as set forth by individual sites have been compiled and will be summarized in the final report on the Economic Survey. These specifications are, in general, performance specifications.

Several sites have developed simplified methods of classifying their air cleaning systems and areas. In general, a color code with transparent plastic overlays are employed to indicate the positions and the types of air cleaning systems used in their plants. These methods and procedures of classification will also be summarized in the final report.

Additional material is being prepared by several of the sites listed above and the material will be submitted for compilation into the final report.

The air cleaning systems that were reviewed included systems in reactor areas, separation processing areas, fuel and accessory fabrication areas, production areas, high level pilot plant and nuclear experimental areas. The collection media that are used in the air cleaning systems reviewed included roughing filters, absolute type filters, bag collectors, cyclone separators, electrostatic precipitators, scrubbers oil mist collectors, and deep bed filters. The capacity of these systems varied in flow rates from  $10^2$  cfm, to  $10^1$  cfm.

The space requirements range from approximately  $10^{-2}$  ft<sup>3</sup>/cfm to  $10^{-4}$  ft<sup>3</sup>/cfm. The efficiency requirements vary from 50% to 70% for precleaning filters; 90 to 99% for high efficiency precleaners and final filters; and greater than 99.9% for ultra high collection units. It should be noted here that in most instances, the actual collection efficiencies are not known. However, the "effectiveness" of the unit, in general, is known since measurements of the effluent are made in the stack and/or in the environs such that the occurrence of the release of quantities greater than the maximum permissible levels are prevented. From an operational and regulatory viewpoint, this measurement of the effectiveness of the collection media is more appropriate than a specific analysis of a collection unit using a liquid particle of a narrow particle size range considerably different in structure, particle size, density, etc., than the toxic material in the effluent. From a cost-effectiveness viewpoint, however, it is somewhat difficult without before and after filter unit sampling data to assign an efficiency to the unit. Since the particle size distribution and the composition of the toxic aerosol can and frequently does change with various operations, an average efficiency would have to be applied. Consequently, a range of efficiencies with respect to a collection medium is presented in Figure 1 which expresses the relationship of the effectiveness of air cleaning systems to cost of these air cleaning operations.

The frequencies at which the collection media are changed vary from period of every two months to once in 10 years. In general, the roughing filters are changed at a frequency twice that required for absolute type filters. The collection media are changed on the basis of pressure drop, time cycle, operational requirements (e.g. time available during reactor shutdown), mechanical failure, pH value of the solution, and observations (indicate unit to be dirty). These collection units are changed when a request is made by a variety of groups including the health physics organization, the industrial hygiene unit, the operations group or the plant maintenance or service section.

The methods of handling, storage and disposal of the filter unit vary considerably from one location to another. Consequently, the costs of these waste management problem vary over a wide range.

Some handling problems involve airborne hazards while others pose a significant external radiation problem. Liquid waste problems may require special processing methods of neutralization. In some instances, materials are incinerated or baled before storage or shipment of the reduced volume to another site for burial or for sea burial.

The actual cost of the air cleaning operations have been expressed on the basis of equipment charges, labor charges and the cost of operations in terms of dollars and/or man-hours per unit volume of air process per year. It will, however, be readily observed that other factors may be more important in the assessment of the cost-efficiency relationship. In some instances, the volume of air processed is maintained at a relatively small value to collect the toxic material near the point of release rather than after dilution in a less toxic atmosphere. In such instances, the cost per curie collected on the filter per year may be a better and more justified assessment of the cost-efficiency relationships. Since, however, the dose-rates from some filter units are relatively higher per curie than from others and therefore requiring more frequent change and a less effective use of man power, etc., the cost per dose-rate per year relationships may be a more realistic ratio than those stated above under certain circumstances. It should be noted that the cost per cfm/year for the cases reviewed in the Appendix vary from \$0.0004 to \$7.0.

The technical and economical data presented in Appendix I (Tables 1 to 7) permits a preliminary assessment of the relationship between cost and efficiency of the various systems. It should be noted that the cost will vary with respect to the conditions expressed in the last section and the efficiencies will vary with respect to the materials present in the effluent. Consequently, a spread of cost values and efficiencies or penetration are presented in Figures 1 and 2.

In essence, one might expect a specific type (e.g. "Absolute Filter") of air collector that the cost would vary directly with the negative logarithm of the penetration. For composite air collection systems (e.g. Dustop followed by an Absolute Air;Filter) the data presented in Figure 1 indicate that the product of the cost and penetration is a constant. Such an approximation can be theoretically justified for small values of p, as indicated by the equation below:

The cost-penetration relationships in general may be expressed by the following equation:

$$p = e^{-kC} \quad (1)$$

where C is in dollars/cfm/year

p is in units of penetration

k = cost absorption coefficient in (cfm) (yr)/dollar

$$\ln p = -kC \quad (2)$$

$$C = \frac{-2.3}{k} \log_{10} p \quad (3)$$

For the special case where kC is much smaller than one, the following relationships is a valid approximation since  $\frac{1}{p} = e^{kC}$ . Since the value of K from the data appears to be in the range of 100 to 1000 cfm years/dollar,

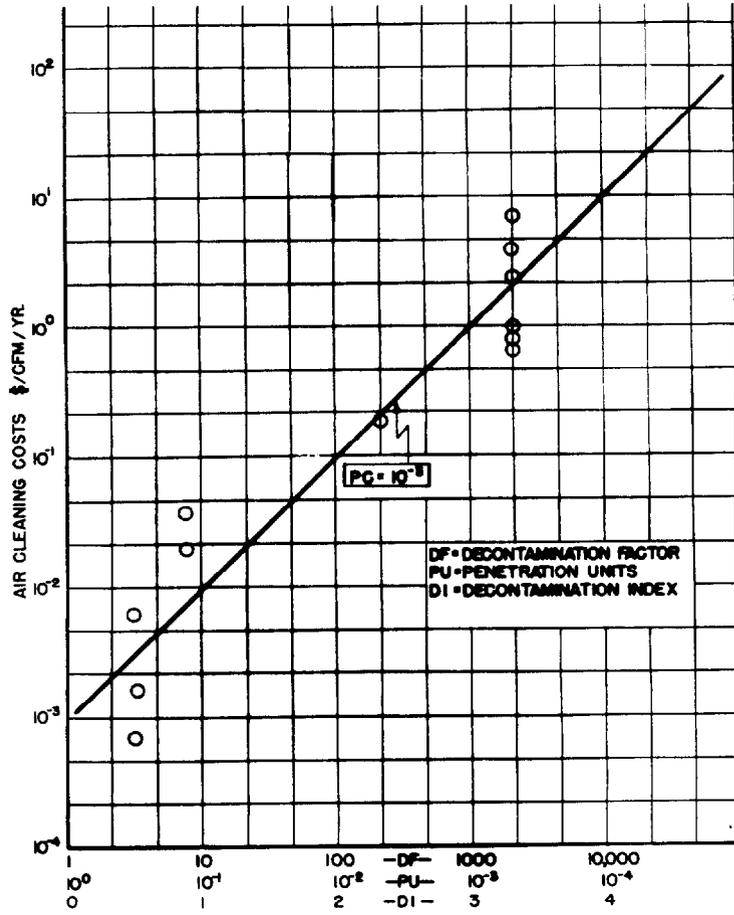


Fig. 1—Cost-penetration relationships of composite air cleaning systems.

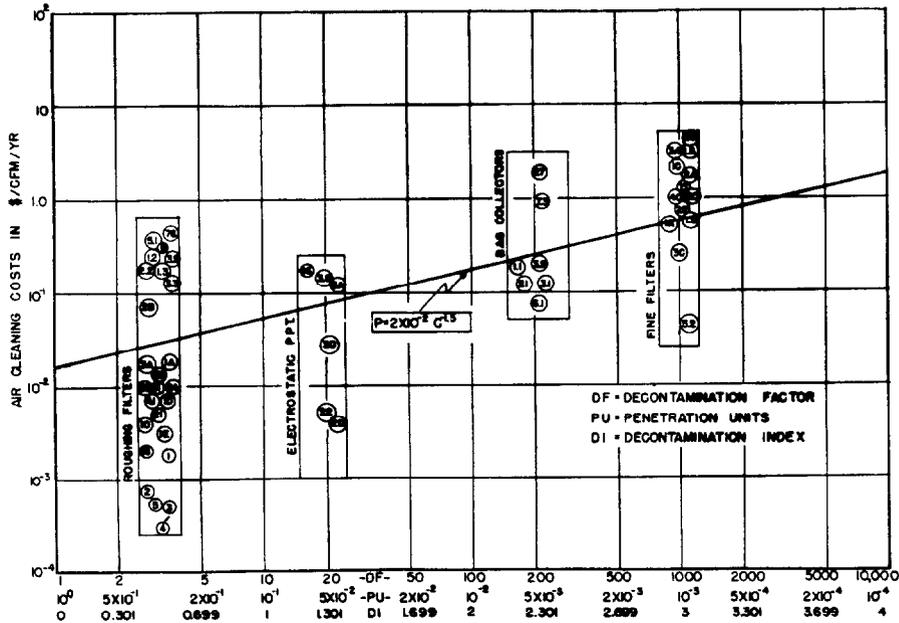


Fig. 2—Unadjusted cost-penetration relationships of individual air cleaning units.

then the cost must be in the range of  $10^{-3}$  to  $10^{-4}$  dollars/cfm/year or less to make equation 4 valid.

$$\frac{1}{p} = 1 + kC \quad (4)$$

$$C = \frac{1}{k} \left( \frac{1}{p} - 1 \right) \quad (5)$$

$$C = K \frac{(1-p)}{p} \quad \text{where } K = \frac{1}{k} \quad (6)$$

Note that the specific case is only valid for  $kC$  values being much smaller than 1 and for values of  $p$  within the range of 0.5 to 1.0 (Specific Equation 6 within 20% at lower range).

The data presented in Figure 1 indicate that the cost-penetration for composite air cleaning systems relationship can be expressed by a relationship similar to Equation 6 but over a range of values for  $p$  approaching zero from 0.2 (within 25% at high value in the range).

$$C_p = K \approx 1 \times 10^{-3}$$

therefore

$$C = 1 \times 10^{-3}/p$$

The data presented in Appendix II and in Figures 2 and 3 indicate that for individual air cleaning units such as the Dustop Filter or the Absolute Filter, the cost-penetration relationship can be represented by the following equation:

$$\text{Low Volume Requirement} \quad C = -2.3 \times 10^{-1} \log_{10} P$$

$$\text{High Volume Requirement} \quad P = 2 \times 10^{-3} C^{-1.5}$$

Since there are so many variables associated with the use of these units, the estimations of the costs and the knowledge of the collection efficiencies, the use of only an approximate value is justified at this time. For comparative purposes, it may be observed that the adjusted costs for air cleaning units in radioactive areas are approximately the same costs determined by Silverman for non-radioactive areas. In the non-radioactive air cleaning systems, the loading may be higher but the waste disposal and handling costs should be less than those associated with radioactive cleaning systems. These factors might explain the agreement in costs but considerable data will be necessary to establish a relationship.

#### Future Plans

As indicated in Table 1, future plans will involve the reorganization of criteria, the initiation of the final survey, the inclusion of additional sites, the setting forth of recommendation on appropriate research and the compilation of an effective manual on Air Cleaning Systems Their Cost and Effectiveness.

#### Conclusions

This study to date has indicated the need for an improved system of communication with respect to air cleaning activities within the various laboratories and sites that we may make known in adequate time the findings

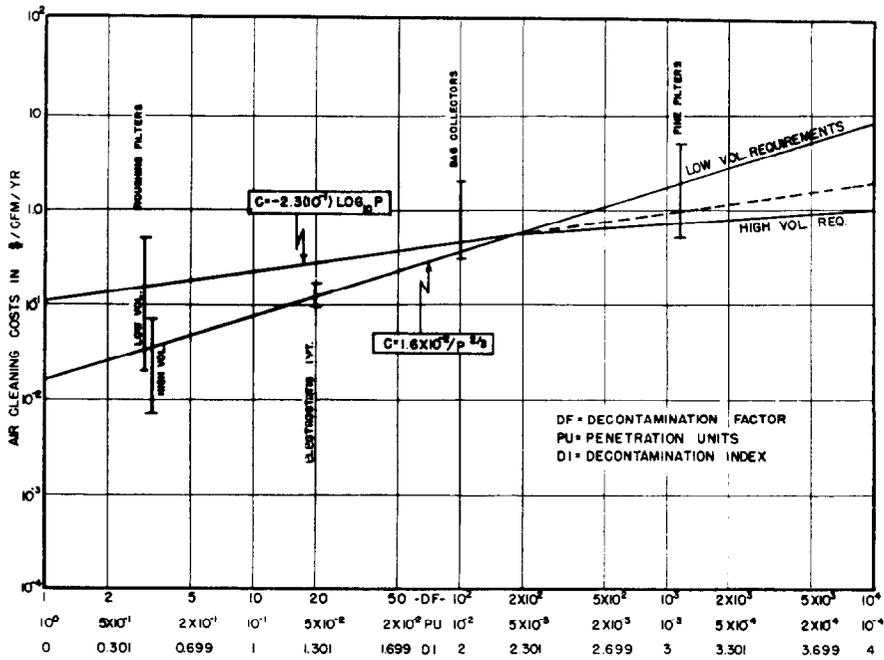


Fig. 3—Adjusted cost-penetration relationships of individual air cleaning systems.

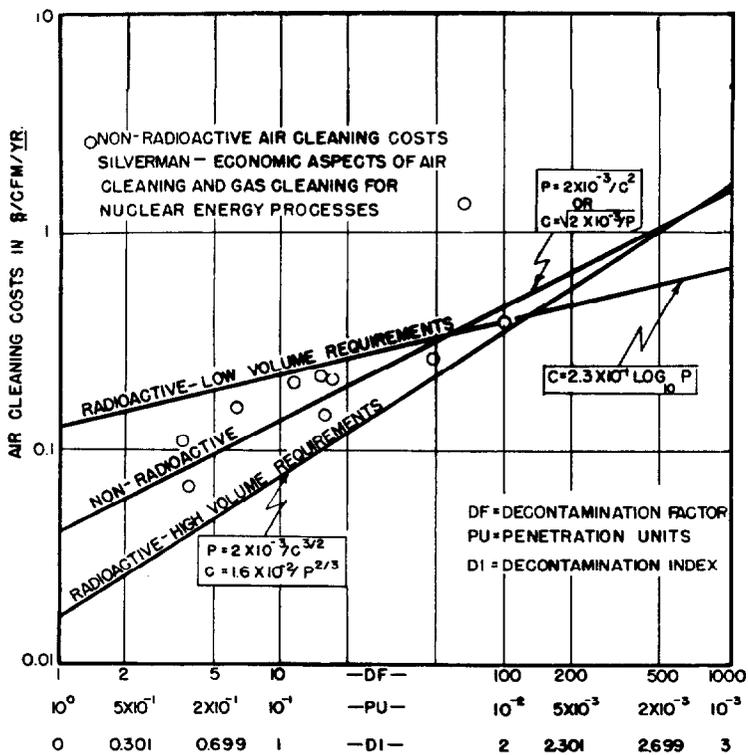


Fig. 4—Comparison of cost-penetration relationships of individual air cleaning units for non-radioactive and radioactive material effluents.

of each Laboratory. In this manner, we may all make progress more rapidly and effectively towards our main objective to provide appropriate and efficient air cleaning systems.

In addition, this preliminary survey has demonstrated the necessity for improved communications between the engineering service groups responsible for the development and maintenance of air cleaning systems and the industrial hygiene or health physics group responsible for the radiological engineering aspects which set the working standards with respect to the maximum permissible penetration of radioactive materials through an air cleaning system.

The preliminary data indicate that an approximate relationship exists between the cost of air cleaning and the maximum permissible penetration of materials through composite air cleaning systems. In general, at the present time we may approximate the cost by the following simplified formula.

$$C = 1 \times 10^{-3}/p$$

To illustrate the use of this formula, the cost of an air cleaning system requiring a collection efficiency of 99% of a penetration value of  $10^{-2}$  would be  $10^{-3}/10^{-2}$  or \$.1/cfm/yr. If an efficiency of 99.9% or  $p = 10^{-3}$  were required, then the cost would be estimated at \$1/cfm/yr.

For a given maximum permissible penetration, there are many variables associated with the evaluation of the economical aspects of air cleaning. Consequently, all values must be well qualified. Listed below are some of the variables.

- (A) Quantity of Air circulated or recirculated
- (B) Quality of the air:
  - (a) Concentrations of radioactive or toxic material
  - (b) Concentration of inert material
  - (c) Corrosive effective of material
  - (d) Particle size distribution
  - (e) Combination of filter units and the corresponding flow rates
- (C) Operational philosophy:
  - (a) Time cycle changing of filter units or cleaning of systems
- (D) Quality of the radioactive material collected:
  - (a) Dose rate problems
  - (b) Airborne problems
  - (c) Liquid waste problems
- (E) Construction of the air cleaning systems such that operational costs are minimized or lessened.
- (F) Managerial aspects influencing and forming policies which refer to the periods in which filter units, etc., are changed by specific groups.
- (G) Research costs and the variations of overhead charges
- (H) Write-off policy for the depreciation of the constructional materials.

The cooperation and participation in the program survey has been excellent - and the results have been expressedly beneficial to many sites even before the completion of the preliminary survey. All of the data presented are preliminary and they are presented through the courtesy of the Sites representatives that prepared and compiled the data. Although considerable benefits have been mutually accrued as a result of this cooperation and participation, we have at this time merely initiated the survey. Considerable information will be forthcoming in the future. Improved survey forms will be developed and then forwarded to each Site along with a sample copy of a completed form. The final survey is scheduled for completion before the end of next year (1960).

APPENDIX I

Technical and Economical Data

**SURVEY OF AIR AND GAS CLEANING OPERATIONS**

OAK RIDGE GASEOUS DIFFUSION PLANT  
UNION CARBIDE NUCLEAR COMPANY  
DIVISION OF UNION CARBIDE CORPORATION  
OAK RIDGE, TENNESSEE

March 23, 1959

NOTE: All equipment cost and labor charges are estimated since records of operating cost are not in this detail.

FILTER LOCATION	EQUIPMENT CHARGES AVERAGE YEARLY COSTS REPLACEMENT PARTS COSTS \$	LABOR CHARGES AVERAGE YEARLY COSTS			DESCRIPTIVE AND OPERATIONAL DATA								REMARKS	
		ROUTINE MAINT AND INSPECTION MANHOURS	CLEANING OR REPLACING MEDIA MANHOURS	HANDLING AND DISPOSAL MANHOURS	MANUFACTURER AND TRADE NAME	CLEANER CLASSIFICATION AND TYPE	SITE APPLICATION	MATERIAL HANDLED	MATERIAL REMOVED	SYSTEM CAPACITY SCFM OR CFM	METHOD OF REPLACING OR CLEANING OF MEDIA	CRITERIA FOR CLEANER CHANGES		HANDLING AND DISPOSAL METHODS
1	2	3	3A	3B	4	5	6	7	8	9	10	11	12	
K-25 Basement Intake Filters	\$1.84 4% of Filters per Year	24	864	None included in Cleaning	Air Mass Mason-Pace	Screen Cloth	Building Ventilation	Outside Air	Dust	3,800,000 CFM	Washing & Reusing	Unable to see thru or Annual	Water to Sump	NOTE No. 1: 88 Filters per bank. Two (2) Banks per Unit and 84 Washed Units in K-25
K-27 Basement Intake Filters	\$200 4% of Filters per Year	6	144	None included in Cleaning	Air Mass Mason-Pace	Screen Cloth	Building Ventilation	Outside Air	Dust	1,650,000 CFM	Washing & Reusing	Unable to see thru or Annual	Water to Sump	NOTE No. 1: Two (2) Banks per unit and 100 Washed Units in K-27
K-29 Basement Intake Filters	\$155 4% of Filters per Year	6	176	None included in Cleaning	Air Mass Mason-Pace	Screen Cloth	Building Ventilation	Outside Air	Dust	2,700,000 CFM	Washing & Reusing	Seen Annual	Water to Sump	NOTE No. 1: Covers 110 banks in 880 Filters in K-29
K-31 Basement Intake Filters	\$10 4% of Filters per Year	6	246	None included in Cleaning	Air Mass Mason-Pace	Screen Cloth	Building Ventilation	Outside Air	Dust	3,400,000 CFM	Washing & Reusing	Seen Daily or Semi-Annual	Water to Sump	NOTE No. 1: Fourteen banks in K-31
K-33 Basement Intake Filters	\$130 4% of Filters per Year	6	50	None included in Cleaning	Air Mass Mason-Pace	Screen Cloth	Building Ventilation	Outside Air	Dust	7,000,000 CFM	Washing & Reusing	When Dirty or Semi-Annual	Water to Sump	NOTE No. 1: Two (2) Banks per unit and eight units in K-33
K-25, K-29, K-31, & K-33 Alumina Traps in Heat Filters	\$300 100 per Alumina Trap	100	76	50	S' Always Safe	Carbon Mesh & Chemical	Operation Heat	U <sub>2</sub>	U <sub>2</sub>		Replaces Alumina	High Resistant Siegel	1 Lump or Recovery	NOTE No. 1: Cleaning done by pumping out traps
K-25, K-27, K-31, & K-33 Alumina Traps in Heat Filters	\$1500 100 per Alumina Trap	800	250	100	S' Always Safe	Carbon Mesh & Chemical	Operation Heat	N <sub>2</sub> , Ar, & U <sub>2</sub>	U <sub>2</sub> & Oil	14,000 CFM	Replaces Alumina	High Resistant Siegel	Storage in Recovery	NOTE No. 1: Approximately 400 traps in heat exchanger system
K-25 & K-27 Uni-Instrument Air Headers	\$40	30 for K-25 & K-27	12		Fultz Cameroid-Filter	Cotton	Instrument Operation	Air for Instrument Control	Exp. B Moisture	150 CFM per Filter See Note No. 1	Replaces Cotton	Pressure Loss	None	NOTE No. 1: Two filters per unit, 54 units in K-25 No. 2: Two filter per unit, 9 units in K-27
K-25 Cell Instrument Air Header	None	180	20	None	Taylor	Bristle Beltes	Instrument Operation	Air for Instrument Control	Dust and Moisture	10 CFM per Filter See Note No. 1	Washed and Dried	Pressure Loss	None	NOTE One filter per cell, 384 cells in K-25
K-29, K-31 & K-33 Uni-Instrument Air Header	\$50	20	10		Fultz RA-5	Cotton	Instrument Operation	Air for Instrument Control	Dust	2000 CFM per Filter See Note No. 1	Replaces Cotton	Pressure Loss	None	NOTE No. 1: Two filters per unit, three units in K-29 No. 2: One filter per unit, six units in K-31 No. 3: One filter per unit, eight units in K-33
K-29, K-31 & K-33 Cell-Instrument Air Header	\$250	80	45	None	Fultz RA-5	Cotton	Instrument Operation	Air for Instrument Control	Dust	30 CFM per Filter See Note No. 1	Replaces Cotton	Pressure Loss	None	NOTE No. 1: Two filters per unit, 70 Cells total in K-29, K-31, & K-33 No. 2: Four filters per unit, 39 units
Plant Air Facilities Shop K-120 100% Air Inlets in Compressor Room							Compressor Air	Dust	18,000 SCFM See Note No. 1		Annual			NOTE 1: Three compressors rated @ 2000 CFM, the compressors rated @ 1400 CFM & 2 Filter cleaned in solvent and replaced with air
O-1 Trap	Uses Media from Dryer	16			Big Tank with Alumina	Resin or Preheating	Compressed Air	Oil	12,000 SCFM	Non-Metallic from Dryer	Annual	Pressure Loss	None	NOTE No. 1: Two 100% saturated
Moisture Absorber in Dryer		32			Big Tank with Alumina	Resin or Preheating	Compressed Air	Moisture	12,000 SCFM	Replaces Tag Heat of Media	Annual	Pressure Loss	None	NOTE No. 1: Two 40% saturated and Dry No. 2: Two Absorbent per Section
Absorber	Cost of Fall	8			Plate of Fall	Fine Cleaner	Compressed Air	Dust	12,000 SCFM	Replaces Plate	Annual Check	Pressure Loss	None	NOTE No. 1: Two 40% Dry No. 2: Two Filters per Section
80% Air Inlets in Compressor Room	\$25	8			Picture Filters	Fine Clean Compressor Room	Pre-Filter in 100 Compressor Room	Air	Dust	18,000 SCFM	Replaces Cotton Filter	Annual Check	Pressure Loss	NOTE Temp. Alarm
K-25 Air Moisture Absorber in Dryer									12,000 SCFM					NOTE 1: Four Preheat Filters in 80% Preheat 2: No maintenance required since installation 3: Temperature 40°F saturated & dry
K-31 Air Moisture Absorber in Dryer									14,000 SCFM					NOTE 1: Two Preheat Filters in 3% facilities 2: No maintenance required since installation 3: Temperature 40°F saturated & dry
K-29, K-25 Air Inlets and After Filter									3,000 SCFM					NOTE 1: One article in compressor and one other filter, a 20% facility 2: No maintenance required since installation 3: Temperature 100°F
Preheating Section (3 Banks)	No Replacement Cost in Data	90 for Inspection 176 for Start up 176 for Replacement (if needed)	2190		Cottrell Precipitator made by Research Corporation	Electrostatic Precipitator	Clean Exhaust Air Located in Gas Screen Prior to Bank 3/20	Hot Combustion Gas from Cell and Gas to Beds	Fly Ash	860,000 CFM See Note No. 1 & 2	Heater	Bring Fall	Fly Ash collected and dumped in Sinking Dump in Field	NOTE 1: One preheater for each bank 2: Each preheater shell contains 90% of the fly ash in gas under full load conditions of 380,000 CFM in this gas at 380°F and the preheater will not exceed 1200°F in this rate of flow 3: Repair costs for these preheaters is \$4,300/y
K-33 Switch House	300 gal of Oil @ 37¢/gal = \$111	128			Compressed Air Filter Inc. Louisville, Ky Model M-125	Rotating Screen Viscous Type	Supply Air General Ventilation for Equipment	Outside Air	Dust	108,000 CFM	Change Oil and Clean Screen	Annual	Drain Oil and Thru Away	NOTE 1: Two rotating screens in K-33 switch house
K-33 Switch House	None	16			Woolingham Electric and Manufacturing Co.	Electrostatic Precipitator	Non-Combustion for Equipment	Outside Air	Dust	19,000 CFM 383 FPM	Air Purge and High Velocity Pulse	Annual	Thru Away	NOTE 1: One preheater for K-33 switch house 2: Discharge T <sub>2</sub> at 40°-50°
K-31 Switch House	200 gal of Oil @ 37¢/gal = \$74	128			Compressed Air Filter Inc. Louisville, Ky Model M-125	Rotating Screen Viscous Type	Supply Air General Ventilation for Equipment	Outside Air	Dust	86,400 CFM	Change Oil and Clean Screen	Annual	Drain Oil and Thru Away	NOTE 1: Two rotating screens in K-31 switch house
K-37 Switch House	300 gal of Oil @ 37¢/gal = \$111	192			Compressed Air Filter Inc. Louisville, Ky Model M-125	Rotating Screen Viscous Type	Supply Air General Ventilation for Equipment	Outside Air	Dust	180,000 CFM	Change Oil and Clean Screen	Annual	Drain Oil and Thru Away	NOTE 1: Three rotating screens in K-37 switch house. Both size 9' 6"
K-25 Switch House	300 gal of Oil @ 37¢/gal = \$111	192			Compressed Air Filter Inc. Louisville, Ky Model M-125	Rotating Screen Viscous Type	Supply Air General Ventilation for Equipment	Outside Air	Dust	180,000 CFM	Change Oil and Clean Screen	Annual	Drain Oil and Thru Away	NOTE 1: Two rotating screens in K-25 switch house
K-1431 Incinerator Stack		10			Webb Colman & Young or Inc.	Aerobic Collector	Final Cleaning Exhaust Air Production Area	Fly Ash Fly Gases	Fly Ash	8900 CFM	Wetted Coating	Pressure Loss or Substituted Filter	Spiral or Baffle	NOTE 1: This filter consists of a primary and secondary section. The primary consists of a covered filter. The secondary consists of a cyclone separator which collects the dust from the primary section.
K-1420 Control Vacuum Cleaner	\$784	6	6		The Spencer Vacuum Co.	Airlock Dust Collector Mechanism	Final Cleaning Exhaust Air Production Area	U <sub>2</sub> , U <sub>2</sub> Oxides	U <sub>2</sub> Oxides	600 CFM	Replacement of Filter Bags	Pressure Loss or Substituted Filter	Isolation	NOTE 1: This system consists of a primary and secondary section. The primary consists of a cyclone separator. The secondary consists of four full bag houses.
K-1420 Vent System for Drum Dryer B. Cleaner for Product Storage Cell	\$132	8	4		Cambridge	Airlock Type	Final Cleaning Exhaust Air Production Area	U <sub>2</sub> Oxides and Compounds Collected from Cleaning	U <sub>2</sub> Oxides	50 CFM @ 1" Water	Replacement of Filter Unit	Pressure Loss	Isolation	

Table 1 ORNL, K-25 Data

Table 2 ORNL, X-10 Data

SCHEMATIC USE AND GENERAL USE	TYPE OF SYSTEM	CLEANER	SITE APPLICATION	CLEANING REQUIREMENT	SPACE REQUIREMENT	OPERATING CHARACTERISTICS	METHOD OF REPLACEMENT AND/OR CLEANING	CRITERIA FOR CLEANING CHANGES	COMMENTS	FREQUENCY OF FILTER CHANGE	MANPOWER (HOURS) REQUIRED: PER CHARGE
301 - Double Pile Reactor Cooling	Inlet air for reactor cooling	Weather tower and 10 ft		Remove atmospheric dust	Approximately 8 units for each cell	100 units Approximately 1000 cfm flow	Replace media during reactor down period	Regular schedule or excessive drop		Once per year	12 hrs - allwright 1 hr - foreman
310 - Helicopter Fission Products Pilot Plant	Exhaust air from reactor for cooling Cell ventilation inlet air for cell space ventilation	Pre-filter, air temp control, fire resistant, 2' x 20 x 7 2' x 20 x 7 2' x 20 x 7	Separate filter house with shielding Nest at cell wall having service ducting air	Filter - particulate matter before release to atmosphere Remove sizeable atmospheric particulate	Approximately 2 or 3 units for each cell	Average 200 cfm/unit	Replace media during reactor down period when activity level permits	Excessive pressure drop or captured unit dirtiness	Change is a routine operation normally scheduled	Once every 4 - 5 years	12 hrs - allwright 9 hrs - utility room 12 hrs - foreman
318 - Pilot Plant	Exhaust air from work cells and process cells	2' throwaway (8 x 10 x 2) Pre-filter - AM, type 8 20 x 20 x 2 - 10 units 11-1/2 x 12 with	Inside cell space Underground shielded box (concrete) with particulate removal duct to 302B stack	Remove sizeable particulate High efficiency particulate removal	Approximately 400 cfm/unit	Approximately 400 cfm/unit	Use hp filter unit Re-filter unit by remote manipulation	Visual inspection of stream or excessive activity	Some re-planting originally designed to accommodate AM type 8 filter also	Changed once after 5 months of operation	9 hrs - allwright 2 hrs - operator
319 - Pilot Plant	Cell ventilation (A) Exhaust air from cell spaces (C) plus cell ventilation operations	Pre-filter - AM, two pocket 1-25 - 1500 20 x 20 x 2 - 10 units 11-1/2 x 12 with	Shielding box (concrete) at grid with top air at grid level Pre-filtering effluent in duct to 302B stack	High efficiency particulate removal	Normal 22,000 cfm flow	Normal 22,000 cfm flow Approximately 1.5 hp/1500 cfm	Excess pressure drop or excessive activity	Excessive pressure drop or excessive activity	System put into operation during reactor down period. No filter change to date. Unit scheduled for re-planting during 30 hr fan unit.	No filter change to date.	3 hrs - allwright 3 hrs - rigger 3 hrs - driver 1 hr - foreman
302B - Stack Area	Cell ventilation air for cooling Cell ventilation air for cooling	Pre-filter, air temp control, fire resistant, 2' x 20 x 7 2' x 20 x 7	Effluent is discharge to 302B stack	Remove atmospheric dust Remove sizeable particulate	Area covers approximately 100 x 10'	Approximately 22,000 cfm flow	Replace media during reactor down period	Regular schedule or excessive drop	State of ductwork and emergency standby changes made 4/52.		
302C - Stack Area	Cell ventilation air for cooling Cell ventilation air for cooling	Pre-filter, air temp control, fire resistant, 2' x 20 x 7 2' x 20 x 7	Effluent is discharge to 302C stack	Remove atmospheric dust Remove sizeable particulate	Area covers approximately 100 x 10'	Approximately 22,000 cfm flow	Replace media during reactor down period	Regular schedule or excessive drop	Plant re-planting off gas cleaning facilities are at this site also.	Filters for building 302C changed approximately once every 1 month	3 hrs - allwright 3 hrs - rigger 3 hrs - driver 1 hr - foreman
302D - Stack Area	Cell ventilation air for cooling Cell ventilation air for cooling	Pre-filter, air temp control, fire resistant, 2' x 20 x 7 2' x 20 x 7	Effluent is discharge to 302D stack	Remove atmospheric dust Remove sizeable particulate	Area covers approximately 100 x 10'	Approximately 22,000 cfm flow	Replace media during reactor down period	Regular schedule or excessive drop	Recent trouble experience in filter failure due to high concentration of particulate matter by or physical failure, being sought.		

action is in progress which is expected to increase the plant radioactive off gas system flow capacity in 5000 cfm (total) and provide additional cleaning facilities for the 4000 cfm increase. The site of this requirement is expected to be near the 302B stack area.

DESCRIPTIVE AND OPERATIONAL DATA

System Component	A. Manufacturer	B. Trade Name	C. Cleaner Classification & Type				D. Site Application				E. Cleaning Requirement & Process				F. Space Requirement		
			1. Roughing or Pre-Cl. Fan	2. High Eff. Pre-Cl. or Final Cleaner	3. Ultra Absolute Type	4. Pre-Filter (Supply)	5. Pre-Cl. (Sch.)	6. Final Clean.	7. Filter Clean.	8. Product Recov.	9. Dust Misc. Vapor, Bare Coats	10. Aerosol Composition	11. Particle Size Characteristics	12. Concentration - Wt. of Activity per Unit Volume of Gas	13. Overall Dimen. (Unit Col.) & Cap. CFM	14. Clean. Cap.	15. Clean. Cap.
(1) Filter	Centrifugal Air Filter	Auto-Metal Screens	-	-	-	BUILDING 9215 - SUPPLY AIR SYSTEM	-	-	-	-	-	-	430,000 cfm	.033	2.5 sq. ft.		
(2) Filter	Auto-Metal Screens	Auto-Metal Screens	-	-	-	BUILDING 9215 - SUPPLY AIR SYSTEM	-	-	-	-	-	-	15,000 cfm	.001	1.3 sq. ft.		
(3) Filter	Cambridge M.S.A. - Juice	Auto-Metal Screens	-	-	-	BUILDING 9215 - SUPPLY AIR SYSTEM	-	-	-	-	-	-	1,000 cfm	.0035	1.3 sq. ft.		
(1) Bag Col.	Turner & Newall	Auto-Metal Screens	-	-	-	BUILDING 9215 - SPECIAL PROJECTS SHOP EXHAUST SYSTEM	-	-	-	-	-	-	42' x 9.5' x 32' x 2 walls	.050	42.3 sq. ft.		
(1) Cyclone	Cambridge M.S.A. - Juice	Auto-Metal Screens	-	-	-	BUILDING 9215 - WASTE INCINERATOR	-	-	-	-	-	-	2,800 cfm	.00385	1.3 sq. ft.		
(2) Filter	Turner & Newall	Auto-Metal Screens	-	-	-	BUILDING 9215 - WASTE INCINERATOR	-	-	-	-	-	-	1,100	.00545			
(3) Filter	Turner & Newall	Auto-Metal Screens	-	-	-	BUILDING 9215 - WASTE INCINERATOR	-	-	-	-	-	-	2,800	.035	1.3 sq. ft.		
(1) Cyclone	Turner & Newall	Auto-Metal Screens	-	-	-	BUILDING 9211 - HIGH-CAPACITY FURNACE EXHAUST SYSTEM	-	-	-	-	-	-	19' x 40' x 60'	0.03			
(2) Bag Col.	Turner & Newall	Auto-Metal Screens	-	-	-	BUILDING 9211 - HIGH-CAPACITY FURNACE EXHAUST SYSTEM	-	-	-	-	-	-	87' x 55' x 161'	0.052	87.4 sq. ft.		

Table 3 ORNL, Y-12 Data

ECONOMIC SURVEY OF AIR & GAS CLEANING OPERATIONS  
TYPICAL SYSTEMS IN OPERATION AT Y-12 PLANT  
UNION CARBIDE NUCLEAR CO. - OAK RIDGE, TENN.

Information for J. J. Fitzgerald  
Harvard University School of Public Health  
June 22, 1959

DESCRIPTIVE AND OPERATIONAL DATA

System Component	A. Manufacturer Name	B. Cleaner Classification & Type	C. Cleaner Classification & Type	D. Site Application	E. Cleaning Requirement & Process	F. Space Requirement
(1) Bag Col.	Fulverizing Col. Mech.	2. High Eff. Pre-Cl. or Final Cleaner	1. Roughing Pre-Cl. Fan	1. Pre-filter (Supply)	1. Dust 2. Aerosol 3. Particle Size Characteristics 4. Concentration - Wt. or Activity per Unit Volume of Gas	1. Overall Dimen. (Unit Col.) 2. Cu.Ft. /CFM Clean. 3. Face Area /1000 CFM Clean. Cap.
(2) Filter	Central Air Filter	Felted Fabric (Wool)	Synthetic	3. Final Clean.	-	15' x 11' x 29' 64,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm 30 cfm
(3) Filter	American Air Filter	10-Ply Paper	10-Ply Paper	4. After Clean.	-	24' x 18' x 28' 85,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm
(4) Filter	Cambridge Absolute M.S.A. - lute	Cellulose Asbestos	Cellulose Asbestos	5. Product Recov.	-	1,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm
(5) Filter	Flanders Absolute	Cellulose Asbestos	Cellulose Asbestos	6. Final Clean.	-	1,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm
(1) Bag Col.	Western Precipitation Air Filter	Felted Fabric (Wool)	10-Ply Paper	3. Final Clean.	-	15' x 11' x 29' 64,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm 30 cfm
(2) Filter	American Air Filter	10-Ply Paper	10-Ply Paper	4. After Clean.	-	24' x 18' x 28' 85,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm
(1) Bag Col.	Western Precipitation Air Filter	Felted Fabric (Wool)	10-Ply Paper	3. Final Clean.	-	15' x 11' x 29' 64,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm 30 cfm
(2) Filter	Central Air Filter	Synthetic	Synthetic	4. After Clean.	-	24' x 18' x 28' 85,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm
(3) Filter	American Air Filter	10-Ply Paper	10-Ply Paper	5. Product Recov.	-	1,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm
(4) Filter	Cambridge Absolute M.S.A. - lute	Cellulose Asbestos	Cellulose Asbestos	6. Final Clean.	-	1,000 cfm 1,000 cfm 1,000 cfm 1,000 cfm
(5) Oil Mist Collector	Westinghouse Elec. Corp.	High Voltage Electrostatic	High Voltage Electrostatic	7. Final Clean.	-	1,200 cfm 1,200 cfm 1,200 cfm 1,200 cfm

(Continued)

DESCRIPTIVE AND OPERATIONAL DATA (Cont.)

G. Operating Characteristics										H. Method of Replacement or Cleaning of Media																			
1. Fil. 2. Pressure					3. Power Requirements					4. Cleaner Service Life					5. Operating Temp. & Humidities					6. Water or Scrubbing Liquid					7. Col. 1. Wash- 2. Wash- 3. Replace- 4. Replace- 5. Vacuum 6. Other				
Vol. FM	Loss - In. Water	Initial Max. Allow.	System	Base Clean. System Loss Only	HP Per 1000 CFM Air	a. Fan	b. Water	c. Motor	d. Rec. for Elect. or Precipitators	Life	a. Before Clean. or Wash	b. Replace- ment	Temp. & Humidities	Vol./1000 CFM Air	a. Spray	b. Recycle	c. Chemical	Req. Basis	7. Col. 1. Wash- 2. Wash- 3. Replace- 4. Replace- 5. Vacuum 6. Other	8. Filter	9. Media	10. i.e. Dust Stop or Absolute							
11.4	1.00	5.00	1.22	1.39	-	-	-	-	-	6 Months	70°F, 50%	-	-	-	-	-	-	-	-	-	-	-	-						
85.70	.10	.50	-	-	-	-	-	-	-	1 Month	"	-	-	-	-	-	-	-	-	-	-	-	-						
36.00	.15	.50	-	-	-	-	-	-	-	1 Month	"	-	-	-	-	-	-	-	-	-	-	-	-						
4.5	1.0	4.0	-	-	-	-	-	-	-	1 Month	"	-	-	-	-	-	-	-	-	-	-	-	-						
4.5	1.0	4.0	-	-	-	-	-	-	-	1 Month	"	-	-	-	-	-	-	-	-	-	-	-	-						
26.7	1.00	5.00	1.70	2.46	-	-	-	-	-	6 Months	70°F, 50%	-	-	-	-	-	-	-	-	-	-	-	-						
36.0	.15	.50	-	-	-	-	-	-	-	1 Month	"	-	-	-	-	-	-	-	-	-	-	-	-						
26.7	1.00	5.00	1.39	2.16	-	-	-	-	-	6 Months	70°F, 50%	-	-	-	-	-	-	-	-	-	-	-	-						
65.70	.10	.50	-	-	-	-	-	-	-	1 Month	"	-	-	-	-	-	-	-	-	-	-	-	-						
36.00	.15	.50	-	-	-	-	-	-	-	1 Month	"	-	-	-	-	-	-	-	-	-	-	-	-						
4.5	1.0	4.0	-	-	-	-	-	-	-	1 Month	"	-	-	-	-	-	-	-	-	-	-	-	-						
300	.50	1.50	.417	-	.050	1 Month	-	-	-	90°F	-	-	-	-	-	-	-	-	-	-	-	-	-						
310	.38	-	-	-	-	-	-	-	-	Varies	-	-	-	-	-	-	-	-	-	-	-	-	-						
362	.50	-	3.1	-	-	-	-	-	-	70°F, 50%	-	-	-	-	-	-	-	-	-	-	-	-	-						
3	1.0	4.0	-	-	-	-	-	-	-	2 Years	"	-	-	-	-	-	-	-	-	-	-	-	-						
25.6	1.0	5.00	1.13	1.77	-	-	-	-	-	1 Year	70°F, 50%	-	-	-	-	-	-	-	-	-	-	-	-						
2.5	0.5	4.0	2.7	4.5	-	-	-	-	-	Varies	130°F	-	-	-	-	-	-	-	-	-	-	-	-						
2300	-	4.0	2.7	4.5	-	-	-	-	-	300°F	-	-	-	-	-	-	-	-	-	-	-	-	-						
228	1.0	4.0	2.7	4.5	-	-	-	-	-	Varies	150°F	-	-	-	-	-	-	-	-	-	-	-	-						
-	4	4	0.625	2.18	-	-	-	-	-	None Req'd.	Years	-	-	-	-	-	-	-	-	-	-	-	-						
15	6	6	0.94	2.18	-	-	-	-	-	Continuous	90°F	-	-	-	-	-	-	-	-	-	-	-	-						

DESCRIPTIVE AND OPERATIONAL DATA (Cont.)

I. Criteria for Cleaner Changes		J. Handling and Disposal Methods			K. Comments Relative to Forgoing Items								
1. Pressure Loss	2. Activity Cycle	3. Film Cycle	4. Other (Mech. Failure, Erosion, Corrosion, Design or Application)	5. Who Determines Criteria for Maintenance (Health Phys., Engineering, Industrial Hygiene, Maintenance)	1. Personnel Protection	2. Packaging	3. Baling	4. Incineration	5. Burial or Storage	1. Reason for Selection of Any One Type Cleaner	2. Is Device Satisfactory as to Quality of Cleaning - Overall Cost?	3. Suggestion for Improving Based on Field Experience	4. Recommended Research
-	-	-	Material Recovery	Chem. Operations	Respirators	Plastic Bags	-	-	-	Efficiency Low Maint.	Yes	-	-
-	-	-	-	-	-	-	-	-	-	Material Recovery	"	-	-
-	-	-	-	-	-	-	-	-	-	Adequate	"	-	-
-	-	-	-	-	-	-	-	-	-	Live-Filter	"	-	-
-	-	-	-	-	-	-	-	-	-	Material Recov.	"	-	-
-	-	-	Material Recovery	Mech. Operations	Respirators	Plastic Bags	-	-	-	Efficiency Adequate	Yes	-	-
-	-	-	-	-	-	-	-	-	-	Low Maint.	"	-	-
-	-	-	-	-	-	-	-	-	-	Eye-Filter	"	-	-
-	-	-	Material Recovery	Mech. Operations	Respirators	Plastic Bags	-	-	-	Efficiency Low Maint.	Yes	-	-
-	-	-	-	-	-	-	-	-	-	Material	"	-	-
-	-	-	-	-	-	-	-	-	-	Recovery	"	-	-
-	-	-	-	-	-	-	-	-	-	Adequate	"	-	-
-	-	-	-	-	-	-	-	-	-	Pre-Filter	"	-	-
-	-	-	-	-	-	-	-	-	-	Efficiency Material Recov.	"	-	-
-	-	-	-	-	-	-	-	-	-	Efficiency	"	-	-
-	-	-	-	-	-	-	-	-	-	Efficiency	Yes	-	-
-	-	-	-	-	-	-	-	-	-	Auto. Filter	"	-	-
-	-	-	-	-	-	-	-	-	-	Automatic	Yes	-	-
-	-	-	-	-	-	-	-	-	-	Features	"	-	-
-	-	-	Material Recovery	Mech. Operations	Respirators	Plastic Bags	-	-	-	Efficiency	Yes	-	-
-	-	-	-	-	-	-	-	-	-	Efficiency	"	-	-
-	-	-	-	-	-	-	-	-	-	Efficiency	Yes	-	-
-	-	-	Material Recovery	Chem. Operations	Respirators	Plastic Bags	-	-	-	Efficiency	Yes	-	-
-	-	-	-	-	-	-	-	-	-	Efficiency	"	-	-
-	-	-	-	-	-	-	-	-	-	Pre-Filter	"	-	-
-	-	-	-	-	-	-	-	-	-	Pre-Filter	No	Better Media	-
-	-	-	-	-	-	-	-	-	-	Pre-Filter	Yes	-	-
-	-	-	-	-	-	-	-	-	-	High Efficiency	"	-	-
-	-	-	-	-	-	-	-	-	-	High Efficiency	Yes	-	-
-	-	-	-	-	-	-	-	-	-	High Efficiency	Yes	-	-
-	-	-	-	-	-	-	-	-	-	High Efficiency	Yes	-	-
-	-	-	-	-	-	-	-	-	-	High Efficiency	Yes	-	-

GAS CLEANING COSTS

System Component	I. Equipment Charges - Average Yearly Costs				D. Replacement Parts (Item C) Cost/Standard Replacement Unit
	A. Initial Collector Cost \$/1000 cfm	B. Item A Based on 5 to 10 Yr. Write Off - \$/1000 cfm/Yr. (Indicate Write Off Period)	C. Replacement Parts Overall Yearly Cost - \$/1000 cfm/Yr.	3. Replace- ment Media	
			1. Throw Away - Roughing Type	4. Filter Bags	
			2. Ultra Filters AEC	5. Other	
BUILDING 9212 - "E" WING MAIN EXHAUST SYSTEM					
(1) Bag Collector	\$308.20	\$61.54	Five (5) Yr. Write-off	\$130.00	\$65.00/bag
(2) Filter	35.30	7.06	"	-	6.80/basket
(3) Filter	30.00	6.00	"	-	6.80/roll
(4) Filter	43.00	8.60	"	-	43.00 ea.
(5) Filter	141.20	28.24	"	-	7.06 ea.
BUILDING 9212 - "N" WING EXHAUST SYSTEM					
(1) Bag Collector	\$302.00	\$60.40	Five (5) Yr. Write-off	\$81.50	\$43.02/bag
(2) Filter	30.00	6.00	"	-	5.90/roll
BUILDING 9215 - "O" WING EXHAUST SYSTEM					
(1) Bag Collector	\$302.00	\$60.40	Five (5) Yr. Write-off	\$65.00	\$43.02/bag
(2) Filter	35.30	7.06	"	-	6.80/basket
(3) Filter	30.00	6.00	"	-	6.80/roll
(4) Filter	141.20	28.24	"	-	7.06 ea.
(5) Oil Mist Col.	583.00	115.60	"	-	7.00/set
BUILDING 9215 - SUPPLY AIR SYSTEM					
(1) Filter	\$ 38.00	\$ 7.60	Five (5) Yr. Write-off	-	\$ 0.25 gai.
BUILDING 9766 - MACHINE EXHAUST SYSTEM					
(1) Filter	\$2000.00	\$400.00	Five (5) Yr. Write-off	-	\$0.007
(2) Filter	30.00	6.00	"	-	0.17
BUILDINGS 9212 & 9998 - SUFFLOWER AREA MACHINE & FOUNDRY EXHAUST SYSTEM					
(1) Bag Collector	\$250.00	\$50.00	Five (5) Yr. Write-off	\$ 27.75	\$65.00
BUILDING 9206 - WASTE DESTROYER EXHAUST SYSTEM					
(1) Filter	\$ 65.00	\$13.00	Five (5) Yr. Write-off	-	None
(2) Cyclone	677.00	135.40	"	-	None
(3) Filter	3820.00	764.00	"	\$38.00	\$58/change
BUILDING 9211 - NICHOLS-HERSHOFF FURNACE EXHAUST SYSTEM					
(1) Cyclone	\$1187.50	\$237.50	Five (5) Yr. Write-off	-	0.24
(2) Bag Collector	1208.30	241.60	Five (5) Yr. Write-off	-	-

GAS CLEANING COSTS (cont.)

II. Labor Charges - Overall Yearly Cost

A. Installation Over & Above Equipment Cost Based on Equipment Write-off Period Man Hours/1000 CFM/Year		B. Routine Maintenance & Inspection Filter Media Man Hours/1000 CFM/Year		C. Cleaning or Replacing Filter Media Man Hours/1000 CFM/Year		D. Hauling & Disposal Man Hours/1000 CFM/Year		E. Labor Charges - Individual Filter Replacement Man Hours/1000 CFM/Year	
				1. Cloth Bags		2. Absolute Filter		3. Other	
BUILDING 9212 - "B" WING MAIN EXHAUST SYSTEM									
(1) Lump-Sum Contract	.48	.50	.90	1.48	-	-	-	-	-
(2) "	-	15.00	15.00	-	-	-	-	-	30.00
(3) "	-	2.00	15.00	-	-	-	-	-	30.00
(4) "	-	6.00	6.00	-	-	-	-	-	12.00
(5) "	-	120.00	120.00	-	-	-	-	-	240.00
(1) Lump-Sum Contract	.48	.90	15.00	1.48	-	-	-	-	30.00
(2) "	-	-	-	-	-	-	-	-	-
BUILDING 9211 - "W" WING EXHAUST SYSTEM									
(1) Lump-Sum Contract	.48	.50	.90	1.48	-	-	-	-	-
(2) "	-	15.00	15.00	-	-	-	-	-	30.00
(3) "	-	2.00	15.00	-	-	-	-	-	30.00
(4) "	-	6.00	120.00	-	-	-	-	-	240.00
(5) "	1.00	2.00	-	-	-	-	-	-	3.00
(1) Lump-Sum Contract	.07	.009	-	-	-	-	-	-	.079
BUILDING 9211 - "W" WING EXHAUST SYSTEM									
(1) Lump-Sum Contract	.13	.73	.75	-	-	-	-	.80	.88
(2) "	-	-	.27	-	-	-	-	-	-
BUILDING 9212 & 9213 - SUPPLY AREA FURNACE & FURNACE EXHAUST SYSTEM									
(1) Lump-Sum Contract	.43	.25	.25	.90	-	-	-	-	-
BUILDING 9213 - WASTE DESTROYER EXHAUST SYSTEM									
(1) Lump-Sum Contract	1.00	20.00	10.00	-	-	-	-	31.00	-
(2) "	-	-	30.00	-	-	-	-	-	30.00
(3) "	-	-	6.65	-	-	-	-	-	19.95
(1) Lump-Sum Contract	-	-	-	-	-	-	-	-	-
(2) "	-	-	-	-	-	-	-	-	-

GAS CLEANING COSTS (Cont.)

F. Costs - Clean Out & Repair of Hoods, Ductwork, Decontamination, etc.		G. Miscellaneous Costs	
1. Average Cost of Lost Production Due to Equipment Down Time	2. Fan Maintenance (% of Total Plant Maintenance)	3. Costs of Air Cleaning (Time to Other Departments Chargeable to Equipment Failure or Maintenance) i.e. Health Physics, Engineering, Etc.	4. Indirect Costs (Time to Other Departments Chargeable to Equipment Failure or Maintenance) i.e. Health Physics, Engineering, Etc.
BUILDING 9212 - "E" WING MAIN EXHAUST SYSTEM			
(1) .062	-	-	-
(2) 2.00	-	-	-
(3) 2.00	-	-	-
(4) -	-	-	-
(5) -	-	-	-
BUILDING 9212 - "H" WING EXHAUST SYSTEM			
(1) .062	-	-	-
(2) 2.00	-	-	-
BUILDING 9215 - "O" WING EXHAUST SYSTEM			
(1) .062	-	-	-
(2) -	-	-	-
(3) -	-	-	-
(4) -	-	-	-
(5) -	-	-	-
BUILDING 9215 - SUPPLY AIR SYSTEM			
(1) -	-	-	-
BUILDING 9766 - MACHINE EXHAUST SYSTEM			
(1) -	-	-	-
(2) -	-	-	-
BUILDINGS 9212 & 9990 - SUNFLOWER AREA MACHINE & POUNERY EXHAUST SYSTEM			
(1) .155	-	-	-
BUILDING 9206 - WASTE DISTRIBUTOR EXHAUST SYSTEM			
(1) 10.00	-	-	-
(2) -	-	-	-
(3) 10.00	-	-	-
BUILDING 9211 - NICKOLIS-HERSCHOFF FURNACE EXHAUST SYSTEM			
(1) -	-	-	-
(2) -	-	-	-

Table 4 CAMEL Project Data

SURVEY OF AIR & GAS CLEANING OPERATIONS  
PRATT & WHITNEY AIRCRAFT - CANEL  
MAY 27, 1959

Bldg. No. & Location	Mfg. and/or Trade Name	Cleaner Classification & Type	Site Application	Cleaning Requirements	Descriptive & Operational Data		Method of Replacing or Cleaning	Criteria for Cleaner Change	Handling & Disposal Method	Equip. Charges - Dollars Yearly	Maintenance & Inspection	Labor Charges - Dollars Yearly Cleaning & Replacement	Disposal	Remarks
					Space Requirements	Operating Characteristics								
Bldg. 440														
HV-1	Cambridge	Aerosol	FA & RC	Dust	(6)	Model 3A-85	None	Time Cycle	Incineration	\$ 4.00	\$ 6.00	\$ 4.00	\$ 4.00	(1) - After time cycle denotes changes per year
AC-2	Dust Stop	Spun Glass	FA & RC	Dust	(6) 23 3/8 x 23 3/8 x 2	(6) 23 3/8 x 23 3/8 x 2	None	Time Cycle	Incineration	8.00	18.00	8.00	8.00	FA - Fresh air
	Cambridge	Aerosol	FA	Dust	(2) 3A-85	(2) 23 3/8 x 23 3/8 x 2	None	Time Cycle (1)	Incineration	2.00	2.00	2.00	2.00	RC - Recirculation
	Dust Stop	Spun Glass	FA	Dust	(2) 23 3/8 x 23 3/8 x 2	(2) 23 3/8 x 23 3/8 x 2	None	Time Cycle (6)	Incineration	6.00	4.00	6.00	6.00	LA - Inside air
AC-3	Cambridge	Absolutes	FA	Dust	(3) 24 x 24 x 11 1/2	Model 1A-1000	None	Time Cycle (6)	Incineration	168.00	4.00	8.00	6.00	B-Z-Kleen
AC-4	Dust Stop	Spun Glass	FA & RC	Dust	(3) 23 3/8 x 23 3/8 x 2	(3) 23 3/8 x 23 3/8 x 2	None	Time Cycle (6)	Incineration	28.08	4.00	8.00	2.00	A-1 - \$1.50 each per 1000 CFM
AC-5	Cambridge	Aerosol	FA & RC	Dust	(4) 3A-85	(4) 3A-85	None	Time Cycle (1)	Incineration	37.44	4.00	5.00	2.00	B - 4 changes per year per 1000 CFM
AC-6	Dust Stop	Spun Glass	FA & RC	Dust	(3) 3A-85	(3) 3A-85	None	Time Cycle (6)	Incineration	28.08	4.00	8.00	2.00	A-2 - .25 per M CFM x 4 per year
AC-7	Cambridge	Aerosol	FA & RC	Dust	(3) 23 3/8 x 23 3/8 x 2	(3) 23 3/8 x 23 3/8 x 2	None	Time Cycle (1)	Incineration	28.08	4.00	8.00	2.00	Dust Stop
AC-8	Dust Stop	Spun Glass	FA & RC	Dust	(4) 3A-85	(4) 3A-85	None	Time Cycle (6)	Incineration	37.44	4.00	8.00	2.00	A-1 - Unit cost per 1000 CFM x 4 changes/year
AC-9	Cambridge	Aerosol	FA & RC	Dust	(4) 23 3/8 x 23 3/8 x 2	(4) 23 3/8 x 23 3/8 x 2	None	Time Cycle (1)	Incineration	37.44	4.00	8.00	2.00	A-2 - 25 per M CFM x 4 per year
AC-10	Dust Stop	Spun Glass	FA	Dust	(2) 3A-85	(2) 3A-85	None	Time Cycle (6)	Incineration	37.44	4.00	8.00	2.00	B-4 - Changes per year per 1000 CFM @ 100/CFM
AC-11	Cambridge	Aerosol	FA	Dust	(2) 16 x 20 x 2	(2) 16 x 20 x 2	None	Time Cycle (1)	Incineration	18.72	4.00	6.00	2.00	@ \$1.00/M CFM
AC-12	Dust Stop	Spun Glass	FA	Dust	(2) 23 3/8 x 23 3/8 x 2	(2) 23 3/8 x 23 3/8 x 2	None	Time Cycle (6)	Incineration	37.44	4.00	8.00	2.00	Aerolite + Absolite
HEP-21	Cambridge	Aerosol	FA	Dust	(2) 16 x 20 x 2	(2) 16 x 20 x 2	None	Time Cycle (1)	Incineration	18.72	4.00	6.00	2.00	A-1 - 90.25 per M CFM x 4 per year
HEP-9-4	B-Z-Kleen	Aerosol	FA	Dust	(4) 24 x 24 x 2	(4) 24 x 24 x 2	None	Time Cycle (6)	Incineration	8.88	4.00	6.00	2.00	B - 7 changes per year per 1000 CFM @ \$1.00/M
HEP-10-4	B-Z-Kleen	Aerosol	FA	Dust	(4) 23 3/8 x 23 3/8 x 2	(4) 23 3/8 x 23 3/8 x 2	None	Time Cycle (1)	Incineration	8.88	4.00	6.00	2.00	AC - Air conditioner
RC AC-11	B-Z-Kleen	Aerosol	FA	Dust	(2) 23 3/8 x 23 3/8 x 2	(2) 23 3/8 x 23 3/8 x 2	None	Time Cycle (6)	Incineration	18.72	4.00	6.00	2.00	SF - Supply fan
RC AC-12	Dust Stop	Spun Glass	FA	Dust	(2) 16 x 20 x 2	(2) 16 x 20 x 2	None	Time Cycle (1)	Incineration	18.72	4.00	6.00	2.00	EP - Exhaust fan
NBEP-111	Cambridge	Aerosol	FA	Dust	(6) 24 x 24 x 12	(6) 24 x 24 x 12	None	Time Cycle (6)	Incineration	448.00	12.00	16.00	8.00	
NBEP-121	Dust Stop	Spun Glass	FA	Dust	(8) 24 x 24 x 12	(8) 24 x 24 x 12	None	Time Cycle (4)	Incineration	49.92	2.00			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(9) 23 3/8 x 23 3/8 x 2	(9) 23 3/8 x 23 3/8 x 2	None	Time Cycle (6)	Incineration	448.00	12.00			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(9) 24 x 24 x 12	(9) 24 x 24 x 12	None	Time Cycle (6)	Incineration	14.04	12.00			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(9) 23 3/8 x 23 3/8 x 2	(9) 23 3/8 x 23 3/8 x 2	None	Time Cycle (6)	Incineration	504.00	12.00			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(9) 24 x 24 x 12	(9) 24 x 24 x 12	None	Time Cycle (6)	Incineration	46.35	12.00			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(1) 12 x 12 x 2	(1) 12 x 12 x 2	None	Time Cycle (6)	Incineration	504.00	12.00			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(1) 12 x 12 x 2	(1) 12 x 12 x 2	None	Time Cycle (6)	Incineration	3.96	4.00			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(4) 12x 18 x 2	(4) 12x 18 x 2	None	Time Cycle (6)	Incineration	3.96	4.00			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(3) 24 x 30 x 2	(3) 24 x 30 x 2	None	Time Cycle (6)	Incineration	8.00	2.20			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(2) 24 x 30 x 12	(2) 24 x 30 x 12	None	Time Cycle (6)	Incineration	2.20	2.20			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(1) 18 x 24 x 2	(1) 18 x 24 x 2	None	Time Cycle (6)	Incineration	4.00	1.46			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(1) 24 x 30 x 12	(1) 24 x 30 x 12	None	Time Cycle (6)	Incineration	1.46	1.46			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(3) 24 x 24 x 2	(3) 24 x 24 x 2	None	Time Cycle (6)	Incineration	1.40	26.00			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(3) 12 x 12 x 2	(3) 12 x 12 x 2	None	Time Cycle (6)	Incineration	26.00	26.00			
By-pass #10	B-Z-Kleen	Aerosol	FA	Dust	(3) 24 x 24 x 12	(3) 24 x 24 x 12	None	Time Cycle (6)	Incineration	5.00	5.00			

Bldg. No. & Location	Mfg. and/or Trade Name	Classification & Type	Size Application	Cleaning Requirements	Descriptive & Operational Data		Operating Characteristics	Method of Replacing	Criteria for Cleaner Change	Disposal Method	A-1 Equip Charges Yearly Per 1000 CFM	A-2 Main emson Per 1000 CFM/yr.	B Labor Charges - Dollars Yearly Cleaning & Replacement Per 1000 CFM	Disposal	Remarks
					Space Requirements	Requirements									
Gen. Lab Bldg. 140															
EP 27-1	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Dust	1-24 x 30 x 12		1200	Remove by hand	Time Cycle Incubation	Incubation	\$ 2.40	\$ 1.20	\$ 2.40		B-2-Kleen
EP 41-1	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Dust	1-24 x 30 x 12		1000	Remove by hand	Time Cycle Incubation	Incubation	4.80	1.20	4.80		A-1 \$1.50 each per 1000 CFM
EP 4-1	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 30 x 12		1250	Remove by hand	Time Cycle Incubation	Incubation	2.00	1.00	2.00		A-2 .25 per M CFM x 4 per year
EP 4-2	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 30 x 12		1250	Remove by hand	Time Cycle Incubation	Incubation	2.50	1.25	2.50		B 4 cleanings per year per 1000 CFM
EP 4-3	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 24 x 12		1250	Remove by hand	Time Cycle Incubation	Incubation	2.50	1.25	2.50		\$ 1.00 per M CFM
HEF 10-1	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 24 x 12		1250	Remove by hand	Time Cycle Incubation	Incubation	2.50	1.25	2.50		Dust Stop (Glass) per year
HEF 11-1	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 30 x 12		1250	Remove by hand	Time Cycle Incubation	Incubation	2.50	1.25	2.50		A-1 Unit cost per 1000 CFM x 4 changes per year
HEF 11-2	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 30 x 12		1250	Remove by hand	Time Cycle Incubation	Incubation	2.50	1.25	2.50		A-2 .25 cents per M CFM x 4 per year
HEF 11-3	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 30 x 12		1250	Remove by hand	Time Cycle Incubation	Incubation	2.50	1.25	2.50		B 4 changes per year per 1000 CFM @ \$1.00/M CFM
HEF 11-4	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 30 x 12		1250	Remove by hand	Time Cycle Incubation	Incubation	2.50	1.25	2.50		Aerosolve + Absolutes
HEF 11-5	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 30 x 12		1250	Remove by hand	Time Cycle Incubation	Incubation	2.50	1.25	2.50		A-1 Price per 1000 CFM
HEF 11-6	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 30 x 12		1250	Remove by hand	Time Cycle Incubation	Incubation	2.50	1.25	2.50		A-2 .25 per 1000 CFM x 4 per year
HEF 13-1	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Hood	1-24 x 30 x 12		1000	Remove by hand	Time Cycle Incubation	Incubation	2.50	1.25	2.50		B 2 changes per year per 1000 CFM @ \$1.00/M CFM
EP 33-1	Aerosolve	A-1200 Spin Glass	Ex Air	Dust	1-24 x 24 x 12		1600	Remove by hand	Time Cycle Incubation	Incubation	3.20	1.60	3.20		HFH Hood exhaust fan MBF Machine exhaust fan
HEF 33-3	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Dust	1-24 x 24 x 12		1100	Remove by hand	Time Cycle Incubation	Incubation	2.20	1.10	2.20		Note: All filters contaminated with radioactivity are banded as radioactive waste.
HEF 33-3	Absolute Fiberglass	A-1200 Spin Glass	Ex Air	Dust	1-24 x 24 x 12		2800	Remove by hand	Time Cycle Incubation	Incubation	5.24	2.80	5.40		
Bldg. 150															
EP 3-1	Dust Stop Absolute	Spin Glass	100% No RC EA	Throw away	1-23 3/8 x 23 3/8 x 2		620	None	Time Cycle	Consum. Quarterly	4.00	4.00			
EP 4-1	Absolute Fiberglass	Flanders I.A. 1250 Spin Glass	Exhaust	Special Attention	4-23 1/2 x 29 1/2 x 2		5000	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 4-2	Absolute Fiberglass	Flanders I.A. 1250 Spin Glass	Exhaust	Special Attention	4-24 x 30 x 12		5500	None	Time Cycle	Spec. Handling & Disposal	8.00	8.00	16.00		
EP 4-3	Absolute Fiberglass	Flanders I.E. 1000	Exhaust	"	6-24 x 24 x 12		5500	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 6-1	Absolute Fiberglass	Flanders I.A. 1250 Spin Glass	Exhaust	Dust	6-24 x 24 x 12		1320	None	Time Cycle	Spec. Handling & Disposal	177.44	177.44	15.00		
EP 6-1	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	6-24 x 24 x 12		1320	None	Time Cycle	Spec. Handling & Disposal	177.44	177.44	15.00		
EP 6-2	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	2-24 x 24 x 12		2600	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 6-2	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	2-23 3/8 x 23 3/8 x 2		2600	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 6-3	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	2-24 x 24 x 12		792	None	Time Cycle	Spec. Handling & Disposal	8.00	8.00	16.00		
EP 6-3	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	2-23 3/8 x 23 3/8 x 2		792	None	Time Cycle	Spec. Handling & Disposal	8.00	8.00	16.00		
EP 6-4	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	2-24 x 24 x 12		1188	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 6-4	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	2-23 3/8 x 23 3/8 x 2		1188	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 6-5	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	2-24 x 24 x 12		1656	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 6-5	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	2-23 3/8 x 23 3/8 x 2		1656	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 6-6	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	2-24 x 24 x 12		3000	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 6-6	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	4-20 x 20 x 2		3000	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 6-7	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	3-24 x 24 x 2		3000	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		
EP 6-7	Absolute Fiberglass	Flanders I.A. 1000 Spin Glass	Exhaust	Spec. Air'n	1-24 x 30 x 12		1320	None	Time Cycle	Spec. Handling & Disposal	10.00	10.00	20.00		

Blgd. No.	Room No.	Manufacturer	Classification	Application	Requirements	Size	CFM	Cleaning	Criteria	Initial Cost
102	None	Pease-Anthony	Scrubber	Final - Exhaust Air	Fume	5 Dia x 13' Hi	5000 CFM	Self-cleaning		\$ 12,500
10	Raw Mat'l's Insp.	Dust Kop (Agst) col.	Dust Collector	Pre-cleaning Exhaust	Dust	3' 0" x 1' 6"	1400	Pressure Loss		
10	Mockup	AAF Rocelone	Dust Collector	Final Exhaust	Dust	12' x 8'	17000	Wood & Plastic Dust	Time Cycle	2,000
10	Assembly	AAF Rocelone	Dust Collector	Final Cleaning	Dust	3' 0" x 9' 0"	2500		Time Cycle	2,500
10	Sheet Metal	AAF Rocelone	Dust Collector	Final Cleaning	Dust	3' 0" x 6' 0"	1400	Pressure Loss		
10	Tool Grinding	Dust Kop (Agst)	Dust Collector	Final Cleaning	Dust	3' 0" x 1' 6"	2030	Vacuum	Time Cycle	3,289
110	Carpenter Shop	Dust Kop	Dust Collector	Final Cleaning	Dust	6' x 6'	2030	Vacuum	Pressure Loss	
110	Stone Saws	Dust Kop	Dust Collector	Final Cleaning	Dust	4' x 6'	2030	Vacuum	Pressure Loss	



Table 6 Savannah River Plant Data

A-B Type Filter	C Type	AIR CLEANING DATA		F Site	G Operational Characteristics	H Replacement Pressure Loss	I Power HP/1000 CFM	J Replacement Frequency	K Disposal Methods	L Who Deter- mines Criteria for Changes	M Criteria for Changes	N Replacement Cost \$/1000 CFM/yr.	O Man-hrs/ 1000 CFM/yr.
		E Application	D Requirements										
Cartridge Type A	Absolute Glass-Asbestos	Final Cleaning Lab Hood	Particle Removing	2x30cell 1/2 2x40cell 1/2 8x8x11 1/2	250 FPM 200 FPM 200 FPM	Int. - 1 in. Final - 2.5	1 1/2 - 20 2 10	2 yrs.	Perf. Prot. Packaging Burial	Reg. Serv. Radn. Cont.	Pressure loss Activity Time cycle Mech. failure	\$10/unit total \$15	10 min/unit 1/4 man-hrs. (total)
Cartridge Type B	Absolute Glass-Asbestos	Final Cleaning Lab Hood	Particle Removing	2x30cell 1/2 12x12x5 7/8	250 FPM	Int. - 1 in. Final - 2.5	1 1/2 5	2 yrs.	Same as above	Reg. Serv. Radn. Cont.	Same as above	\$50/unit	10 min/unit
Cartridge Type D	Absolute Glass-Asbestos	Final Cleaning Lab Hood	Particle Removing	2x30cell 1/2	250 FPM	Int. - 1 in. Final - 2.5	1 1/2 5	2 yrs.	Same as above	Reg. Serv. Radn. Cont.	Same as above	total \$25	1/4 man-hrs. (total)
Cartridge Type F	Absolute Glass-Asbestos	Final Cleaning Lab Hood	Particle Removing	2x30cell 1/2 12x12x5 7/8	250 FPM	Int. - 1 in. Final - 2.5	1 1/2 5	2 yrs.	Same as above	Same as above	Same as above		
Micro-Metallic	Porous Stainless Steel	Pre-Cleaning Process System (Moisture Sep.)	Particle & Vapor Removal					5 yrs.	Same as above	Bldg. Serv.	Pressure loss	No cost	-
Dollinger (Fiber)	Fiber (?)	Exh.-Process System (Moisture Sep.)	Vapor & Liquid Removal					2 yrs.	Same as above	Bldg. Serv.	Pressure loss Mech. failure	\$10/unit total \$50/yr	1 man-hr/yr/unit 10 man-hrs. (total)
Research Products, Inc. Alumalloy	Oil Coated Glass-Metal Screen	Exh.-Special Hood	Particle Removal	12x12x2			3	1 month	Cleaning & re-use	Bldg. Serv. Op. Group	Pressure loss Mech. failure Time cycle	No cost	1 1/2 man-hrs (total)
Dust-Stop Prefilter	Glass Fibers	Pre-filters Gas Ventilat. Hoods	Particle Removal	25x25x2 20x25x2 16x20x2 12x12x2 8x8x2		Final - 0.5 in.	1 1/2 - 2 - 5 10	3 months	Person prot. Packaging, burial	Reg. Serv. Radn. Cont. Op. Groups	Pressure loss Activity Time cycle Mech. failure	\$3	1/3 man-hrs. (total)
Alu-Met	Woven Fiber	Pre-filter Supply A/C	Particle Removal			Int. - 0.5 in. Final - 1.0 in.		3 months	Same as above	Bldg. Serv. Radn. Cont.	Time cycle Pressure loss Mech. failure	7	3 man-hrs. (total)

Submitted by R. H. Hale, Savannah River Plant

Table 7 KAPL Data

ECONOMIC SURVEY OF KAPL AIR CLEANING OPERATIONS

<u>Manufacturers</u>	<u>Trade Name</u>	<u>Cleaner Classification</u>	<u>Site Application</u>	<u>Cleaning Requirement and Process</u>	<u>Space Requirements</u>		
					<u>Overall Dimensions</u>	<u>Capacity (CFM)</u>	<u>cu ft/CFM Cleaning Capacity</u>
						<u>Face Area (sq ft)</u>	<u>1000 CFM</u>
American Air Filter Co.	Throw away type glass fibre filter.	Precleaning performed glass	Prefilter Gen. Ventilation	Suburban Area atmosphere prepared for nuclear fuel examination and waste processing areas.	2"x24"x24"	1200	5.6x10 <sup>-4</sup>
American Air Filter Co.	Multi-Duty Air Filter automatic, self-cleaning.	Precleaning, oil-coated metal screens, type MS	Prefilter Supply Air, Gen. Ventilation.	Suburban area atmosphere prepared for production machine shop and laboratories.	8'x8.5' - 18'x12'	18,900 - 60,000	6x10 <sup>-3</sup>
Dollinger Co.	Dollinger automatic, self-cleaning.	Precleaning, oil-coated metal screens	Prefilter Supply Air, Gen. Ventilation.	Suburban Area atmosphere prepared for laboratories.	10'x12.5' - 15'x12.5'	40,000 to 60,000	6.25x10 <sup>-3</sup>
American Air Filter Co.	Throw away type glass fibre filter.	Precleaning performed glass	Precleaning Exhaust Air Multi-Curie Fission Product Lab.	Laboratory exhaust air prepared for subsequent ultra filtration.	2"x24"x24"	1000	6.4x10 <sup>-4</sup>
Flanders Filter Co.	Air pure, Gas. No. 2G70b	Ultra filter-F200 filter media	Final Cleaning Exhaust Air Multi-Curie Fission Product Lab.	Laboratory exhaust air prepared for public environment.	11"x24"x24"	100 - 1000	4x10 <sup>-2</sup> - 4x10 <sup>-3</sup>

Western Precipitation Corporation	Multicone Type 9VG/2 Model P-19923-40	Precleaning cyclone separator	Precleaning Exhaust Air Production Mach, Shop	Machine Shop metal dust removal from exhaust air	8'x8'x8'	59,000	$8.6 \times 10^{-3}$	---
Improvised	None	Final cleaner, Fibre bed performed	Final Cleaning-Exhaust Air Production Mach.Shop	Machine Shop air prepared for public environment.	1'x10'x8'	59,000	$1.4 \times 10^{-3}$	1.1

APPENDIX II

**Estimated Costs of Air Cleaning Systems**

Table 8. Air Cleaning Costs of Roughing and Precleaning Filters

<u>ID</u>	<u>Flow Rate</u>	<u>Depreciation</u>	<u>Equipment</u>	<u>Cost in Dollars per cfm per year</u>			<u>Comments</u>	<u>Type</u>
				<u>Power</u>	<u>Labor</u>	<u>Total</u>		
8c	--	--	0.003	2.775	0.002	2.780	Power Costs included and dominate	Dustop
7c	--	--	--	0.450	0.027	0.477	Initial Cost high	OCMS
5.1	16,000	.4000	0.0002	--	0.0053	0.4055	↑	OCMS
9	3840	--	0.0000	--	0.3120	0.3120	Labor Costs Dominate	Taylor
1.2	1000	.0071	0.0816	--	0.1800	0.2687	and	Ca-24
3.2	1000	.0071	0.0816	--	0.1800	0.2687	Equipment Charges	Ca-24
1.3	1000	.0060	0.0816	--	0.1800	0.2676	Relatively High	PI-24
2.2	1000	.0060	0.0816	--	0.1800	0.2676	↓	PI-24
3.3	1000	.0060	0.0816	--	0.1800	0.2676	↑	PI-24
11	10200	--	0.0250	--	0.0750	0.1100	High Flow	F:PA,5
1e	100,000	--	0.0324	--	0.0015	0.0339	Rates	F:15R/OT
2b	1760	.0096	0.0558	--	0.0082	0.0736	Low Equipment	PI-24
1a	6847	--	0.0027	--	0.0161	0.0188	and	Dustop
3a	92865	--	0.0023	--	0.0155	0.0178	Labor Costs	Dustop

Air Cleaning Costs of Roughing and Precleaning Filters (Cont'd)

23	65,400	--	0.0010	--	0.0117	0.0127	RSVT
25	120,000	--	0.0008	--	0.0096	0.0104	RSVT
24	120,000	--	0.0008	--	0.0096	0.0104	RSVT
4.1	430,000	0.0076	0.0001	--	0.0005	0.0082	OCMS
21	108,000	--	0.0009	--	0.0071	0.0080	RSVT
1d	65,000	--	0.0049	--	0.0030	0.0079	OCMS
10	40,000	--	0.0001	--	0.0045	0.0046	F:15R/QT
16	26,000	--	0.0010	--	0.00185	0.0020	Pritchard
1	3,600,000	--	0.00033	--	0.00148	0.0018	AM:KF
2	1,630,000	--	0.00012	--	0.00054	0.0007	AM:KF
5	7,200,000	--	0.00002	--	.00043	0.0005	AM:P-5
3	2,700,000	--	0.00002	--	.00041	0.0004	AM:P-5
4	5,400,000	--	0.00001	--	0.00028	0.0003	AM:P-5

F:----, Fulflo-----

OCMS: Oil Coated Metal Screen

RSVT: Rotating Screen Viscous Type  
 AM:KF; Air Maze Kleen Flow

Table 9. Air Cleaning Costs of Electrostatic Precipitators

<u>ID</u>	<u>Type</u>	<u>Flow Rate, in cfm</u>	<u>Depreciation</u>	<u>Equipment</u>	<u>Power</u>	<u>Labor</u>	<u>Total</u>	<u>Comments</u>
1b	Electro- matic	184,000	0.085	0.024	*	0.058	0.167	Adjusted power; equipment and labor costs indicate total cost of \$.15 to 0.2 per cfm/year.
3.5	Oil Mist Prec.	1200	0.117	0.012	--	0.018	0.147	
5	Electro- matic	5380	0.104	--	0.028	--	0.132	
20	Cottrell Ppt	960,000	--	**	0.007	0.021	0.028	Depreciation costs not included. The deprecia- tion and power costs would result in an esti- mated addition cost of \$.01 per cfm per year
22	West. Elect. Ppt	19,000	--	**	--	0.005	0.005	
2d	Oil Mist Prec.	65,000	--	*	--	0.0044	0.0044	

\* Included under labor costs

\*\* No costs to date

Table 10. Air Cleaning Costs of Bag Collectors

ID	Type	Flow Rate, in cfm	Cost, in Dollars per cfm per year				Total <sup>***</sup>	Comments
			Depreciation*	Equipment	Power <sup>**</sup>	Labor		
27	Aeroturn	600	--	1.307	--	0.620	1.927	Unit costs high with low flow rate
7.3	Disc. Filter	?200	0.764	0.058	--	0.120	1.942	High installation cost but low operational costs.
8.2	Amerjet	3500	0.238	0.0002	--	--	0.242	
1.1	Mikro-Col	64000	0.062	0.130	--	0.009	0.201	Costs decreases with
2.1	Dual-Aire	85000	0.060	0.065	--	0.009	0.134	increase in flow rate
3.1	Dual-Aire	85000	0.060	0.065	--	0.009	0.134	
6.1	Aeroturn	300,000	0.050	0.028	--	0.006	0.084	

\* Write-off over a period of 5 years

\*\*\* Avg. labor costs of \$6/man-hr were assumed

\*\* Hp/1000 cfm requirements for the above collectors vary from 0.94 to 4.5 for 8000 hrs operations per year with fan and motor efficiency taken as 60%, 1 Hp/1000 cfm would result in a power cost of \$0.150/cfm/yr.

Power costs for ID 7.3 is estimated at \$0.6/cfm/yr whereas the other power costs are approximated at \$0.3/cfm/yr on the basis of \$0.015/kw-hr.

Table 11. Air Cleaning Costs of High Efficiency Filters

ID	Type	Flow Rate, in cfm	Cost in Dollars per cfm per year					Total	Comments
			Flow Rate, in cfm	Depreciation	Equipment	Power	Labor		
28	Absolute	50	--	2640	--	1.440	4.080	Unit cost high at cont. flow rate. Add. 0.015 for Power and 0.028 for depreciation	
3.4	Abs.(Cell-Asb)	1000	0.028	1.694	--	1.440	3.162	Units replaced each month. Add 0.30 for Power.	
1.5	Abs.(Cell-Asb)	50	0.028	1.694	--	1.440	3.162	Low flow rate and monthly re- placement. Add 0.015 for Power.	
1.4	Abs.(Glass-Cell)	--	--	0.015	2.025	0.002	2.042	High power costs dominate	
2a	Abs.(Cell-Asb)	6847	--	0.261	--	1.460	1.721	High level activity area	
7.1	Abs.(All Glass)	2200	0.013	1.200	--	0.186	1.399	Equipment costs dominate	
2c	Abs.(Glass-Cell)	--	--	0.025	0.975	0.002	1.002	Costs governed by power requirements	
4c	Abs.(Glass-Cell)	--	--	0.025	0.975	0.002	1.002		
2e	Abs.(Glass)	100,000	0.680	0.027	--	0.020	0.727	Installation costs high, operational relatively low.	
1.4	Abs.(Cell-Asb)	1000	0.008	0.516	--	0.072	0.596	Add 0.30 for power costs.	
4a	Abs.(Cell-Asb)	92865	--	0.140	--	0.396	0.536	Flow rate high contributes to relatively low costs.	

Air Cleaning Costs of High Efficiency Filters (Cont'd)

3c	Abs.(Glass- Cell)	--	--	0.025	0.225	0.002	0.252	Replacement costs low, filters changed every two years
5.2	Abs.(All Glass)	1000	0.006	0.030	--	0.005	0.041	Filters replaced every two years. Add 0.30 for Power.

Conclusions: Under conditions specified above the annual operational costs (including power and depreciative costs) for the use of Absolute Filters is estimated to be 0.5 to 5.0 dollars / cfm.

Table 12. Air Cleaning Costs of Composite Systems

Composite System	costs, in dollars/cfm/year										Total	Comments
	Flow Rate, in cfm	Eff.	F	D.F.	Depreciation	Equipment	Power	Labor				
Rad. Materials Lab.	5380	99.95	.0005	2000	--	7.732	--	**	7.732	Includes LEF, HEF, EP		
Exhaust Systems	67050	99.95	.0005	2000	--	2.614	--	1.881	4.495	Includes LEF, HEF, BC		
Waste Incinerator	5500	99.95	.0005	2000	--	2.487	--	.486	2.973	Includes CY, HEF, BC		
Ten Site	27600	?		2000	.361	.319	*	.218	.898			
Reactor Exhaust	100,000	99.95	.0005	2000	.680	.028	--	.020	.728	DPF, HEF		
Chemical Metallurgical	35,000	99.95	.0005	2000	.195	.362	*	.118	.675	LEF, HEF, etc.		
D.P.W.	184,000	99.5	.005	200	.095	.080	*	.066	.241	Includes LEF, EP		
Reactor Supply Air	100,000	75	.25	4	--	.043	--	.006	.049	Includes LEF		
Reactor Supply Air	100,000	75	.25	4	--	.032	--	.002	.034	Includes LEF		
General Supply Air	430,000	60	.4	2.5	.0076	.0001	--	.0005	.0082	OCMS		
General Supply Air	26,000	60	.4	2.5	--	.00010	--	.00185	.0020	LEF		
General Supply Air	7,200,000	60	.4	2.5	--	.00002	--	.00043	.0005	AM		

\* Included new equipment and labor costs

\*\* Included under equipment costs

\*\*\* LEF, Low Efficiency Filters, the Dustop, etc.

HEF, High Efficiency Filters, the Absolute Filter, etc.

EP, Electrostatic precipitators

BC, Bag Collectors

CY, Cyclone

DPF, Deep Pocket Filters

## Discussion

- Q. (C. E. Lapple, Stanford Research Lab.) I would like to ask you about your proposal to express equipment costs in terms of penetration. If I interpreted your suggestion correctly the first approximation you would present costs in dollars per year per CFM, for a unit of penetration, as being a rough constant. On that basis if you have 39% efficiency and want to raise it to 99.99 you say it would cost a hundred times as much per year to do that. Am I interpreting your suggestion right?
- A. If you have 99% efficiency and want to raise it, you would use a factor of 100 - seems that would be extremely pessimistic - expect implementing cost would be factor of 3 to 4.

Suppose you have filter giving 99% efficiency and put an filter in series with it, if you have a homogeneous aerosol you would get 99% over all at just about twice the cost. Actually aerosol is not homogeneous so you would not get that much efficiency, but it would still be 99 something percent efficiency. I suggest consideration for presenting the costs in terms of dollars per year - for the present time, let's take what we have because we have to go along with experiment data. Experimental data shows penetration times the cost is equal to the constant.

- Q. (Belter - AEC Washington) Joe, has any consideration been given especially after more data is accumulated to breaking down this data by the type of facility. Whether it would be say a laboratory facility or production site or perhaps a certain type of reactor site.
- A. Yes, definitely. We have even started on that. Our data as I presented it, there are specific systems but we are also going to integrate that into the broad functions of the whole site. We must get the basic data and the essential data so that we can build up on it.
- Q. (B. L. Rich, PFCo.) I was wondering -- an economic review seems to intimate that you would evaluate a process in terms of economics rather than evaluate in terms of process in regard to filtration problems. Is this part of your program?
- A. Yes, as I pointed out - we are interested not only on the economics of the efficiencies with respect to the financial setup but also with respect to the physical or the effectiveness of that system. Thereby wherever we can be helpful in pointing out something in pointing out what others have done I think we would put into it as we have already done that in the survey. You will notice that the economics is just one phase of the whole evaluation.

## PROGRESS REPORT ON HARVARD-AMERICAN IRON AND STEEL INSTITUTE RESEARCH PROJECT

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### ABSTRACT

Research studies on removal of fine fumes ( $< 0.5\mu$ ) from high temperature gases ( $1000^{\circ}\text{F}$ ) are being conducted at Harvard for the American Iron and Steel Institute. Four main phases of this project are discussed in this report: (1) agglomeration of fine fume; (2) heat transfer characteristics of rotary screw agglomerators; (3) shock wave cleaning of mineral wool filters; and (4) pilot plant investigations of use of mineral wool for high temperature fume filtration.

Through agglomeration, submicron particles in metallurgical furnace effluents can be increased in size, facilitating their removal by fiber filters and extending filter life. The rotary screw agglomerator used for this purpose has shown a heat transfer rate in excess of what normally might be expected which considerably reduces ( $100$  to  $600^{\circ}\text{F}$ ) the temperature of gases going to the filtering unit. Shock wave cleaning of mineral wool filters has been used to extend filter life in laboratory and field units as well as to reduce space requirements on a prototype unit. Using this shock wave cleaning method, as well as features from previous pilot plants, we have had very encouraging results on a  $2000$  cfm mineral wool filtering unit operated on fume from open hearth and electric furnaces.

### Introduction

Many industries exhaust high temperature gases containing sub-micron fumes directly into the atmosphere. There is cleaning equipment available to control these situations, but because of the small particle size ( $< 0.5\mu$ ) and the high temperatures ( $> 1000^{\circ}\text{F}$ ), cost of such equipment presents an undesirable capital burden.

Steel industry problems are primarily concerned with removing visible (non-toxic) particulates from metallurgical furnace exhaust gases from the standpoint of air pollution control, and as such, they require removal of greater than  $90\%$  of the fumes. Results of these studies can be applied to certain AEC problems such as incinerator effluents, air or gas cooled nuclear reactors, certain gaseous, liquid and solid process wastes, etc.

TABLE 1

Characteristics of Experimental Rotary Screw Agglomerators

	3	6	12	24
Nominal Diameter, Inches				
Actual Diameter, Inches	2-3/4	6	12	24
Pitch or Lead, Inches	2	6	12	24
Screw Length, Inches	24	36	64	140
Number of Screw Turns	12	6	7	6
Shaft Diameter, Inches	1	2-1/2	3	4-1/2
Inlet and Outlet Size <sup>a</sup> , Inches	1-1/2 ID	3-1/2 ID	6 ID	In 24 x 4-3/4 Out 12 ID
Cross-Section of Gas Path <sup>b</sup> , Square Feet	0.011	0.080	0.38	1.625
Hydraulic Radius of Gas Path, Feet	0.025	0.062	0.136	0.289
Total Length of Gas Path, Feet	7.3	7.8	17.5	29.9
Spiral Channel Reynolds Number	10 <sup>4</sup> -1.5 x 10 <sup>5</sup>	10 <sup>4</sup> -1.5 x 10 <sup>5</sup>	10 <sup>4</sup> -1.5 x 10 <sup>5</sup>	1.5 x 10 <sup>5</sup> -3.5x10 <sup>5</sup>
Overall Resistance <sup>c</sup> , Inches, Water	7.2	3.0	2.5	2.2
Gas Flow, cfm, STP	38	200	600	2400
Collection Efficiency <sup>d</sup> , %	47 LF	15 LF	4 OFF	44 FF
Spiral Channel Friction Factor (f)	0.013-0.0085	0.013-0.0085	0.013-0.0085	0.026

- a. Twenty-four inch model constructed with slotted inlet extending across two adjacent flights.
- b. Assumed from a plane passing through the screw axis.
- c. Inlet velocity 3000 feet per minute at stated gas flow.
- d. LF = laboratory fume simulant, FF = field open hearth fume.

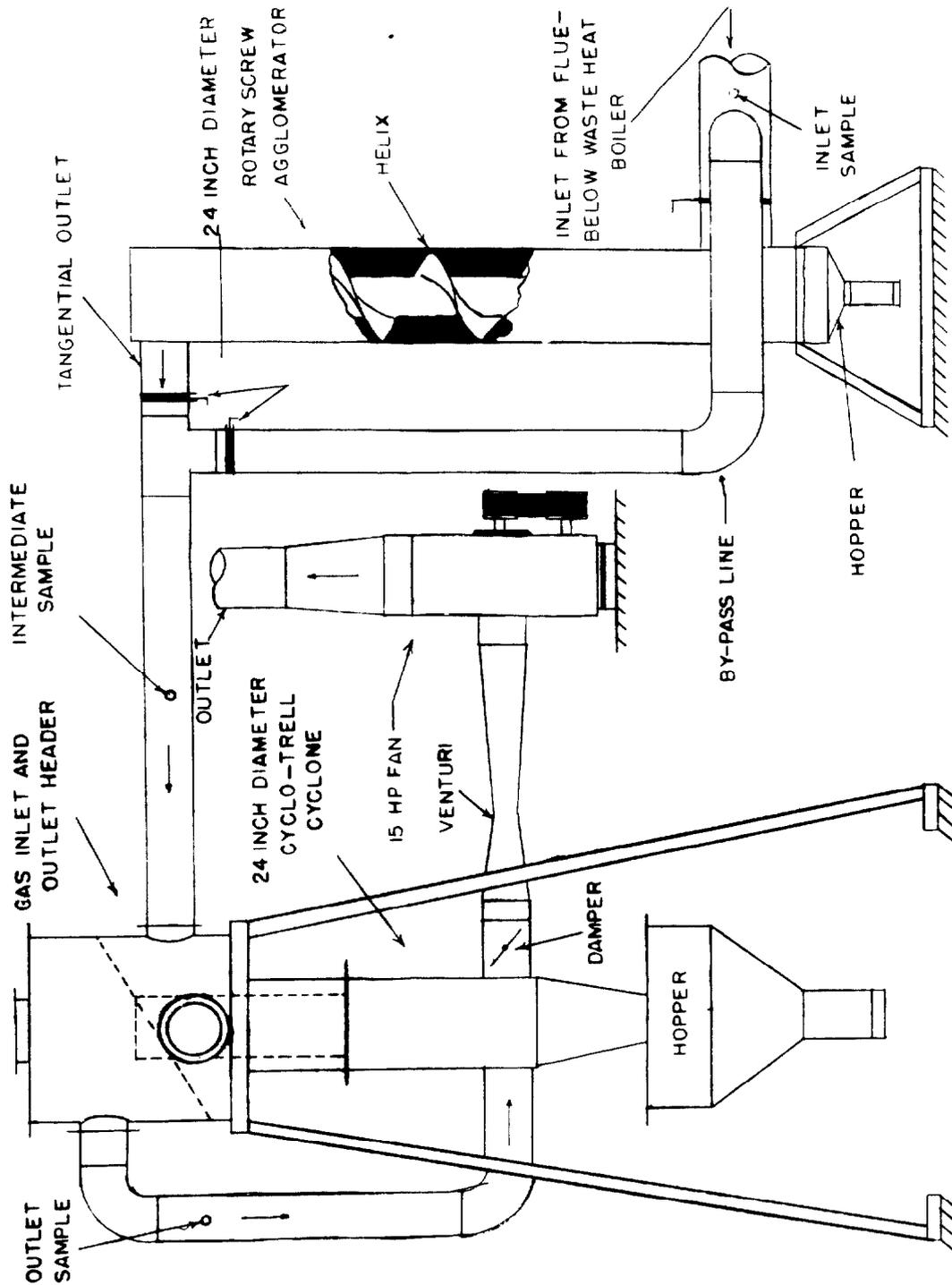


Fig. 1—Field installation of agglomerator and cyclone.

The principal objective of this project is to produce a gas cleaning unit that will require minimum floor space, low capital investment and low operational cost. Research work directed toward this end has shown that a rotary screw agglomerator can both increase particle size, facilitating subsequent fume filtration, and greatly reduce gas temperatures, simplifying the construction of the filtering unit. In addition, mineral wool fibers (1¢/lb.) can be used repeatedly on iron oxide fume when cleaned with shock waves to extend filter life. This development has been applied to a pilot plant unit presently being field tested which can filter and clean within the same chamber thereby reducing floor space and auxiliary equipment.

### Agglomeration Studies

The study of agglomeration is divided into two parts; the particle concentration instrumentation, to be presented separately, and the means of producing agglomeration, mechanisms of which have been presented (1). This paper is a continuation of studies reported at the 5th Air Cleaning Conference, with some of this previous information being included in the tabulations.

A vertical 24 in. diameter rotary screw agglomeration unit (see Table 1) has been field tested on open hearth furnace effluent. A 24 in. diameter cyclonic vane type collector was operated in series with the agglomerator or with the agglomerator by-passed as shown in Figure 1. The field operations showed that neither intermittent nor continuous rotation of the screw caused any apparent change in collection efficiency above that when the screw was held stationary. Efficiencies of the various arrangements tested are listed in Table 2.

TABLE 2

Particle Removal Efficiency of Rotary Screw Agglomerators

Nominal Screw Size Inches	Aerosol*	Efficiency** %	Remarks
3	LF	0	Insulated, no settling chamber
	LF	2.5	Insulated, with settling chamber
	LF	47.0	Uninsulated, with settling chamber
6	LF	15.2	Uninsulated, no hopper
	Fly Ash	22.0	Uninsulated, no hopper
12	FF	40.0	Uninsulated, with long. hopper
	24***	43.8	Screw Agglomerator
	FF	15.5	Cyclone Eff. (following screw)
	FF	35.6	Cyclone Eff. (by-pass screw)
	FF	52.6	Cyclone and screw

\* LF = laboratory simulant iron oxide, FF = field open hearth fume

\*\* Inlet temperature 500°F or above, screw stationary or rotating at 1 to 2 rpm.

\*\*\* Screw unit in vertical position.

Collection efficiency of the 24 in. agglomerator (primarily not a collector) was slightly larger than the collection efficiency of the 24 in. cyclone.



An analysis of electron-microscope targets of simultaneous inlet and outlet fume samples from the 12 in. and the 24 in. agglomerator are presented in Table 3. In 2 out of 3 cases for each agglomerator the outlet particle size is in excess of the inlet size and this increase is in excess of what might be expected for unaided diffusion coagulation.

Presently a 6 in. agglomerator is being adapted to use an additional agglomeration producing mechanism, the introduction of moving targets such as alundum shot or extended surface packings.

Another phase of the agglomeration studies is the examination of resuspended particles from a loaded filter. It was first suggested by E. Anderson (2) in 1934 that filters could act as agglomerators with reentrained larger particles collected subsequently by other devices. The results of these agglomeration tests using low level shock waves to dislodge particles from mineral wool filters are presented in Table 4. Line 1 shows the characteristics of the initially generated fume with the following tests being made on resuspended

Table 4. Particle Size of Iron Oxide Fume Removed From Mineral Wool Filters By Shock Wave Cleaning

Test No.	Particle Size - Microns <sup>a</sup>			Magnification	Blast Pressure In.Hg
	Mg	$\sigma_g$	Mg'		
1	0.056	1.9	0.19	30,700	<sub>b</sub>
2	0.12	2.1	0.62	30,700	3
2'	0.32	1.7	0.72	7,700	3
3	0.076	1.9	0.27	30,700	4
4	0.37	2.1	2.0	7,700	6
5	0.063	2.0	0.29	30,700	12

a. Mg = count median diameter, microns;  $\sigma_g$  = standard geometric deviation; Mg' = mass median diameter, microns.

b. Initial fume size as generated and filtered.

particles. Lines 2 and 2' are the results from the same grid of an electron microscope target but at different magnifications. The lower magnification evidently over-estimates the fume particle size by a factor of about the same as the ratio of the magnifications. Lines 2, 3 and 5 show that the dislodged particle size is larger than the generated size but that it is decreased as the blast pressure is increased.

#### Heat Transfer Study on 6 in. Jacketed Agglomerator

One of the unanticipated but desirable aspects of the screw agglomerator has been its performance as a heat transfer unit. Because of the spiral flow and disturbed boundary layer, eddy transfer is enhanced. An added advantage of the unit is the walls may be cleaned by merely rotating the enclosed screw so that the agglomerator becomes a self cleaning heat transfer unit.

## Unit Description

Our present model (Figure 2) consists of a helical screw within a vertical steel tube with an outer concentric steel tube forming a jacket for the cooling liquids. The  $9\frac{1}{2}$  in. outside diameter by 5 ft. long jacket has a 1 in. pipe inlet and outlet. High temperature gas is admitted by a rectangular tangential entry to the screw through the base of the jacket. A round tangential exit is above the expansion collar connecting the steel tubes. The 6 in. diameter by 6 in. pitch screw can be held stationary, rotated, or removed from the unit.

Table 5

### SUMMARY OF HEAT TRANSFER CHARACTERISTICS OF ROTARY SCREW AGGLOMERATORS

Cooling Fluid	Screw	Inlet Temp. °F	Gas Flow lbs./hr.	Coeff. Btu/hr./ft. <sup>2</sup> /°F	Temp. Drop °F
<b>A. VALUES REPORTED IN PERRY, J.E., "CHEM. ENG. HANDBOOK"</b>					
Nat'l. Conv., Gas	-	-	-	0.6-2	-
Forc. Conv., Gas	-	-	-	2 -6	-
Nat'l. Conv., Liquid	-	-	-	1 -3	-
Forc. Conv., Liquid	-	-	-	2 -10	-
Nat'l. Conv., Boil. Liq.	-	-	-	1 -10	-
<b>B. SIX INCH DIA. UNJACKETED AGGLOMERATOR - LAB. STUDY (Scr. Horiz.)</b>					
Nat'l. Conv., Air	Out	670	340-560	0.60-0.66	70-95
" "	In	700	370-550	1.3 -1.8	120-190
" "	In	1000	410-500	1.8 -2.4	220-360
Running Water Film	In	500	440-620	13 -17	220-230
" "	In	700	400-540	12 -16	320-350
" "	In	1000	310-480	10 -16	520-530
<b>C. TWENTY-FOUR INCH DIA. UNJACKETED AGGLOMERATOR - FIELD STUDY (Screw Vert.)</b>					
Nat'l. Conv. Air	In	840 to 1200	7600 to 12800	157,000* to 885,000* *Btu/hr.	55 to 270
150 hours operation analyzed for 12 days, upon rotation of screw the heat transfer rate increased 30%.					
<b>D. SIX INCH DIA. JACKETED AGGLOMERATOR - LAB. STUDY - (Scr. Vert.)</b>					
Nat'l. Conv., Air	In	1000	200-660	1-3	100-150
Forc. Conv., Air	In	1000	200-700	3-5.5	150-300
Forc. Conv., Water	In	1000	250-850	7-16	300-550
Boil. Water - Steam(100#)	In	1000	250-800	5-15	300-400
F.C. - Dowtherm A	In	1000	200-850	6-16	250-560
" "	In	1500	170-740	6-15	590-950
" "	Out	1000	190-820	3-13	270-350
" "	Out	1500	190-750	5-13	500-650

## Test Results

Table 5 lists the results of heat transfer studies obtained with this unit using air, water, steam, and Dowtherm A, with the screw in place and removed. The results of previous tests on a 6 in. and 24 in. unjacketed agglomerator in addition to values from a standard reference are also reported. It is evident from these studies that

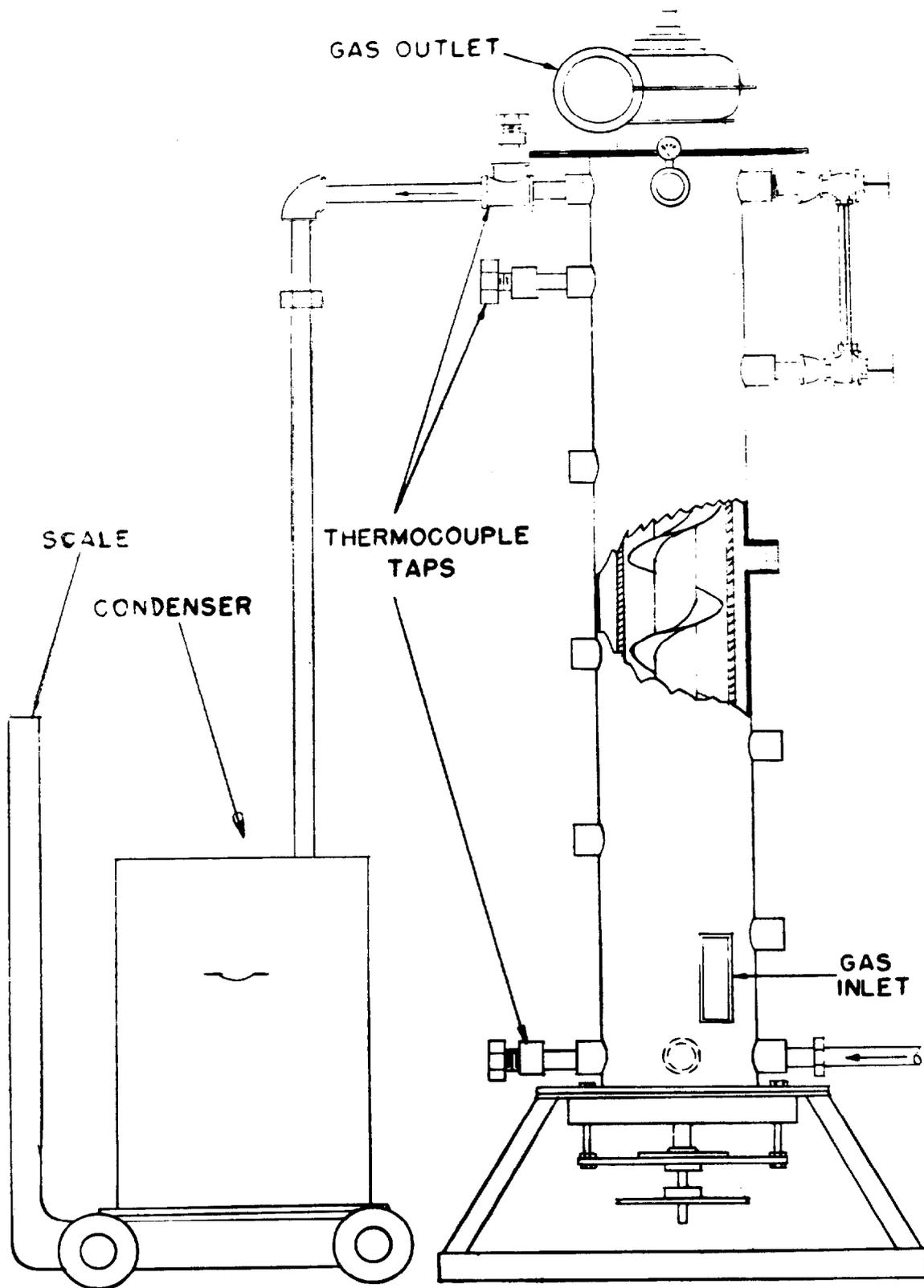


Fig. 2—Rotary screw agglomerator, heat transfer unit.

the overall heat transfer is on the order of 1.5 to 2 times greater than standard values. Studies are presently being continued with modifications to the 6 in. jacketed screw unit, to investigate heat transfer in addition to agglomeration effects, as mentioned previously.

### Shock Wave Studies

#### Results of Previous Investigations

Prior to the start of the present study in the laboratory, a comprehensive investigation had been undertaken for the U. S. Atomic Energy Commission on the effects of shock waves on gas cleaning equipment, particularly filters and electrostatic precipitator plates. This AEC study was composed of two parts; (a) an investigation of filter damage and dust reentrainment from commercial Dust-Stop and AEC High Efficiency (Absolute) Space Filters held in a 20 in. diameter laboratory shock tube (3), and (b) an extended investigation of dust dislodged from 6 and 12 in. deep AEC absolute filters and electrostatic precipitator plates (coated and uncoated) in a ventilation system subjected to a shock wave from a detonated nuclear weapon (4). (Shock waves were produced in the laboratory tube by bursting calibrated Kraft paper diaphragms.) Both of these studies have been reported in detail in references cited, so only a partial summary of pertinent test results is presented in Table 6. Laboratory shock tube tests on standard Dust-Stop filters and 6 in. deep AEC filters (24 x 24 x 6 in.) indicated some structural failure occurred at overpressures of 1.5 and 6.0 in. Hg., respectively. Moderate damage or partial failure consisted primarily of movement of filter media within the filter frame, usually  $\frac{1}{4}$  in. or more away from the blast direction.

Dust reentrainment studies from 6 and 12 in. deep AEC filters in laboratory and field installations indicate from 4 to 98% of initial dust loading is removed by weak shock waves, at overpressures ranging from 1.1 to 5.0 in. Hg. Dust removal (%L) from AEC filters tested in the field was found to be proportional to overpressure, initial dust loading, and inversely proportional to filter depth:

$$\% L = \frac{126 L_1 P^{0.4}}{D^{0.8}} \quad (1)$$

where the overpressure (P) is expressed in psi, the initial filter loading ( $L_1$ ) in grams/sq.ft. of filter surface (100 sq.ft. for 500 cfm filter, 200 sq.ft. for 1000 cfm filter) and depth (D) in inches (6 or 12). The amount of dust removed from these filters was proportional to the amount of dust on the filter before the blast, i.e., a filter with 100% dust load (defined as amount required to double the initial filter resistance) lost essentially all of this dust when exposed to a shock wave. It was found experimentally that peak overpressure was a somewhat less important factor than had originally been suspected, i.e., a doubling of the overpressure with a constant amount of dust on the filter caused only a 30% increase in dust removal.

The purpose of these laboratory and field tests was to establish levels of shock wave overpressures that caused structural damage to elements of gas cleaning systems, particularly filters; to determine amount of dust reentrained from gas cleaning devices below critical (damage) pressures; and to determine effective means of controlling or minimizing both. The rather large amounts of dust removed by shock waves below damage level overpressures suggested this method

TABLE 6. -- DUST DISLODGED FROM FILTERS BY SHOCK WAVES

Test Device <sup>a</sup>	Shock Wave Pressure <sup>b</sup> in.Hg.	Initial Dust Load grams	Initial Dust Load %	Dust Loss grams-%	Remarks
<u>A. Laboratory 20 Inch Diameter Shock Tube Study</u>					
Dust-Stop	1.5	-	-	-	Blast effects study - moderate damage <sup>c</sup>
Dust-Stop	3.0	-	-	-	Blast effects study - complete failure
AEC-6	4.3	-	-	-	Blast effects study - no damage
AEC-6	6.3	-	-	-	Blast effects study - partial failure
AEC-6	12.1	-	-	-	Blast effects study - complete failure
AEC-6	3.4	155	75	152 98	
AEC-6	3.7	126	56	74 59	
AEC-6	3.8	26	10	8 32	
AEC-12	5.0	429	100	359 84	
AEC-12	4.7	39	8	20 51	
<u>B. Field Study of Simulated Ventilation System Exposed to Shock Wave from Nuclear Explosion</u>					
AEC-6	2.6	357	98	306 86	
AEC-6	3.2	213	30	155 73	
AEC-6	1.4	275	100	177 64	
AEC-6	1.3	212	25	110 52	
AEC-12	2.8	744	100	557 75	
AEC-12	2.4	575	31	331 58	
AEC-12	3.0	554	56	294 53	
AEC-12	1.1	826	69	460 56	
AEC-12	1.3	585	50	26 4	Filter preceded by blast attenuation device.
AEC-12	1.3	548	49	224 41	

- a. Dust-Stop Fiberglas filter - 20 x 20 x 2 inch - 800 cfm rated capacity.  
 AEC-6: Pleated cellulose asbestos paper filter - 24 x 24 x 6 inch - 500 cfm rated capacity.  
 AEC-12: Same as above, 12 inches deep - 1000 cfm rated capacity.
- b. Peak over-pressure; positive phase duration 800 millisecc. in laboratory study, and 800 to 1000 millisecc. in field study.
- c. Extensive reentrainment of dust initially on filter, but not quantitated.

as a potential means of cleaning filters for reuse. This has led to the application of shock wave treatment to mineral wool filters used to collect open hearth fume, to lower their resistance periodically during use as described below.

#### Description and Operation of Test Equipment

To test the effectiveness of shock waves for cleaning of mineral wool filters, our standard 6 in. diameter filter test unit (5) was modified by addition of a 6 in. diameter by 6 ft. long (1.22 cu.ft.) pressure reservoir downstream of (behind) the filter test section and the blower used to draw air through the system was connected to a tee, as shown in Figure 3. During normal operation, room air (30 cfm for 150 fpm filtering velocity) was drawn into the 6 in. diameter pipe, entraining iron oxide fume generated by combustion of iron pentacarbonyl ( $\text{Fe}(\text{CO})_5$ ) at the inlet. Fume-laden air passed to the 6 in. diameter by 2 in. thick slag wool filter (from right to left in Figure 3) where fume was removed at 90-99% efficiency. The cleaned air was then exhausted through an orifice meter in the branch line to a fan. Up- and downstream samples (1 cfm) were withdrawn simultaneously at locations indicated, by means of sampling probes holding 1-9/16 in. diameter all glass filter papers. As fume accumulated on the slag wool filter, resistance rose to a predetermined level, whereupon generation of the aerosol was stopped and the valve on the branch leading to the fan was closed. A Kraft paper diaphragm (one or more sheets, as required) between the pressure reservoir and the filter was then burst by admitting compressed air to the reservoir (to the desired overpressure, usually 5 to 10 in. Hg.) and puncturing with the lance shown. This simple process caused a minor explosion which generated a shock wave that traveled down the tube through the slag wool filter (from left to right in Figure 3). This procedure of loading the filter with iron oxide and subsequently removing it with a shock wave was repeated until the filter efficiency decreased below 80%, when the test was stopped.

Figure 4 is a picture of the shock tube prior to the blast. The normal steel inlet is replaced with a transparent plastic tube to indicate the results of the blast shown in Figure 5.

#### Laboratory Results

The blast pressure should be large enough to reduce the filter resistance to the initial value, or near it, and yet not dislodge excessive amounts of the filter media. This value was found to be 5 in. Hg for an arrangement of 6/1.2/5 (6 in. diaphragm diameter, 1.2 cu.ft. blast chamber volume, 5 in. Hg overpressure). (See lines 1 and 4, Table 7.)

The ratio of the diaphragm to the filter area was varied from 1:1 to 1:7 and 1:9. Two orifice plates with 2.3 in. diameter openings holding a diaphragm between them were installed to give the 1:7 ratio. The chamber pressure had to be increased to 10 in. Hg overpressure to obtain adequate cleaning. A temporary 18 in. diameter filter holder with transition pieces was installed to operate in conjunction with the 6 in. diameter diaphragm. This arrangement also required at least 10 in. Hg overpressure for adequate cleaning. (See lines 1, 2, 3 & 5 in Table 7.)

The blast chamber size was varied from 1.2 to 0.72 and 0.44 cu. ft. by inserted objects. The 6/0.7/5 and the 2.3/0.7/10 arrangements tended to function similar to those using the 1.2 cu.ft. blast

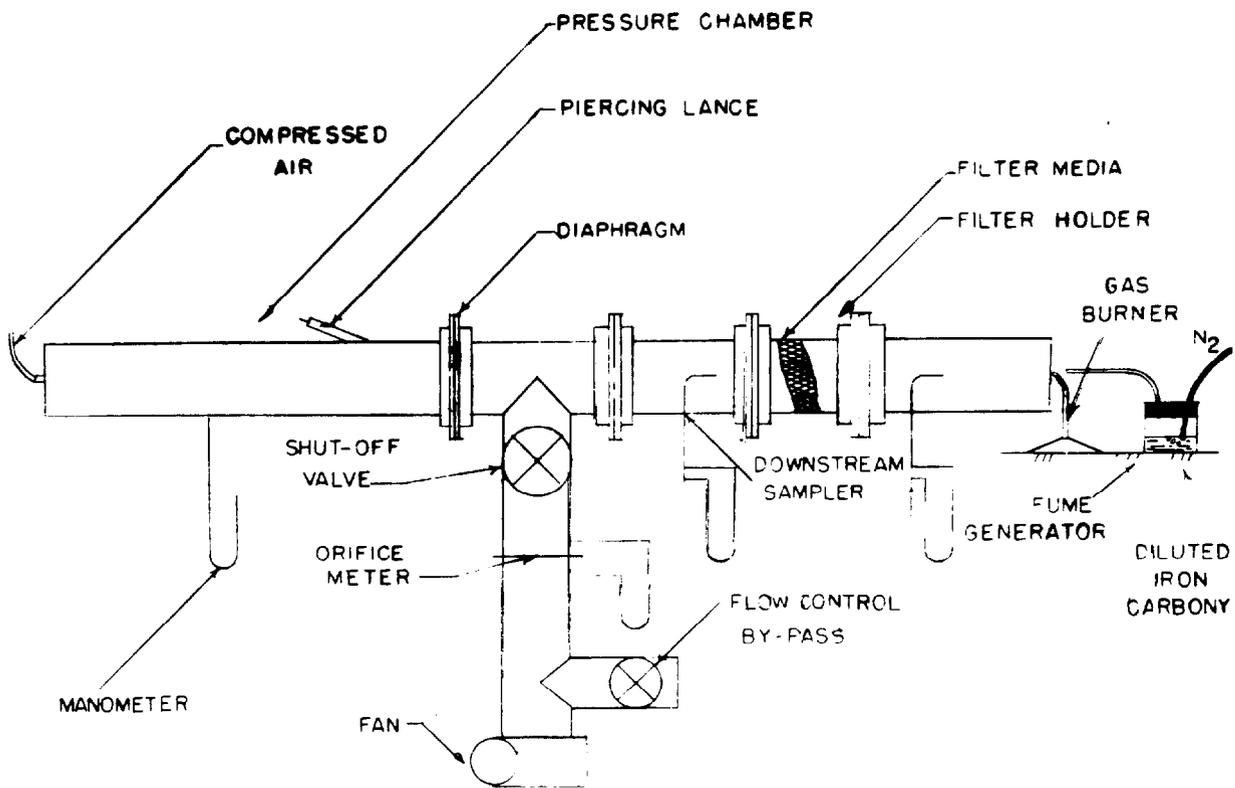


Fig. 3—Shock-tube setup.

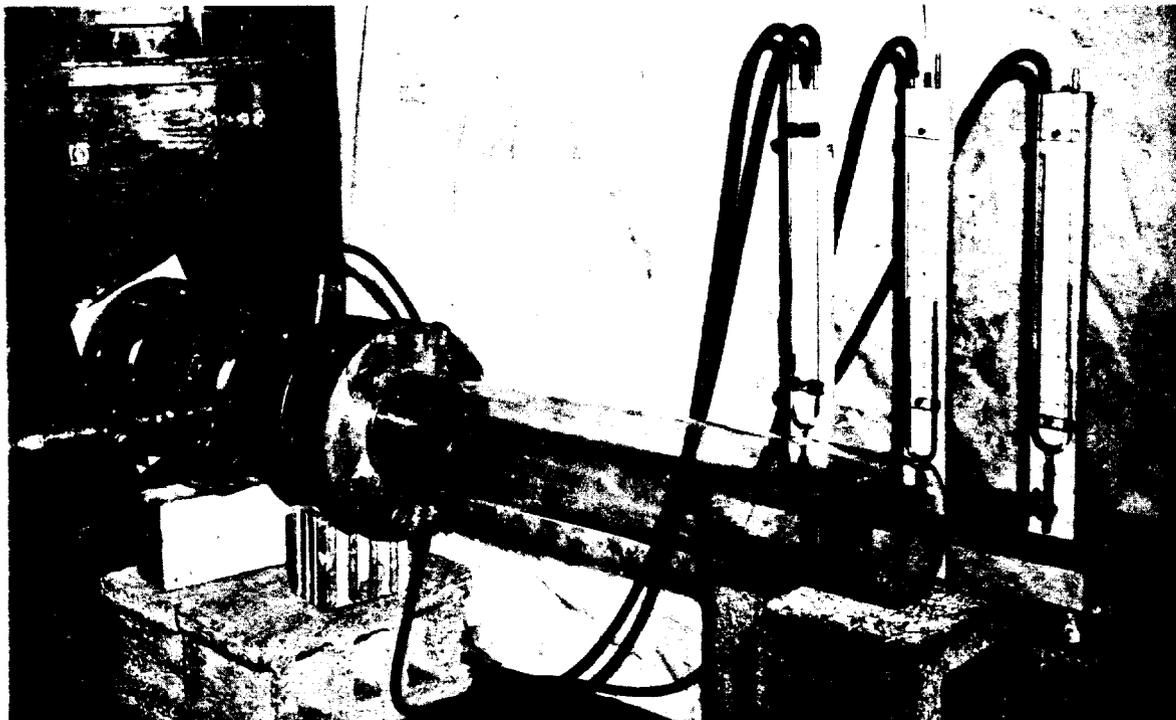


Fig. 4—Blast wave filter cleaning setup (photograph before blast).

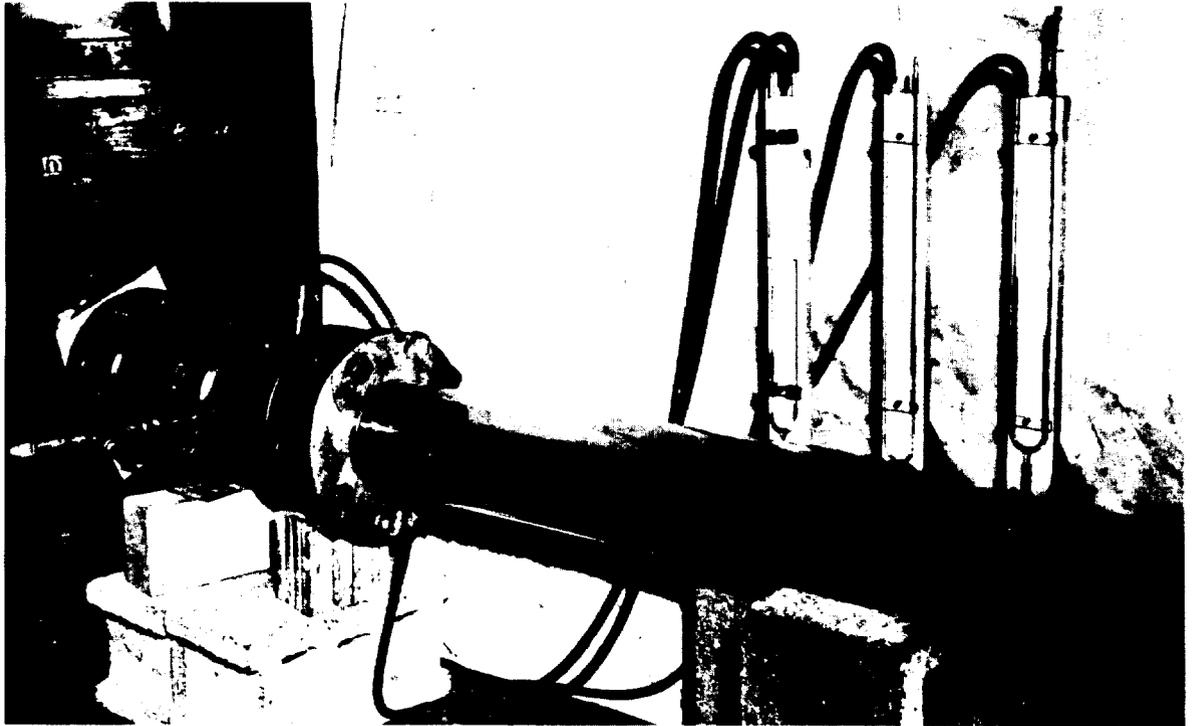


Fig. 5—Blast wave filter cleaning setup (photograph during blast).

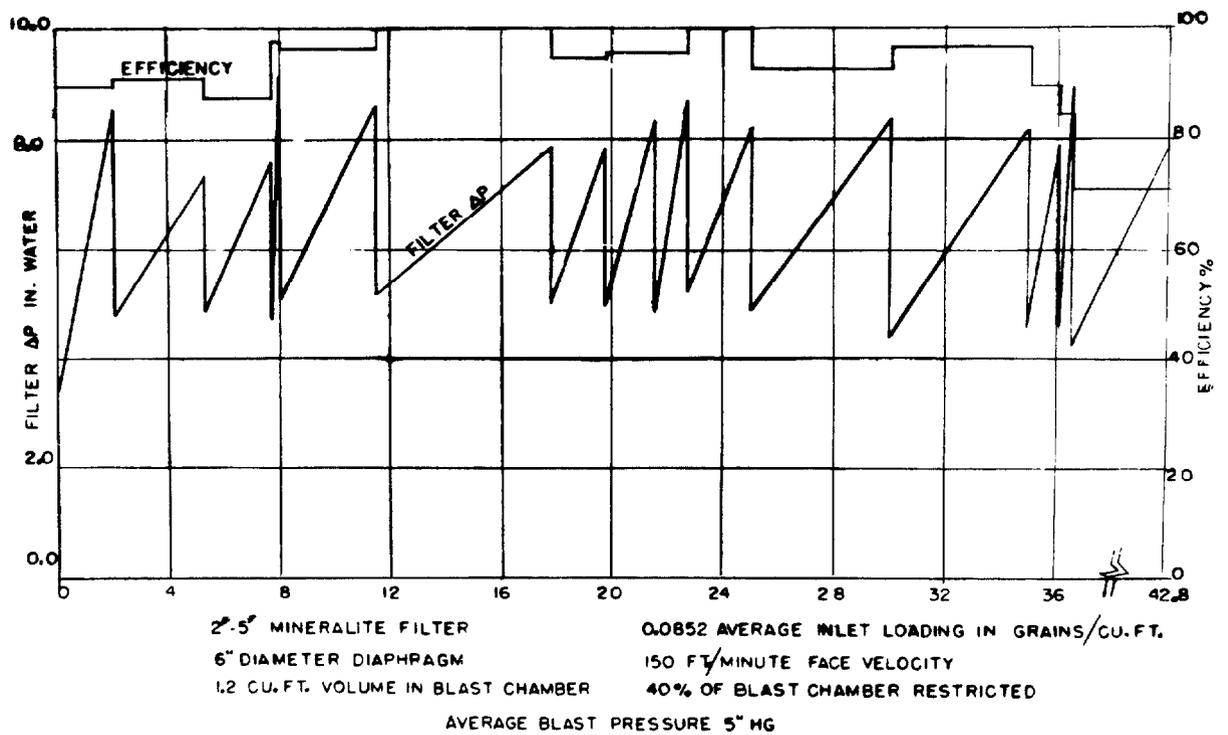


Fig. 6—Blast performance study curves.

Table 7. Summary of Shock Wave Cleaning Tests on Mineral Wool Filters<sup>a</sup> After Collection of Iron Oxide Fume

Total Tested <sup>b</sup>	Shock Tube Characteristics <sup>c</sup>		Inlet Conc. gr/cu.ft	Filter <sup>d</sup> Packing Density	Filter Resistance In. H <sub>2</sub> O <sup>e</sup>		Avg. Eff. % <sup>f</sup>	Total Number Bursts	Time Mins.	% Wt. Loss
	Dia./R.V./B.P.	Tube			First	Fin. Avg.				
2	6	1.2 5	0.12	5	4.0	4.2	8.0	31	69	17
5	2.3	1.2 10	0.06	5	3.8	4.7	8.1	42	128	12
1	18 <sup>h</sup> -6	1.2 10	0.01	5	2.6	3.3	4.0	13	188	-
2	6	0.7 5	0.03	5	3.6	4.8	8.2	32	89	8
1	2.3	0.7 10	0.06	5	3.6	4.1	7.9	10	16	9
3	6	0.4 5	0.07	5	3.3	5.2	7.5	29	59	3
4	6	1.2 8	0.05	3	2.1	2.3	5.5	13	88	12
1	6	1.2 5	0.02	7.5	7.5	9.0	14.1	13	44	-
1	6	1.2 5	0.02	10	9.4	14.7	28.2	13	84	0

- a. Bethlehem Mineral Wool - 2 inches thick by 6 inches diameter (except in line 3, 18 in. diameter).  
 b. Number of filters used in total series of tests.  
 c. Dia. = diameter of burst paper diaphragm, inches; R.V. = reservoir volume, cu.ft.; B.P. = blast overpressure, in. Hg.  
 d. Filter packing density - pounds per cu.ft.  
 e. At 150 fpm filtering velocity, avg. initial does not include "first" value.  
 f. Average weight efficiency in all tests including last one of each series which was less than 80%, the criterion for stopping test.  
 g. Total number of exposures to blast of all filters tested.  
 h. 18 in. diameter (2 in. - 5 lb./cu.ft.) filter mounted on 6 in. reservoir.

chamber. The 6/0.4/5, however, was not as effective on cleaning as the previous two. (See lines 1, 4 and 6 in Table 7.)

Increasing the filter packing density resulted in increased efficiencies and initial resistances as was expected, but the 5 in. Hg overpressure shock wave cleaning was not as effective on the denser filters as can be seen in the difference between the first and the initial resistances. (See lines 1, 8, and 9 in Table 7.)

Filters can be cleaned from 10 to 20 times by low level shock waves before the efficiency is reduced below 80%, the arbitrarily set minimum. (See Figure 6.)

#### Slag Wool Filter Pilot Plant 4

A 2000 cfm pilot plant has been developed using slag wool for a high temperature filter media. The unit is designed to evaluate three methods of cleaning the filter media. Cleaning is done within the filter chamber conserving space and equipment. Another feature is the elimination of mechanical motion during filtration enabling the use of simple seals.

#### Unit Description

Major items in the pilot plant unit are a 700 gallon holding tank, 200-300 gpm slurry pump, a 30 HP gasoline engine driven fan and the 5 ft. diameter filter chamber. (See Figure 7.) The filter chamber consists of a 5 ft. steel cylindrical shell 7 ft. high, containing two reinforced expanded metal screens, a blast chamber on the top of the shell, and a compressed air manifold at the conical chamber base. The bottom screen, on which the slag wool filter is formed, can be rotated about a major axis to dump the spent wool. When not raised to storage position the top screen holds the bed in place between the screens for upward flow of gas or water. A 110 gal. chemical drum forms the blast chamber, which is equipped with a two ton jack to position a 2 ft. diameter diaphragm and a mechanical lance to puncture this diaphragm and create the shock wave. Compressed air is supplied to the manifold on the bottom for mixing slurries within the filter housing.

#### Operation

This unit incorporates three methods of cleaning the filter media, which are designated PP4, A, B, and C. The initial operations of each are quite similar with the slag wool being separated from the slurry to form the filter media, dried of almost all moisture, and exposed to the furnace effluent. The next operation differs in the cleaning method with PP4 A, B, and C being cleaned by a reslurrying of the media similar to the initial operation, a reverse flushing of water through the media, and a blast wave in opposite direction to the normal gas flow, respectively. The final mutual step consists of dumping of the spent wool and flushing it to waste or reclaiming processes. (See Figures 8, 9 and 10.)

#### Open Hearth Field Results

The data taken on the unit arranged to operate as PP4 A or B using the exhaust fume (700°F) from a local 20 ton cold metal open-hearth furnace are presented in Table 8, except for orientation runs 1 and 2. Runs 3, 5, 7, and 8 on new beds, which maintained a 3 in. H<sub>2</sub>O initial filter resistance, showed increasing efficiencies of 55

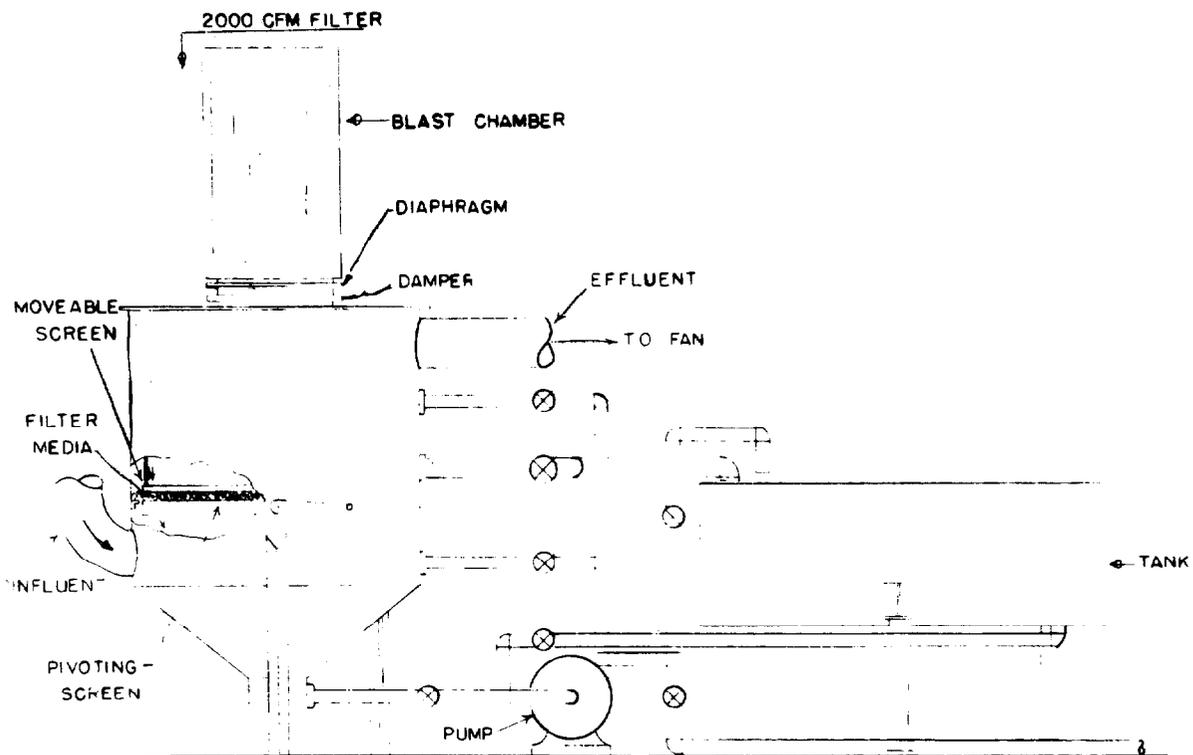


Fig. 7—Pilot plant 4A.

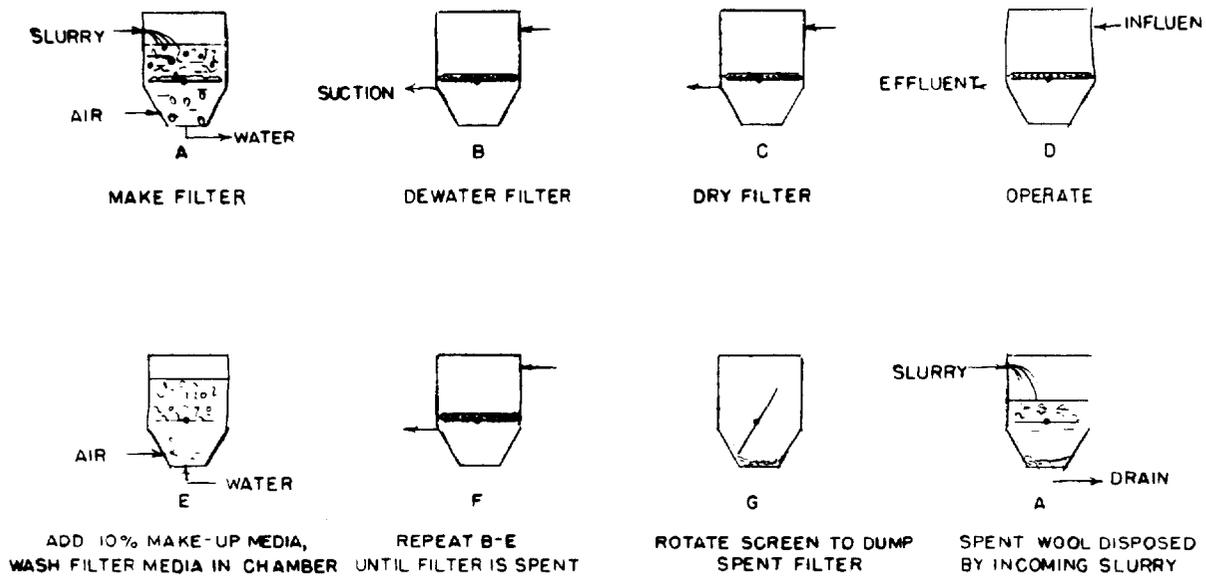


Fig. 8—Operation of pilot plant 4A (reslurry).

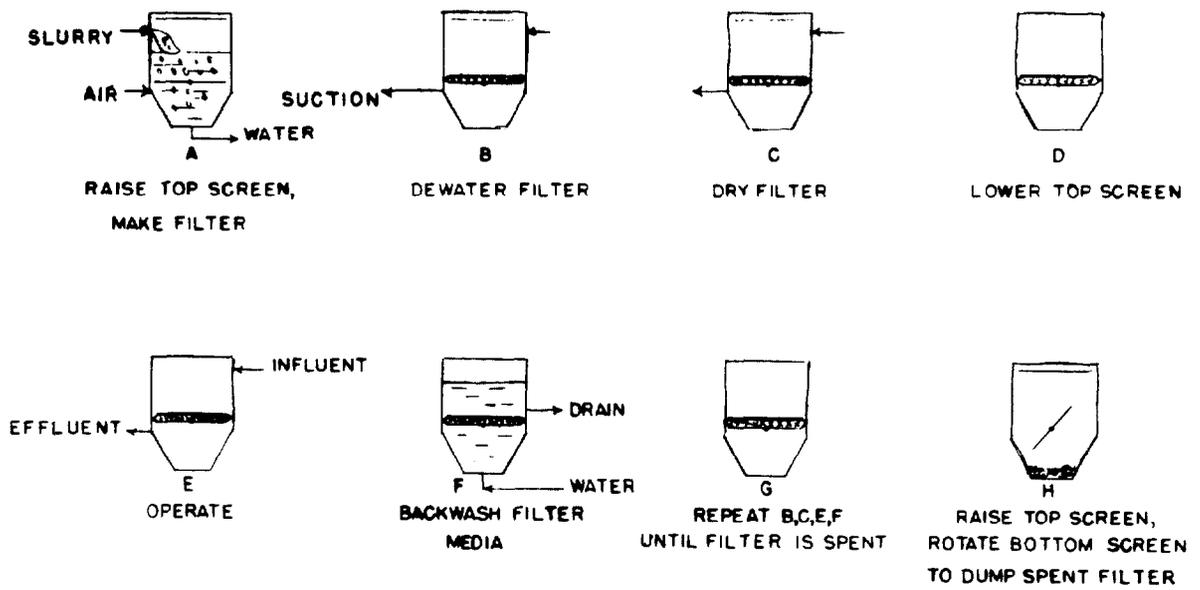


Fig. 9—Operation of pilot plant 4B (backwash).

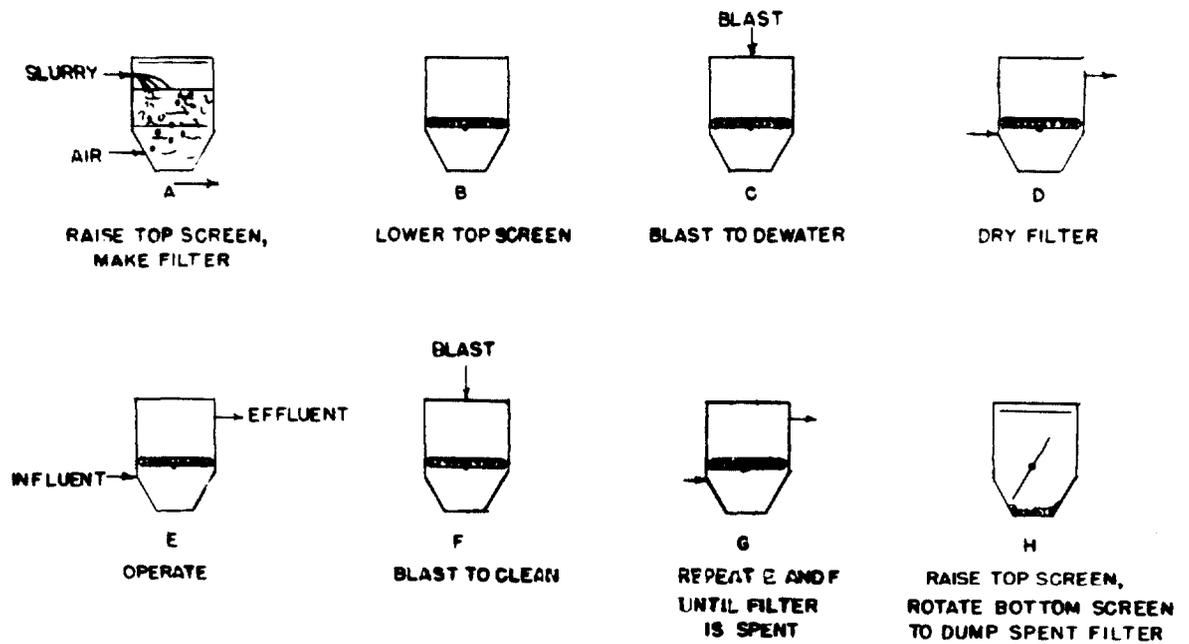


Fig. 10—Operation of pilot plant 4C (blast).

Table 8.  
SUMMARY OF SLAG WOOL FILTER PILOT PLANT 4A, B TESTS ON 20 TON COLD METAL OPEN HEARTH FURNACE FUME

Test No.	Filt. Vel. a-fpm Fin.	In. Conc. gr./cu.ft.	Filt. Res. b-In. H <sub>2</sub> O Fin. Inlt.	Eff. %	Time <sup>c</sup> Min.	Temp. d °F	Remarks
3	96	0.02	3.3	55	48	550	New bed - 6# - DHG
4	95	0.02	5.7	94	46	580	Same bed
5	92	0.05	3.6	68	44	550	New bed
6	44	0.03	14.0	99	44	480	Same bed
7	90	0.10	3.4	89	60	540	New bed - 5# - DRA
8	90	0.09	3.2	95	52	510	New bed - DRA
9	89	0.05	4.7	98	48	500	New bed - 2#
10	50	0.03	12.7	99	47	440	Same bed
11	91	0.05	-	92	16	500	10 Backwashed
12	73	0.24	-	89	28	440	11 continued
13	67	0.11	9.3	99.7	53	430	New bed - 4# - DHG
14	31	0.05	15.5	-	23	370	Same bed
15	92	0.04	3.0	93	42	550	New bed - 3 - DRA
16	75	0.02	8.8	95	41	500	Same bed
17	93	0.05	2.0	68	48	540	16 Backwashed - DRA
18	85	0.03	8.2	31	62	530	17 Continued
19	93	0.10	2.3	44	52	520	18 Backwashed - DRA
20	93	0.09	3.2	97	50	520	New bed - 2
21	82	0.05	1.1	60	50	530	20 Reslurried in place

a. Filtering velocity, feet per minute at temperature indicated in column 8.

b. At temp. in column 8.

c. Total operating time, sampling time usually 1 to 10 min. less.

d. Average of max., min. from both inlet and outlet gas.

e. Indicates origin of bed, packing density in lb./cu.ft. when available and method of drying -

DHG = dried on hot clean furnace gas (furnace banked) for about 20 mins.;

DRA = dried on room air for about 4 hours.

Table 9. Shock Wave Cleaning Tests on 2000 CFM Slag Wool Filter (2"-5#/cu.ft.) With Electric Furnace Fume

Test No.	Filt. Vel. a-fpm		In. Conc. gr/cu.ft.	Filt. Resist. a-In.H <sub>2</sub> O		Bl. Press. In.Hg	Eff. %	Time Mins.	Remarks
	Init.	Final		Init. Fin.	Aft. Bl.				
22	118	109	0.70	5.0	8.0	4.8	70	37	New filter
23	114	101	0.61	4.8	9.4	-	61	49	Same filter
24	117	101	0.05	5.4	8.7	5.6	79	42	New <sup>b</sup>
25	116	82	0.16	5.6	14.7	6.6	64	35	Same
26	111	90	0.03	6.6	12.3	6.5	73	24	"
27	111	92	0.02	6.5	12.3	-	67	29	"
28	117	90	0.08	5.2	11.7	6.2	84	31	New <sup>c</sup>
29	114	95	0.04	6.2	11.7	6.5	74	18	Same
30	113	90	0.17	6.5	11.7	-	82	10	"
31	113	87	0.08	5.2	12.3	6.0	93 <sup>e</sup>	22	New <sup>d</sup>
32	112	87	0.04	6.0	12.3	6.1	79	12	Same
33	109	-	-	6.1	12.3	6.2	-	1	"
34	106	89	0.19	6.2	12.3	6.4	86	3	"
35	106	89	0.06	6.4	12.3	6.5	79	7	"
36	108	86	0.04	6.5	12.3	6.8	92	17	"
37	108	89	0.04	6.5	12.3	6.5	-	-	" (extra blast)
38	104	85	0.02	7.0	12.3	7.0	88	22	"
39	106	89	0.04	7.0	12.3	7.5	-	-	"
40	104	90	0.02	6.7	12.3	6.6	86	14	"
						6.9	81	28	"

a. At gas temperature of 120°F, approx.

b. Periphery of filter provided with rubber tubing seal.

c. Periphery of filter packed with slag wool lightly by hand.

d. Periphery of filter packed with slag wool heavily by hand.

e. No plume visible from tests 31 through and including 40.

68, 89 and 95, respectively, as the layer formation procedure was improved. Higher efficiencies produced lower downstream loadings and in these field tests required changing of the downstream glass wool filled canister (weighing 50,000 mgs and collecting only a few mgs) to an 1106B glass filter disk (weighing about 100 mgs). Subsequent testing on similar new beds with 1106B filters indicated efficiencies over 90 per cent for runs 9, 13, 15 and 20. Again, the initial pressure drop was about 3 in. H<sub>2</sub>O. Continued testing of beds already loaded with particulates (runs 4,6,10,12,14, and 18) gave generally higher efficiencies and higher filter resistance as was expected. Runs 11, 17 and 19, which were cleaned by backwashing the principle of PP4 B, had efficiencies of 92, 68 and 44, respectively, and run 21, which had been cleaned by reslurrying, the principle of PP4 A, had an efficiency of 60 per cent. These studies will be continued to evaluate the most feasible cleaning method.

#### Electric Furnace Field Results

Upon completion of the above studies an effluent test was made on a 13 ton electric furnace in the same vicinity. Furnace fume conditions were quite similar except that effluent temperatures were lower (150°F); so the unit was relocated with the required changes to function as PP4 C.

The unit was arranged and operated in essentially the same manner as at the O.H. location, except for the reversal of gas flow (upward) through the filter chamber, which necessitated the use of the top screen. Initial average efficiency of 65 per cent was due to leakage of the furnace fume past the edge (or periphery) of the filter. After a new filter bed was formed, a sand filled rubber hose was placed on the periphery of the filter media to act as a more positive edge seal, and this resulted in an increased average efficiency of 71 per cent for runs 24-27. The periphery of another new bed was then hand packed with additional dry wool giving a higher average efficiency of 80 per cent for runs 28-30, and when the periphery of still another new bed was tightly packed, the highest average efficiency of 87 per cent occurred with no visible effluent plume for 10 runs, 31-40. (See Table 9.)

The original resistance of filters tested with shock wave cleaning was about 5 in. H<sub>2</sub>O (higher than expected), and subsequent cleaning by low level shock waves (5 in. Hg) gave generally increasing initial resistances. Following runs will be made with higher blast pressures (10-12 in. Hg). The unit is presently being modified to handle these higher pressures as well as to eliminate the need of hand packing the edges of the filter.

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# DEVELOPMENT OF AN IONIZATION DETECTOR FOR THE MEASUREMENT OF AEROSOL PARTICLE CONCENTRATIONS

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## ABSTRACT

A portable instrument has been developed which can readily detect aerosols in concentrations from  $2 \times 10^3$  particles/cm.<sup>3</sup> to  $1 \times 10^9$  particles/cm.<sup>3</sup>. The instrument consists of two ionization chambers connected as series arms of a Wheatstone bridge. The ionization is produced by a Radium D foil lying on the inner chamber wall. Aerosol particles passing through one of the ion chambers will carry away some of the ions in the sensitive volume and a decrease in the ion current will result. The change in current is proportional to the particle concentration.

A second ion chamber will compensate for changes in the carrier gas composition and battery fluctuations. The complete instrument weighs less than two pounds exclusive of a vacuum pump capable of drawing 5 liters per minute.

## Introduction

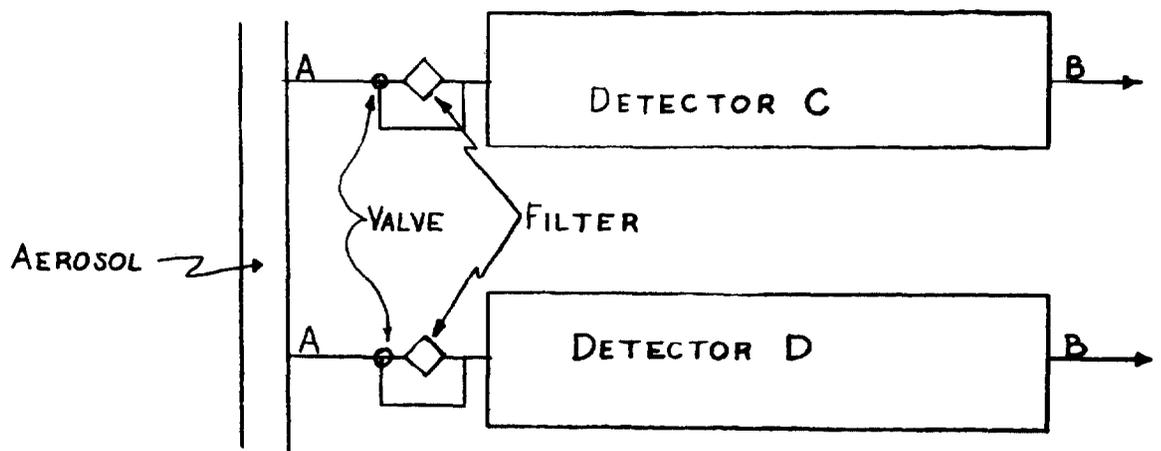
In the study of dynamic aerosol systems it is frequently necessary to evaluate number concentrations of the suspension during the action of external forces. We are presently developing dynamic particle agglomeration devices whose performance is

best evaluated in terms of a change in particle numbers per unit gas volume (particles/cc). Several methods have been used for actually measuring particle concentrations, among them being various electronic counters (cumbersome, expensive), light scatter (particle size shape and index of refraction dependent), and optical or electron microscopy (more or less absolute, but tedious and not adapted to "in vivo" measurements. Limitations of these methods appear to be excessive size, cost, or time required for analysis. What is required is a portable, inexpensive device which responds instantly to particle concentration changes in some readily discernable manner. We have investigated the cloud chamber technique originally used by Aitken as modified by Vonnegut (1) and by Saunders (2). The aerosol particles flow into a chamber with a collimated light source at one end and a photoelectric detector at the other; the air is saturated, and a slight vacuum is drawn on the chamber to permit moisture to condense on the particles, causing them to grow to a uniform size and interrupt the light beam in proportion to their number. This device was built and tested on industrial dust loadings. As was indicated by Vonnegut (1), when dealing with high number concentrations ( $> 10^6$  particles/cm.<sup>3</sup> approx.), the response curve no longer remains proportional to numbers present, but flattens out and the result becomes indeterminate. Dilution systems to reduce particle concentration from  $10^9$  particles/cm.<sup>3</sup> or greater, down to  $< 10^6$  particles/cm.<sup>3</sup>, are generally large, and must be very carefully calibrated to minimize the large order of magnitude error possible by successive dilution. A commercial model of this device is available, but is limited to about  $10^6$  particles/cm.<sup>3</sup> (3).

Another unique method is presently under development utilizing the ionization of air by means of a small radioactive source and the collecting of the ions formed, by a central wire. The ion current so generated is measured on a microammeter. When an aerosol passes between the ion source and the collector wire, some ions attach themselves to particles, reducing the ion current in proportion to the number of particles present. This method has been used in principle by Drozin and La Mer (4) to measure particle size, and by others (5) to measure gas concentrations (by first forming the aerosol from the gas).

#### Instrument Design

An ionization current will flow between two oppositely charged electrodes if the gas between them is ionized by some external source, such as x-rays, ultraviolet light, or nuclear radiations. The ionization current is proportional to the intensity of the source of ionization, the gas composition between the electrodes and the geometry of the ion collecting system. Figure 1 shows the design of the ion chamber used to detect aerosols. The outer wall is a brass tube 10 centimeters long and 1.6 centimeters in diameter and the center electrode is a 0.020 in. diameter stainless steel wire. Each chamber is fitted with Lucite end pieces designed to allow gas flow through the chamber and also support the center electrode. Clean insulators are necessary as a leakage current as large or larger than the ionization current being measured may flow in the circuit thereby affecting the system balance and sensitivity. In any electric field some particles will be precipitated. A particle may be transported through the field by the gas stream but be deflected by the weak field sufficiently to be deposited on the Lucite insulators. The conductivity of a gas (the



### AEROSOL FLOW DIAGRAM

Fig. 1—Detector and compensator ion chambers.

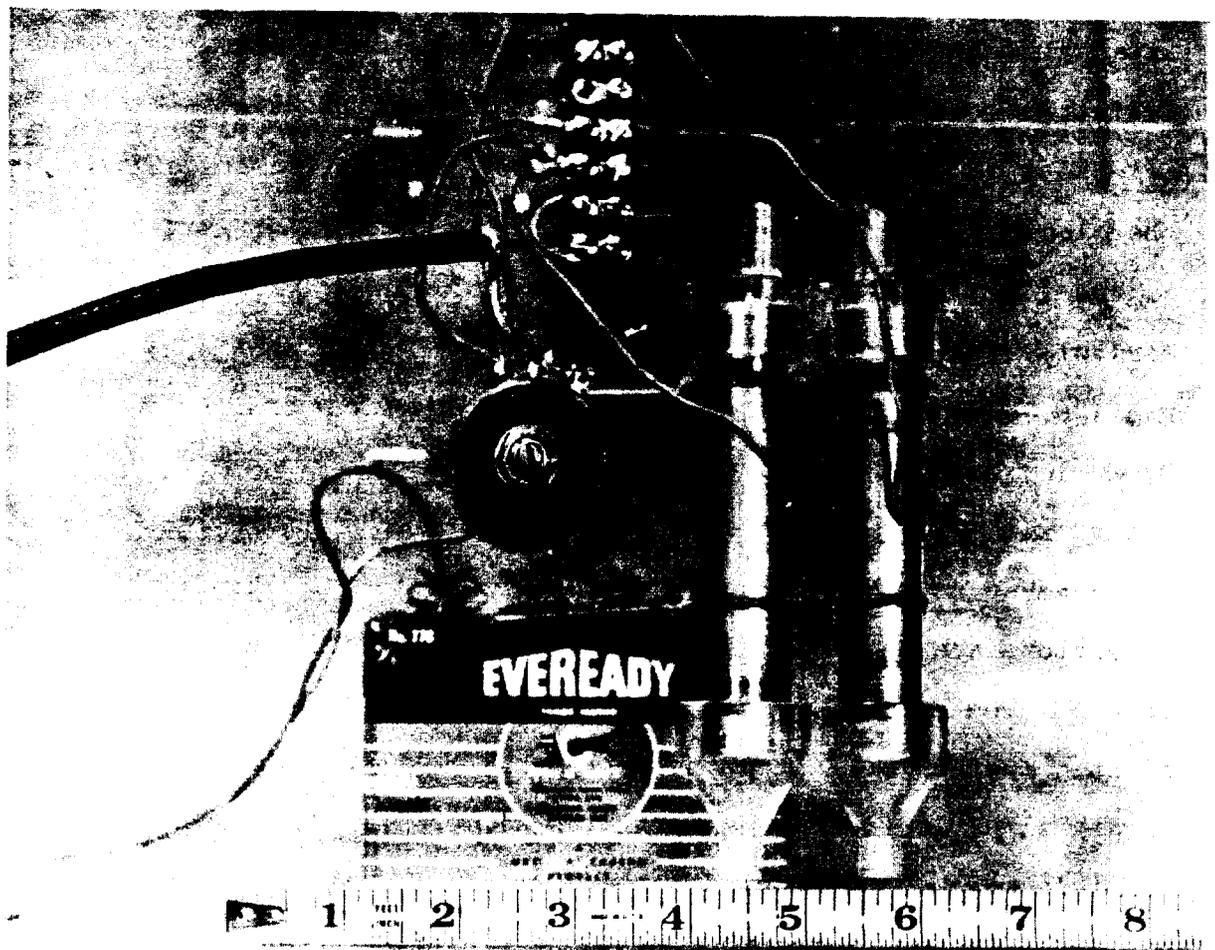


Fig. 2—Ion current vs. voltage in either detector or compensator chamber.

reciprocal of the resistance) varies with the potential difference established across the gas between the electrodes. Particles collected on the electrodes change the geometry of the electric field sufficiently to change the instrument sensitivity.

Ionization within the chambers is produced by a Radium D + E + F alpha source of approximately 500 micro-curies in a foil  $\frac{1}{4}$ " wide and 2" long located at the entry to the ion chamber. A 500 micro-curie alpha source produces  $18.5 \times 10^6$  alpha particles per second. The alpha particles are produced by the decay of the 138 day half-life Po-210 (RaF) and each alpha has an energy of 5.03 Mev and will produce  $1.4 \times 10^5$  ions (at 35 e.v./i.p.). There are available  $26.4 \times 10^{11}$  ions per second but at most only one-half enter the chamber and one would expect a current of  $2.1 \times 10^{-7}$  amp. Actually a much lower value of current occurs because the low voltage used allows a great deal of ion recombination. Figure 2 is a typical ion current vs. voltage curve, (and is similar to that for almost any ion chamber).

The interesting thing to note here is the independence of flow rate upon the ion current. For convenience a flow of 3 liters per minute has been arbitrarily selected for normal use. The highest signal to noise ratio will lie in the low voltage proportional region between 15 and 100 volts. At this voltage level any loss in ion current (or decrease due to particle capture) will be a larger fraction of the total current than at any higher voltage where a plateau is approached. Generally, 30 volts are used across each chamber. (Voltage is supplied by hearing aid batteries).

The electrical circuit of the detector is shown in Figure 3. A Wheatstone bridge is balanced with the variable resistors 1 and

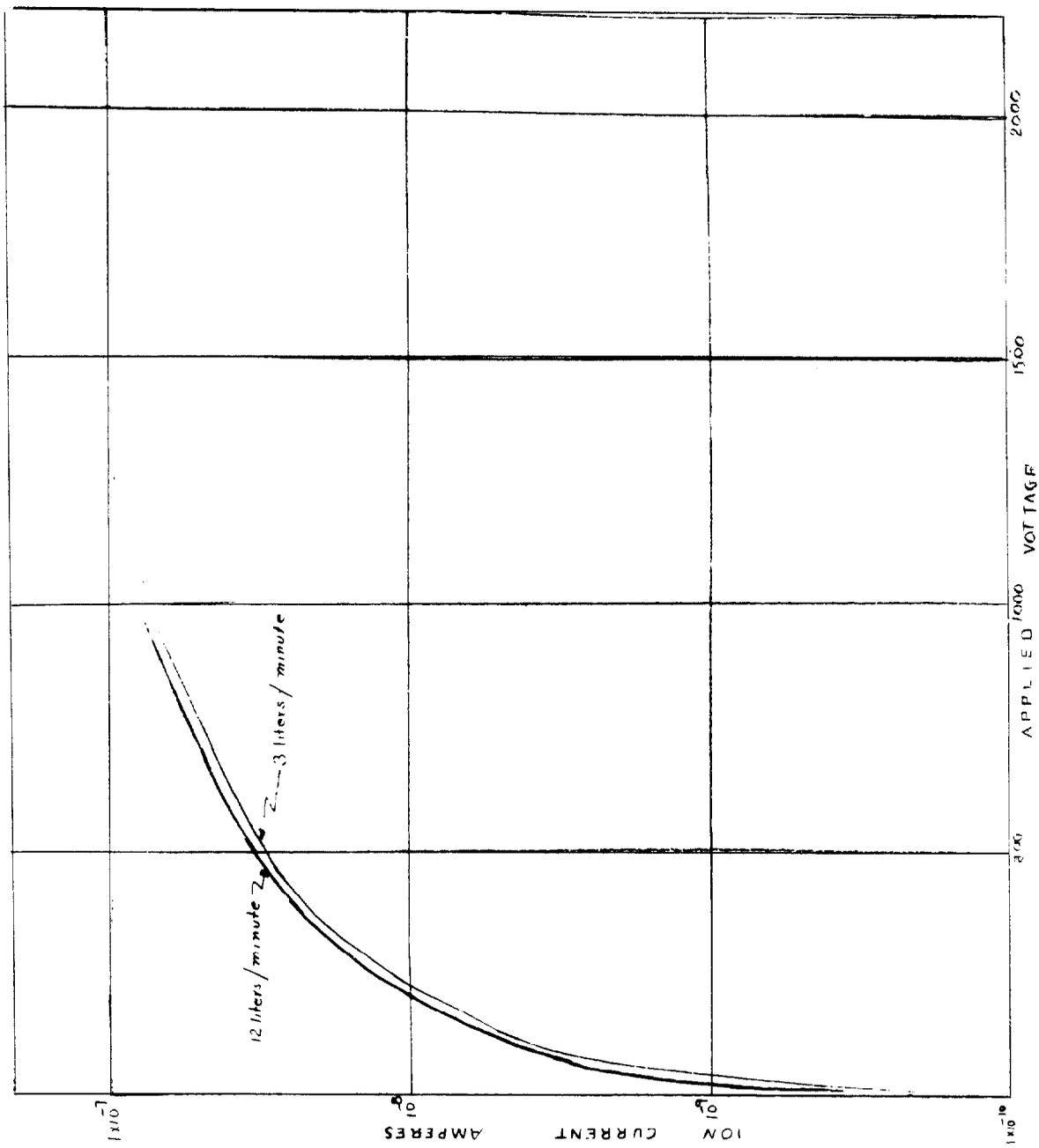


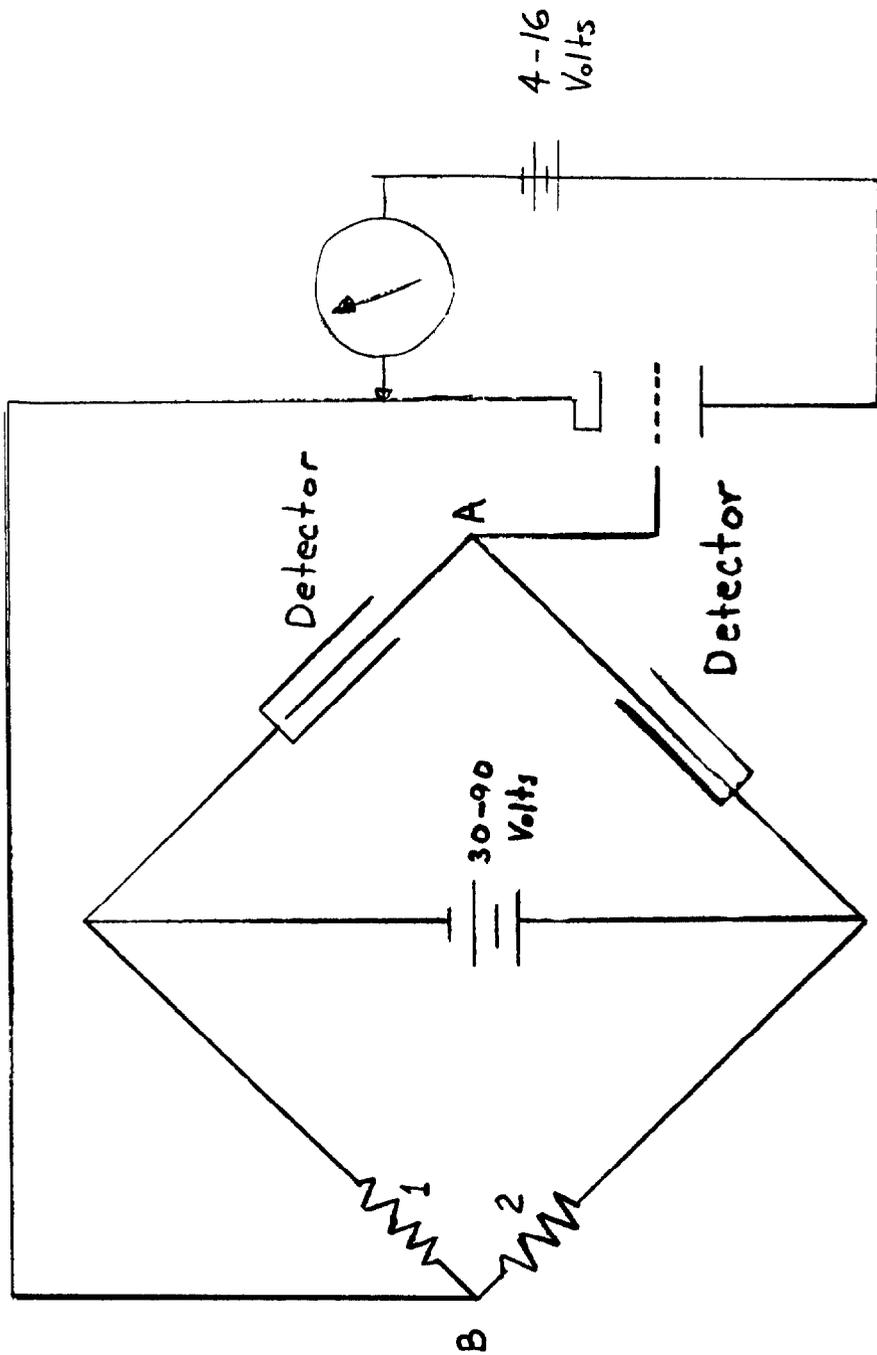
Fig. 3 — Detector and electrometer circuit.

2, which have a value of 5 meg ohms. Electrical balance is determined with a high input impedance voltmeter (preferably an electrostatic unit should be used but a high quality, high input impedance vacuum tube voltmeter may be used). The electrometer circuit is then activated. If the chambers are dynamically balanced as regards impressed voltage, ionization activity and flow rate, no current will flow between junctions A and B. The tube used is relatively unimportant as long as it is a high quality electrometer tube with characteristics such that the grid current is less than  $10^{-13}$  amperes. Some electrometer tubes are available with grid current of  $10^{-15}$  amperes, and would be preferable, but are too delicate for a portable instrument. Any change in the conductance of either ion chamber will cause an unbalance in the bridge and will upset the grid bias thereby increasing or decreasing the current in the electrometer tube.

A flow diagram is shown in Figure 4. The aerosol enters the system at A, passes through chambers C and D simultaneously and exits at B. Air entering both chambers is filtered and the system balance is obtained. One chamber is then exposed to unfiltered air containing particulate material. Some of the ions present in the chamber will become attached to the aerosol particles which pass through the electric field. The charges captured by these particles are carried out of the chamber and a decrease in the ion current is measured.

#### Instrument Calibration

We are presently calibrating the instrument under various operating conditions. Table 1 presents a summary of data on detector-cell response in the presence of gases and aerosol particles of known diameter (approximately). Type of aerosol or gas alone is shown in Column 1, the response of the instrument



# DETECTOR CIRCUIT

Fig. 4 — Schematic aerosol flow diagram.

microammeter is shown in Column 2, and the approximate particle concentration in Column 3. Concentrations  $<10^6$  particles/cm.<sup>3</sup> are being determined by means of the continuous condensation nuclei meter developed at Oak Ridge by Saunders (2).

The first four tests shown were made with ambient air containing atmospheric dust, and with oil smoke (Diol 55). Calibration in the low ranges was determined with successive dilutions of filtered air. Since the instrument has been developed with a view toward uses on industrially occurring aerosols, such as open hearth furnace stack effluents, the

TABLE I  
INSTRUMENT RESPONSE

The following data was obtained using filtered (1106B glass paper) and unfiltered laboratory air and an oil smoke of 0.6 micron diameter

Aerosol	Meter Reading ( $\mu$ a)	Particle Concentration particle/cm. <sup>3</sup>
Filtered air	0.75	600
Laboratory air	1.25	15,450
Oil smoke (0.6 $\mu$ diameter)	5.0	38,700
Oil smoke 1:1 dilution	2.50	19,120
SO <sub>2</sub> in detector	Full Scale	
SO <sub>2</sub> in compensator	Zero	
SO <sub>2</sub> in detector and compensator	1.5	
Filtered air	1.5	

presence of SO<sub>2</sub> gas was considered as a likely interference. By using a filtered stream through our detector chamber, the signal due to change in gas composition can be eliminated, since both chambers see the same amount of gas simultaneously,

but the unbalance is caused by particles in one chamber.

We are presently investigating the influence of aerosol particle size on detector response, by means of homogeneous DOP particles from a LaMer-Sinclair (6) generator.

#### Conclusion

The development of an ionization-type aerosol detector for agglomeration studies has indicated that response is proportional to concentration of particles, at least in the lower ranges ( $<10^6$  particles/cm.<sup>3</sup>). Further development will continue with studies of particle size sensitivity, and response at higher loadings. By using two detector tubes, it is possible to eliminate spurious signals due to changes in gas compositions, as might be expected in industrial aerosols.

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## IODINE COLLECTION STUDIES

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### ABSTRACT

Several methods for the removal of radioactive iodine from process and laboratory gas streams are under investigation by the Harvard Air Cleaning Laboratory. Major test objectives are to develop collectors which (1) afford at least 90 per cent  $I^{131}$  collection, (2) have low resistance, (3) are relatively inexpensive and easy to fabricate and maintain, (4) have a long, i.e. up to 2 year service life in terms of holding capacity and corrosion resistance, (5) can function at gas temperatures up to  $300^{\circ}\text{C}$ , and (6) are non-combustible. None of the collectors now in field use, i.e. Hanford silver reductor, caustic scrubbers, and activated carbon satisfies all of the above requirements.

Preliminary studies were made with normal  $I^{127}$  to simplify analytical and handling techniques during the screening phase of the study.

Of the several chemical and metallic coatings applied to slag wool fibers (KI,  $\text{AgNO}_3$ , Cd, Cd-Sb, and Ag) vacuum plated silver on slag wool showed the highest efficiency,  $>99.9$  per cent and lowest resistance, 1.1 in. water.

Tests on metal ribbon (Sn and Cu) and Zn granules indicated a very high efficiency for Cu,  $>99.99$  per cent and low resistance, 0.1 in. water at 60 ft. per min. face velocity. Activated carbon was the only adsorbent showing high efficiency, but the resistance was considerably greater, 4-5 in. water.

Copper ribbon performed well at room temperature but failed after 25 hours of hot ( $300^{\circ}\text{C}$ ) operation. Silver plated copper ribbon showed no sign of breakdown after 100 hours of hot operation. Presence of moisture and high temperatures improved performance of both Cu and Ag-Cu ribbon indicating that chemisorption was the primary iodine collecting mechanism.  $\text{NH}_3$ ,  $\text{HNO}_3$ , and  $\text{H}_2\text{S}$  did not interfere with iodine collection.

Special tests on Ag-Cu ribbon with mixed isotopes ( $1 \text{ mg/M}^3 \text{ I}^{127}$  and  $10^{-8}$  to  $10^{-6} \text{ mg/M}^3 \text{ I}^{131}$ ) showed that iodine collection was (1) concentration dependent and (2) was the same for  $\text{I}^{127}$  and  $\text{I}^{131}$ . Increased metal surface area per unit collector volume, attained by increasing ribbon dimensions or increasing the packing density, improved collection efficiency significantly. Iodine  $^{131}$  efficiency of Ag-Cu (25 mil x 2 mil ribbon, 33 lbs./cu.ft.) was estimated to be 50 per cent with an inlet iodine concentration of  $10^{-6} \text{ mg/M}^3$  ( $123 \text{ } \mu\text{c/M}^3$ ). For the same inlet loading the efficiencies of 5 mil x 4 mil ribbon (58 lbs./cu.ft.) and 3 mil x 2 mil ribbon (71 lbs./cu.ft.) were estimated to be >97 and >98 per cent, respectively.

## INTRODUCTION

At the Fifth Air Cleaning Conference at Harvard (1) we presented a brief discussion of a new approach to the problem of iodine removal and at that time indicated that we were concentrating on the development of an inexpensive, practical unit for this purpose. As you know, the principal devices that have been used for iodine removal include caustic scrubbers (1), activated carbon beds (2), and heated reductors packed with silver nitrate-coated saddles such as are used for dissolver off-gas streams (3). Various other collectors have been tried such as other scrubbing liquors (4) and electrostatic precipitators (5).

It was our intent to develop a unit which would function at temperatures as high as  $300^\circ\text{C}$  and which would not offer significant resistance to air flow. It became apparent after due consideration that an appreciable compaction could be obtained by modifying the Hanford dissolver off-gas cleaning system. In this unit the particulates, including the iodine, are filtered through a fiberglass filter and then the iodine is subsequently removed by a silver nitrate granule reactor. We believed it was possible to combine the filtering and absorbing functions in a single device. At the Fifth Air Cleaning Conference we reported some preliminary data on the use of silver plating (chemically) on 4 micron diameter slag wool fibers. Although the efficiency was rather high, extended testing indicated a relatively short life for the chemical deposit. The major application for our project in 1957 is still an important consideration. A device is needed for large ( $>10,000 \text{ cu.ft. per min.}$ ) gas flows containing iodine in varying concentrations such as might be associated with a large air-cooled reactor. A successful high performance unit developed for this application could, of course, be adapted to many other problems. The use of scrubbers or activated carbon beds results in high resistance carryout or potential fire problems. We recognize that extended fine fiber beds can create high air flow resistance. However, the optimum size of coated fibers for iodine removal does not need to coincide with maximum aerosol collection.

The processes where iodine contamination is most likely to occur are off-gases from dissolvers, uranium and plutonium separations, reactor cooling air and contaminated exhaust air from hot laboratory facilities. There may be variations in

gas volume from 100 to 40,000 cu.ft. per min. or greater and temperatures may range from ambient to 1500°C for air or gas cooled reactors.

For the design of iodine collecting equipment, the following tentative performance criteria were established.

1. Efficiency greater than 90 per cent (in some cases decontamination factors\* of  $10^4$  to  $10^6$  may be required).
2. Retention of several grams of radioactive iodine without significant reduction in performance. (Efficiency and resistance constant if possible.)
3. Unmaintained collector life of two years if possible.
4. Efficient operation at temperatures from 20 to 300°C.
5. Satisfactory operation in the presence of oxides of nitrogen, nitric acid mists, ammonia, hydrogen fluoride, hydrogen chloride, or other corrosive substances or solvents found in dissolver and other off-gases.
6. Operate at face velocities of 1 foot per second or greater to conserve space.
7. Low resistance to gas flow (<1 inch of water at 1 fps).
8. Minimal space requirements (possibility of insertion in existing ducts or piping).
9. Fireproof or resistant to decay heat and combustion.

Although 90 per cent iodine removal appears to be rather low, it is believed that operation at this level may constitute satisfactory cleaning for many applications in which continuous losses rather than intermittent releases take place. On the other hand, decontamination factors on the order of  $10^4$  to  $10^6$  may be desirable, particularly where hazardous situations are likely to arise.

Holding capacity is somewhat arbitrary and is extremely conservative in view of the high specific activity of  $I^{131}$ .

A filter life of two years is a realistic target, particularly in operations presenting accessibility and handling problems.

Satisfactory performance at elevated temperatures or in the presence of corrosive gases may or may not be a specific cleaning requirement, depending upon the collector application.

\* Decontamination factor is defined as the ratio of upstream to downstream concentrations. Decontamination index is referred to as the log of this ratio.

Low collector resistance is desirable, but other considerations (high decontamination requirements, small gas volumes, etc.) may make higher pressure losses acceptable. High velocities associated with optimum removal will provide minimal space.

The several iodine removal methods investigated and reported here were selected on the basis that they would fulfill essentially all of the tentative performance requirements. It has been assumed that the effluent gas stream would require pre-cooling to temperatures not in excess of 300°C. This is based on the following facts:

1. Collection by physical adsorption is adversely affected by high temperatures.

2. Most chemical compounds of iodine either decompose or volatilize at temperatures above 300°C.

The number and type of tests on any one medium varied directly with its relative performance. When initial screening showed an efficiency less than 90 per cent, low holding capacity, or high resistance to gas flow, extensive tests were eliminated.

Iodine collectors employed in this investigation were composed of either granular or fibrous materials which were amenable to packing between supporting pads or screens in cylindrical filter holders. The primary mechanisms responsible for removal of gaseous iodine were either physical or chemical adsorption, or a combination of both, depending upon the chemical composition of the collector. The removal process should not be classified as filtration (although many of the finer carbon fibers are actually good particulate filters) except where there exists a possibility of iodine adsorption upon suspended solids prior to encountering the fibrous or granular collector, or where condensation might have occurred producing droplets containing iodine or iodide particles.

Detailed descriptions of test equipment and methods and evaluation of the various iodine collectors will be presented in a complete AEC report at the completion of this study. This report will summarize the principal results obtained.

#### Test Equipment and Procedures

Two types of filter holders were used in this study (a) a 12 in. long, 1 in. diameter Pyrex glass tube, (Figures 1 and 2), and (b) a 3 ft. long, 6 in. diameter steel pipe (Figure 3). Both granular and fibrous media were tested in the 1 in. glass cylinder whereas only fibrous materials were tested in the 6 in. steel pipe. Figure 2 shows a typical silver plated copper mesh test medium in place.

Most data were obtained at a constant air flow of 60 cu.ft. per min. per sq. ft. of media face area (60 ft. per min. face velocity). Velocity effects were studied in the 6 in. steel pipe over the range of 60 to 240 ft. per min.

Tests were conducted with normal iodine at inlet concentrations varying from 2 to 600 mg. per cu.m. Iodine vapors

### LEGEND

- |   |                 |
|---|-----------------|
| 1 GLASS TUBE -0.875" I.D., 12" LONG         | 8 BURET         |
| 2 SILVERED COPPER RIBBON                    | 9 BUBBLER       |
| 3 THERMOMETER                               | 10 AIR FILTER   |
| 4 LEAD SHIELD                               | 11 MANOMETER    |
| 5 U-TUBE EVAPORATOR                         | 12 SURGE BOTTLE |
| 6 TEFLON NEEDLE VALVE                       | 13 ORIFICE      |
| 7 IODINE <sup>131</sup> IN CCL <sub>4</sub> | 14 LEIMAN PUMP  |

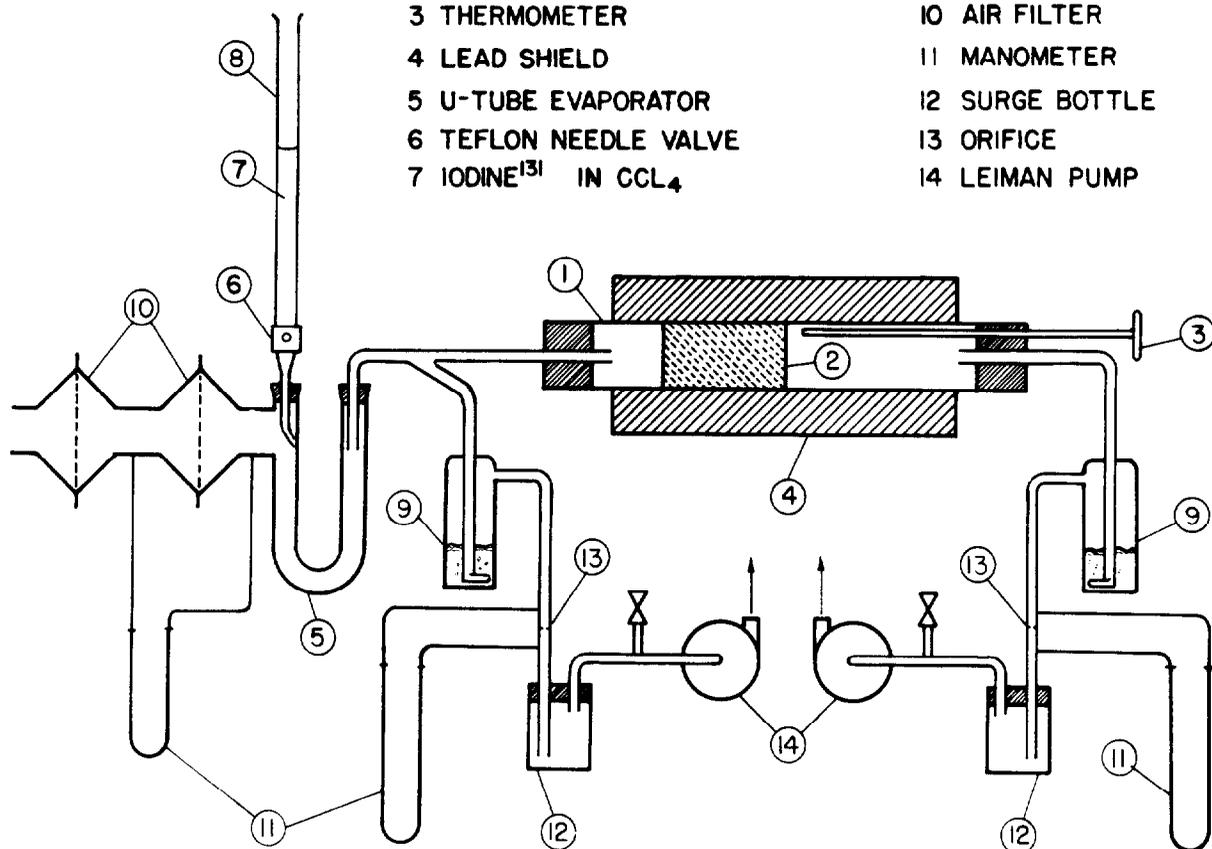
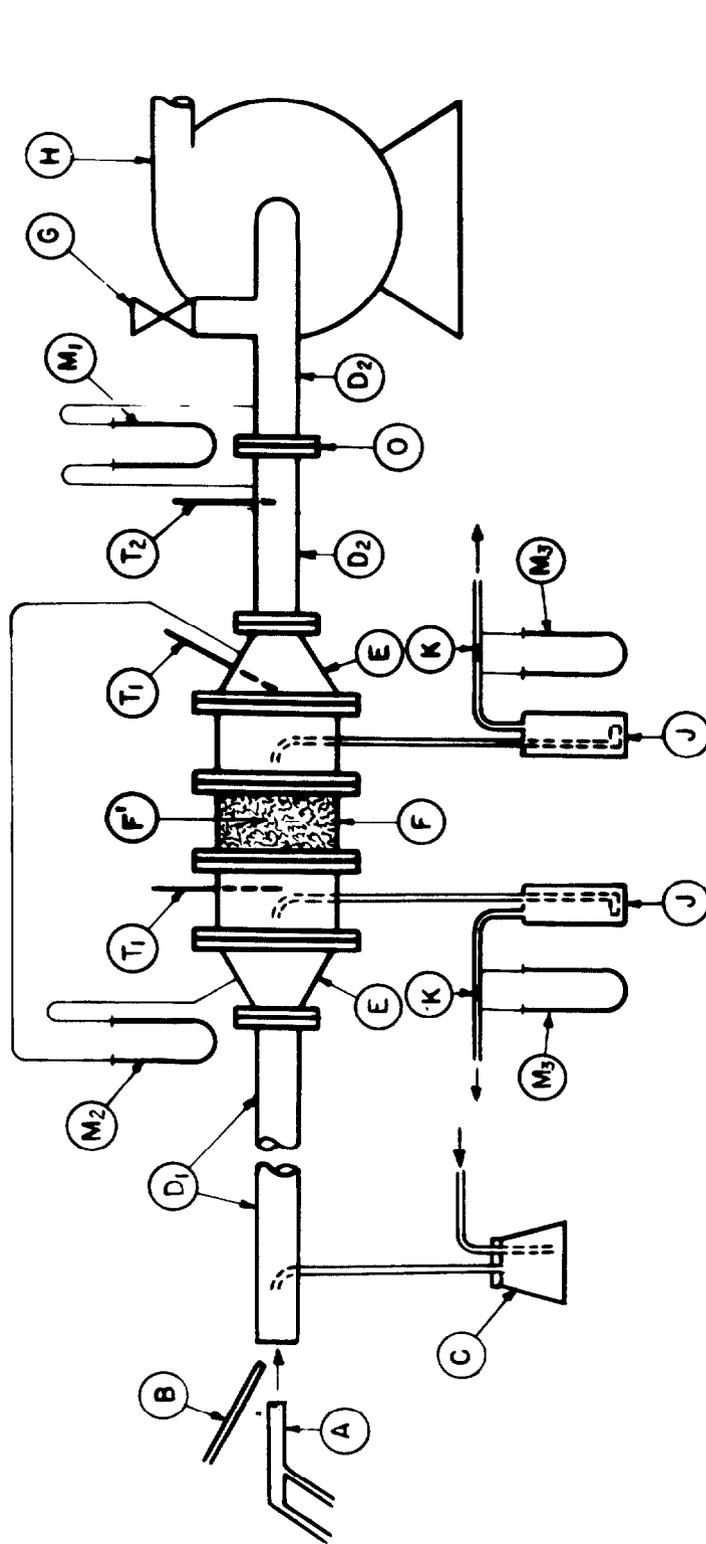


Fig. 1— Iodine-131 collection test apparatus.



Fig. 2— Silver-plated copper ribbon in glass tube,  $\frac{7}{8}$  in. inside diameter, bed depth, 4.5 in.



- A = GAS BURNER
- B = STEAM SUPPLY
- C = IODINE GAS GENERATOR
- D<sub>1</sub> = 2" DIAM., 3'-4" LONG PIPE
- D<sub>2</sub> = 2" DIAM. PIPES
- E = 6" X 2" RED.
- F = FILTER HOLDER, 6" DIAM., 2" DEEP
- G = 2" VALVE, BY-PASS AIR FLOW CONTROL
- H = EXHAUST FAN
- F' = SILVER-PLATED COPPER RIBBON
- F = PACKING DENSITY 27 LBS./CU. FT.
- J = FRITTED GAS ABSORBER
- K = SAMPLE FLOWMETERS
- M<sub>1</sub> = ORIFICE MANOMETER
- M<sub>2</sub> = FILTER RESISTANCE MANOMETER
- M<sub>3</sub> = SAMPLE MANOMETERS
- O = ORIFICE
- T<sub>1</sub> = THERMOCOUPLE
- T<sub>2</sub> = THERMOMETER
- ← = DIRECTION OF AIR FLOW

Fig. 3 — Experimental equipment for iodine collection studies.

were generated by sweeping an aliquot of the inlet air stream across the surface of iodine crystals. The sublimation rate was increased when necessary by applying heat to the iodine crystals. Radioactive iodine  $I^{131}$  was obtained from commercial sources as iodine  $I^{131}$  with normal iodine carrier in carbon tetrachloride, carrier free iodine from tellurium metal, or  $NaI^{131}$  in sodium sulfate ( $Na_2SO_3$ ) solution. The carbon tetrachloride solution was volatilized as shown in Figure 1 in the U-tube evaporator. The carrier free iodine from tellurium was transferred to sodium thiosulfate ( $Na_2S_2O_3$ ) and heated.

The carrier free iodine, prepared from  $Te^{130}$ , was handled by extraction with 5 per cent sodium thiosulfate ( $Na_2S_2O_3$ ) which was then dried in aliquots and heated in a U-tube similar to that shown in Figure 1. The  $NaI^{131}$ , carrier free, was supplied in a 5 per cent  $Na_2SO_3$  vehicle. This was treated by adding 5 per cent sodium thiosulfate in serial dilution. An aliquot was heated for each run. The carrier free studies reported in this paper are limited and will be presented in greater detail as more information is accumulated.

In later tests which are briefly mentioned here prefiltered air was employed by use of filters shown in location in Figure 1 to ascertain the effect of possible deposition of iodine on atmospheric nuclei. Chamberlain and DeWaffen (7) have indicated that very high concentrations of nuclei can adsorb carrier free  $I^{131}$ .

For high temperature measurements the gas stream was heated by indirect methods, electrical coils or gas burner in the case of the 1 in. Pyrex tube and by direct flame gas combustion products with the 6 in. steel pipe as shown in Figure 2. Thermocouples measured average gas temperature through the collection medium.

Fritted absorbers operating at 10 liters per min. and containing 50 ml. of 5 per cent potassium iodide were used to collect the iodine  $I^{127}$ . Collection efficiency was determined from iodine concentrations in the up- and downstream gas samples with a Klett-Summerson photoelectric colorimeter at  $440 m\mu$ . Absorber efficiencies were dependent upon the amount of iodine collected in the potassium iodide solution and ranged from 92 per cent at 150 mg.  $I_2$  per liter of KI to 89 per cent at 500 mg. per liter. This, of course, was largely due to the volatility of the iodine in 5 per cent KI solution.

In the presence of materials which would liberate iodine from potassium iodide, i.e. nitric acid, carbon tetrachloride was substituted as the absorbent for potassium iodide. An ice-salt water bath was used to reduce  $CCl_4$  evaporation losses. Iodine collected in the carbon tetrachloride was also determined colorimetrically in the photometer.

Iodine  $I^{131}$  distribution in the collection tube and collector was ascertained by scintillation detectors. Variations in  $I^{131}$  loading were determined by placing a scintillation head in contact with the absorber. Integral counting was employed with a pulse height of 200 MEV. The cumulative count rate was plotted against time with a recording galvanometer. The recording obtained indicated a nearly constant  $I^{131}$  feed rate. The

collected absorber samples were measured by differential counting (350-370 KEV) of aliquots in a well scintillation detector calibrated with a simulated 0.067  $\mu\text{c}$  source. Distribution of activity through the collector depth was checked by (a) traversing the tube surface through a port in a lead brick with the integral counter head in place and (b) actual assay by cutting the material (copper or silver-copper mesh) into segments which could be placed in the well scintillation detector. These results are reported as counts per minute per gram of collector. The concentration of  $\text{I}^{127}$  in the  $\text{I}^{131}$  isotope when carrier was present was determined colorimetrically and the initial mass ratio was determined from these data. After establishing the initial mass ratio the ratio at any time due to decay could be established.

### Results

Data for all the tests reported here are summarized in a series of tables, Tables 1 to 8. Most of the initial study was performed with normal iodine since it could be readily utilized for screening of many materials.

The information in Table 1 refers to treatment of slag wool fibers with various surface coatings. An examination of the reactions of iodine with various metals and reagents indicates that several metals, metallic iodides and iodine reactants would have potential application. The most promising of these were tried at what appeared to be an optimum velocity of 60 fpm or 1 fps for space requirements. It is obviously not the most desirable velocity for collection in many of the cases shown in Table 1. The most effective unit shown was obtained by vacuum plating silver metal on the slag wool fibers (Test No. 8) since it afforded high efficiency at the lowest flow resistance. The silver nitrate treatment as used on Berl saddles at Hanford however, gives comparable removal at somewhat higher resistance. The Rochelle salt mirroring was next in order of performance. In the case of Rochelle salts several milligrams of iodine could be collected but the efficiency decreased with extended use.

On a basis of these tests further screening was felt desirable so that a number of media were assayed as shown in Table 2. Of the solid adsorbents, activated charcoal from various sources was the best but because non-combustible adsorbents or absorbents might be necessary, activated alumina, Thirsty glass (microporous), Attapulugus clay, mossy zinc, tin foil and copper mesh were examined.

Over-all evaluation in terms of resistance, temperature, economy, total recovery, and collection efficiency indicated copper mesh to be one of the most promising of this series. Therefore, a more detailed test program was established for this medium.

Table 3 presents temperature and extended performance data for copper ribbon mesh placed in the 6 inch unit shown in Figure 3. The data are consistent with those of Table 2 when correction is made for the difference in packing density. The presence of water vapor added as steam was found to enhance performance of collector A. It was also observed however,

Table 1

Iodine Collection with Various Coatings on 4 Micron Diameter  
Slag Wool Fibers

Test No.	Collector Description <sup>a</sup>			Coating Material	Collector Performance	
	Weight grams	Depth inches	Packing Density #/cu.ft.		Initial Efficiency per cent	Resistance inches of water
1	178	1	24.0	KI <sup>b</sup>	23	2.4
2	As above moistened (H <sub>2</sub> O)			KI <sup>b</sup>	80.2	5.3
3	133	1	17.9	Cd <sup>c</sup>	40	3.8
4	212	1	29.0	74% Cd-26% Sb <sup>c</sup>	31	5.2
5	As above moistened (H <sub>2</sub> O)			74% Cd-26% Sb <sup>c</sup>	39	8.6
6	148	1.5	18.8	AgNO <sub>3</sub> <sup>d</sup>	> 99.9 <sup>e</sup>	5.8
7	208	2	14.0	Ag <sup>f</sup>	90.0	6.7
8	4.9 <sup>g</sup>	4	2.0	Ag <sup>h</sup>	> 99.9	1.1

- a. Slag wool pads, 6 inch diameter, face velocity 60 ft./min., 20°C.  
b. Coated by dipping in saturated KI solution and drying.  
c. Coated by spray metallizing one side, 7 layers in filter.  
d. Coated by dipping, 61 grams AgNO<sub>3</sub> retained in filter.  
e. Efficiency decreased to 97.7% after collecting 1.4 grams I<sub>2</sub>.  
f. Chemically plated, Rochelle salt technique.  
g. Bed diameter = 1 inch.  
h. Vacuum plated, 14 layers of fiber, plated one side only.

Table 2

Iodine<sup>127</sup> Collection with Miscellaneous Media  
at 60 Ft. Per Min. Face Velocity

Collector Description	Temp. °C	Resistance In. water	I <sub>2</sub> Inlet Conc. mg/M <sup>3</sup>	I <sub>2</sub> Retained grams	Collection Efficiency per cent	
					Initial	Final
<u>Mossy Zinc</u> - 76 grams, coarse granules	20	-	150	0.20	97.0	89.6
<u>Potassium Hydroxide</u> - 74 grams, pellets	20	-	750	0.56	99.8	99.9
<u>Tin Foil</u> - 20 grams, 30 x 3 mil ribbon	20	-	61	0.084	92.6	96.9
<u>Tin Foil</u> - 74 grams, 30 x 3 mil ribbon	120	-	360	0.84	99.0	95.0
<u>Activated Alumina</u> - 8/14 mesh, 36 lb/ft. <sup>3</sup> , 2" bed, Aluminum Ore Co.	30 200	1.3 -	600 170	0.030 0.007	86 avg. 78 avg.	
<u>Thirsty Glass</u> - 53 lb./ft. <sup>3</sup> , 2" bed, Corning Glass Works	20 200	0.3 -	150 150	0.008 0.004	45 avg. 37 avg.	
<u>Attapulugus Clay</u> - 15/30 mesh, 28 lbs/ft. <sup>3</sup> , 2" bed, Minerals and Chem. Corp. of America	20	1.4	6	0.00005	6 avg.	
<u>Carbon Fibers</u> - 24 lb/ft. <sup>3</sup> , 1 in. bed. Carbonized wool fibers, Atomic Laboratories, Inc.	27 150	2.4 -	240 60	0.024 0.0001	40 avg. 5 avg.	
<u>Activated Charcoal</u> - 8/14 mesh, 28 lbs/ft. <sup>3</sup> , 1.7" bed, Columbia Carbon, Grade 60	30 170	4.8 -	250 200	0.018 0.011	> 99.9 avg. > 99.9 avg.	
<u>Activated Charcoal</u> - 12/30 mesh, 30 lbs/ft. <sup>3</sup> , 1" bed, Pittsburgh Coke & Chem. Co., Type B PL	25	0.7	120	0.20	> 99.98 avg.	
<u>Copper Ribbon</u> - 25x2 mil, 42 lbs/ft. <sup>3</sup> , 3" bed - "Chore Girl" Scouring Pad, Metal Textiles Co., Roselle, N.J.	20 120	0.1 -	200 500	0.16 2.96	99.99 > 99.9	93.5 90
						(25 hr. test)

Table 3

Effect of Steam and Temperature on Iodine<sup>127</sup> Collection  
with  
Copper Ribbon (25 mil x 2 mil)

Collector	Test	Temp. °C	Test Period hrs.	Cumulative Test Period hrs.	I <sub>2</sub> Inlet Conc. mg/M <sup>3</sup>	Collection Efficiency per cent
A	1	25	0.33	0.33	50	97.4
A	2 S	25	0.67	1.0	40	99.8
A	3 S	300-350	0.16	1.16	120	> 99.98
B	1 S	300	1	24	100	> 99.98
B	2	25	1	25	100	13.4
B	3 S	25	1	26	100	49.7
B	4 S	300	1	27	100	> 99.98
B	5 S	450	0.5	27.5	100	Negative*
						Eff. per cent      Iodine Retained grams
C	1 S	300-350	7	7	100	> 99.98      6
D	1 S	300	24	24	100	> 99.98      6
D	2 S	300	6	30	100	87      7.3
E	1 S	300	24	24	100	> 99.98      1.0
E	2 S	300	5	29	100	77      1.2

Note: S indicates steam addition, 1 lb./1000 cu.ft. of air at indicated temperature.  
A,B,C,D,E indicate separate collectors.

\* Iodine lost as Copper Iodide and Iodine Vapor

Bed Packing Densities, 27 lbs./cu.ft. - Bed Depths, 2 in. -  
Face Velocities, 60 ft. per min.

(collector B) that the copper oxidized on extended use and that this media when again retested at room temperature gave poor results which could only be partially improved by steam. When elevated to 300°C it again performed well with steam present. At a temperature of 450°C the copper iodide was completely volatilized. As much as 29 hours of a high loading (100 mgs. per cubic meter) was used for exposure and apparently a 25 hour period was the limit for greater than 99 per cent efficiency.

The exact nature of the steam treatment is unknown but might be attributed to either a formation of HI or a conditioning of the copper surface. The copper collector surface was also treated with hydrogen sulfide which performed as well as the copper surface in iodine removal. At elevated temperatures the copper sulfide behaved similarly to the copper alone. Since this medium could not be expected to be protected from oxidation effects at high temperature its use, as with copper, should be confined to room temperature operations or standby installations in an inert gas storage device.

The favorable performance of the mesh extended surface prompted us to explore the feasibility of plating the copper with a protective surface. Since silver is iodine reactive and fairly reasonable in cost and simple to obtain as a plating material on a copper base, it was selected for this purpose.

The results of  $I^{127}$  collection by the silver plated material (0.5 per cent Ag by weight) are presented in Table 4. The results are very favorable particularly at elevated temperature, whereas copper pads failed after 30 hours of operation. At comparable loadings the silver plated surface was still effective after 100 hours of service. Tests with silver plated copper indicated that the collector became relatively ineffective (31.5 per cent efficient) when used at room temperature after high temperature operation. However, once returned to high temperature use, the original performance was attained. The effect of silver oxide is thus apparent. It is not believed that this poses any operational problem as the operating conditions would not be expected to produce this variation. It does appear desirable to maintain fixed temperature limits for practical operation.

The silver surface was evaluated under conditions of nitric acid mist, ammonia and hydrogen sulfide exposure without observing any deterioration in performance.

The radioisotope evaluations with carrier iodine are shown in Table 5. These data indicate an efficiency of the silver-copper medium at room temperature between 89.5 and 95.9 per cent with increased removal at higher temperatures. Higher iodine loadings give a greater driving force for silver surface chemical reaction as shown in Figure 5. The data for the copper efficiency tests in Table 6 indicate, as found with  $I^{127}$ , that iodine removal at room temperature is significantly greater than with the silvered surface. The copper data indicate an apparent reverse effect of iodine concentration on removal, namely, lower values of loading give greater removal. At present we believe this inconsistency

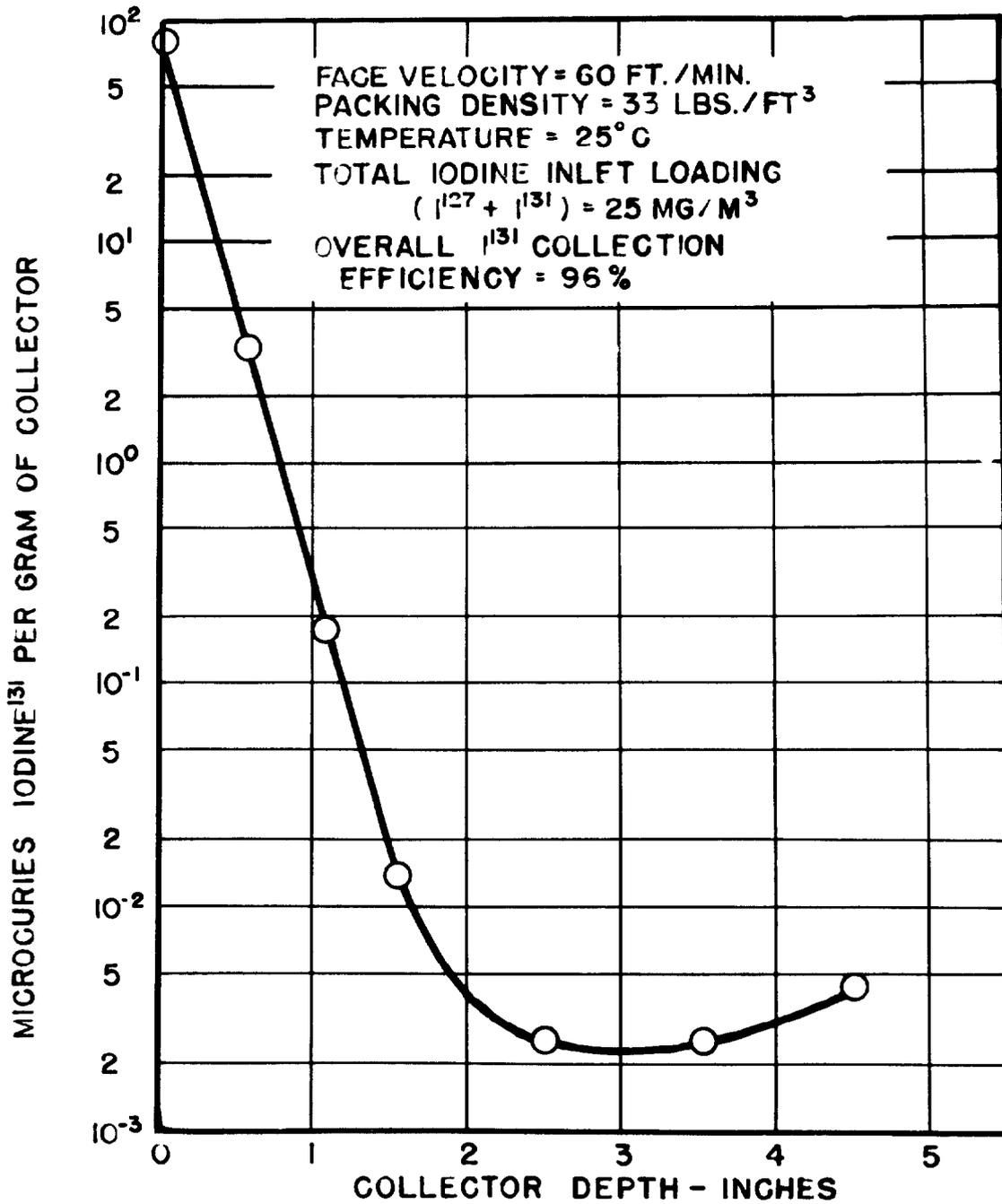


Fig. 4 — Iodine-131 distribution within 5-in. bed of silver-plated copper ribbon.

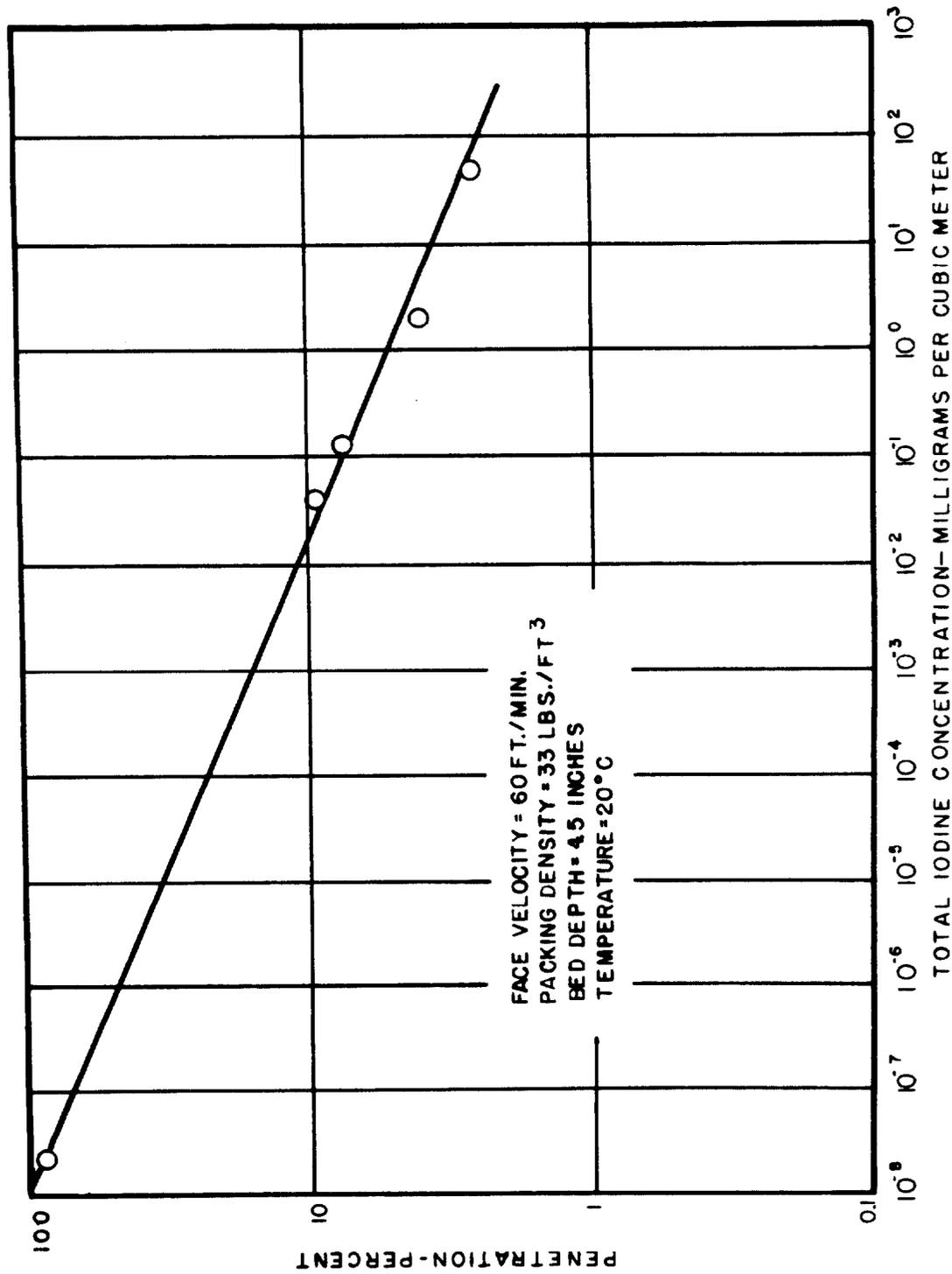


Fig. 5—Effect of iodine inlet concentration on penetration with silver-plated copper collectors.

Table 4

Iodine<sup>127</sup> Collection by Silver Plated Copper (25 mil x 2 mil) Ribbon  
at  
60 Feet Per Minute Face Velocity

Collector <sup>a</sup>	Test	Temp °C	Test Duration Cumulative hrs.	Inlet <sup>b</sup> Iodine <sup>127</sup> Conc. mg/M <sup>3</sup>	Iodine <sup>127</sup> Retained Cumulative grams	Collection Efficiency per cent	
						Initial	Final
A	1	20	0.16	378	0.038	-	99.91
A	2	20	0.50	738	0.186	99.91	98.2
A	3	20	0.83	192	0.224	98.2	84.2
B	1	300	2.25	715	0.966	99.997	99.986
B	2	300	4.75	1000	1.010	99.986	96.1
J <sup>c</sup>	1	300	100	150	2.3	> 99.8	99.6

- a. Collector A and B, Packing Density = 45 lbs./cu.ft., Depth = 2.5 in., Weight = 22 grams.; Collector C, Packing Density = 27 lbs./cu.ft., Depth = 2 in., Weight = 400 grams.
- b. Loading constant with Collectors A and B, Intermittent with Collector C.
- c. Efficiency reduced to 31 per cent when cooled, but greater than 99.6 per cent when reheated to 300°C.

Note: Silver content of plated ribbon = 0.5 per cent by weight.

Table 5

Iodine<sup>131</sup> Collection by Silver Plated Copper Ribbon and Copper Ribbon  
 Presence of Carrier Iodine<sup>127</sup> (25 mil x 2 mil ribbon)

Collector <sup>a</sup> No.	Weight grams	Temp. <sup>b</sup> °C	Inlet Iodine <sup>c</sup> Concentration			Collection Efficiency Iodine <sup>131</sup> per cent
			I <sup>127</sup> mg/M <sup>3</sup>	mg/M <sup>3</sup>	I <sup>131</sup> μc/M <sup>3</sup>	
<u>Ag-Cu</u>						
1a	22	28	0.049	$3.8 \times 10^{-8}$	4.7	90.56
1b	44 <sup>d</sup>	28	0.067	$3.4 \times 10^{-8}$	4.2	89.50
1c	22	210	0.032	$1.7 \times 10^{-8}$	2.1	99.44
2a	22	28	0.84	$7.6 \times 10^{-7}$	93	94.62
2b	22	28	2.5	$2.4 \times 10^{-6}$	295	95.96
2c	44	28	12.0	$5.6 \times 10^{-6}$	690	95.94
<u>Cu<sup>e</sup></u>						
3a	22	28	0.06	$2.0 \times 10^{-6}$	246	98.99
3b	22	28	2.4	$4.3 \times 10^{-8}$	5.3	99.75

- a. Packing Density of all collectors - 33 lbs./cu.ft., Face Velocity - 60 ft./min., single test per collector, Resistance - 0.1 to 0.2 in. water.
- b. Effect of temperature - compare collectors 1a and 1c.
- c. Effect of total (I<sup>127</sup> and I<sup>131</sup>) concentration - compare 1a vs. 2b.
- d. Effect of bed depth (4.5 vs. 9.0 in.) - compare 1a and 2b vs. 1b and 2c.
- e. Comparison of Ag-Cu vs. Cu efficiency - 1a and 2b vs. 3a and 3b.

attributable to experimental error. The effect of bed depth is also shown in Table 5. These data indicate almost no effect indicating that most of the removal takes place in the first increment of the bed. This is shown graphically in Figure 4 where almost 99 per cent of the removal takes place in the first inch of medium.

Table 7 shows the effect of increasing packing density of the silver plated copper ribbon. It was found possible to get greater compression by employing a 5 x 4 mil ribbon as opposed to the 25 x 2 size used previously. These ribbons have approximately the same surface area per gram but as indicated in Table 7, the packing density of the former can be increased to 58 pounds per cubic foot. It should be noted that the air flow resistance under this condition is also increased about fourfold. The data of Table 7 indicate more effective I<sup>131</sup> removal as well as comparable performance at 4 times the velocity of the previous tests (Table 5).

Our most recent tests on media that may afford better performance at room temperature operation are shown in Table 8. Tests with I<sup>127</sup>, Table 2, and with carrier free I<sup>131</sup>, Table 8 in addition to data reported by Browning et al (2) indicate that commercially available activated carbon is generally the superior collector. However, Lomac 40, a carbon impregnated rayon ribbon, developed by American Viscose Corporation for odor removal gives outstanding results at high velocity and low resistance and should prove useful in many applications where fire problems do not exist.

In the investigation for a non-combustible granular solid adsorbent we have already presented data in Table 2 for activated alumina and "Thirsty glass". Table 8 presents data for silica gel which like alumina has a primary preference for water vapor. It shows a comparable performance to Thirsty glass although alumina was considerably higher. By silver mirroring, however (which could also be done with the mineral adsorbents) the efficiency was raised to over 99.9 per cent.

The activated carbon of Table 2, when retested with carrier free I<sup>131</sup> and prefiltered air indicated lower performance. This is in agreement with Chamberlain and Wiffen (7).

Table 8 also shows some preliminary data on a finer silver-plated copper ribbon with approximately twice the surface area per pound as the previous ribbons. This appears to be very promising on carrier free iodine even at velocities approaching 343 feet per minute or nearly 7 feet per second. This may be of especial value in instances where space requirements may demand such operating conditions.

### Conclusions

Based on the data presented here the following conclusions may be drawn from this study.

1. No significant difference exists between I<sup>127</sup> and I<sup>131</sup> removal on silver-copper media assuming that comparable loadings, temperature, gas velocity, and packing density are maintained.

Table 6

Comparative Collection Efficiencies of Silver Plated Copper Ribbon  
(25 mil x 2 mil) for Iodine<sup>127</sup> and Iodine<sup>131</sup>

Collector <sup>a</sup>	Iodine Inlet Concentration			Collection Efficiency	
	I <sup>127</sup> mg/M <sup>3</sup>	I <sup>131</sup> mg/M <sup>3</sup>	I <sup>131</sup> μc/M <sup>3</sup>	I <sup>131</sup> <sup>b</sup> per cent	I <sup>127</sup> <sup>c</sup>
A	68.5	1.7 x 10 <sup>-8</sup>	2.1	98.12	98.21
B	62.9	1.6 x 10 <sup>-8</sup>	2.0	97.96	97.12
C	66.0	6.1 x 10 <sup>-9</sup>	0.72	98.22	96.57

- a. 22 gram bed, 33 lbs./cu.ft. packing density, 60 ft./min. face velocity.  
 b. By radioactive count.  
 c. By chemical (colorimetric) analysis

Table 7

Iodine<sup>131</sup> Collection with Silver Plated Copper Ribbon (5 mil x 4 mil)  
Effect of Bed Depth and Face Velocity

Collector <sup>a</sup> No.	Bed Depth In.	Face Velocity ft./min.	Iodine Inlet Concentration			Collection Efficiency Iodine <sup>131</sup> per cent
			I <sup>127</sup> mg/M <sup>3</sup>	I <sup>131</sup> mg/M <sup>3</sup>	I <sup>131</sup> μc/M <sup>3</sup>	
A	4	60	0.71	2.4 x 10 <sup>-8</sup>	2.9	> 99.95
B	1	60	0.42	1.1 x 10 <sup>-8</sup>	1.3	> 99.71
C	4	240	0.42	1.1 x 10 <sup>-8</sup>	1.3	> 99.89
D	1	240	0.36	0.9 x 10 <sup>-8</sup>	1.1	97.1

- a. Constant packing density - 58 lbs./cu.ft., resistance, 0.4 to 1.6 in. water.

Table 8

Iodine <sup>131</sup>I Collection With Miscellaneous Collectors (Room Temperature 25°C)

Collector Description	Face Velocity ft./min.	Resistance In. Water	Iodine Inlet Concentration		Collection Efficiency Iodine <sup>131</sup> I per cent
			I-127 mg/M <sup>3</sup>	I-131 μc/M <sup>3</sup>	
LOMAC-40 - 250 Denier Ribbon containing 40% act. carbon with rayon, 3, bed depth 1.5"	60	0.16	0.015	3.36 x 10 <sup>-8</sup>	4.2 99.72
17.4 lbs/ft. <sup>3</sup> , bed depth 2.5"	166	2.12	0.10	2.1 x 10 <sup>-8</sup>	2.6 99.93
Silica Gel - 6/12 mesh Unimpregnated, bed depth 2.75"	60	2.75	0.38	2.4 x 10 <sup>-8</sup>	3.0 39.9
Silica Gel - 6/12 mesh Silver coated by Rochelle salts - 12 mg. Ag per gram of silica gel - bed depth 2"	60	2.75	0.16	1.0 x 10 <sup>-8</sup>	1.2 > 99.92
Activated Carbon - 8/14 mesh Air prefiltered with AEC Absolute Filter, bed depth 2"	60	4.8	0.0	1.4 x 10 <sup>-8</sup>	1.7 96.8
Silver plated copper ribbon (3 mil x 2 mil) 71.0 lbs/ft. <sup>3</sup> , bed depth 4"	343	4.0	0.42	2.5 x 10 <sup>-9</sup>	0.3 99.45

2. At room temperature copper is more effective in iodine removal than the silver plated-copper mesh for  $I^{131}$ .
3. Iodine penetration of the media tested varies inversely with loading.
4.  $I^{131}$  removal varies inversely with velocity on a fixed bed.
5. Bed depth above a certain value which cannot be predicted at the present time is not a significant variable. Most of the  $I^{131}$  removal takes place in the first 20 per cent of medium surface or depth. It is anticipated that continued loading will cause progressive migration into the relatively unused portions.
6. Elevated temperature improves operational performance of copper or silver media and lowers performance of adsorbents.
7. Efficiency of removal of silver plated-copper surfaces, appears to be dependent upon concentration over the range  $10^2$  to  $10^{-8}$  mgs. per cu. meter in iodine.
8. Steam enhances the performance of copper surfaces for iodine removal at room and elevated temperatures.
9. Preliminary data on fine mesh (2 x 3 in.) silver plated-copper with higher specific surface indicates better performance. However, greater air flow resistance results.
10. Iodine adsorption on atmospheric dust was not found responsible for low collection efficiency measured at low  $I^{131}$  loading under our test conditions.
11. Silver plated-copper media when once exposed to high temperature operation and then reused at room temperature shows markedly reduced performance. However, this same material when reheated shows values comparable to initial high performance. The failure at room temperature is attributed to oxide formation.
12. Practical adsorbents for use at high temperatures that are not combustible in themselves require chemisorption as well. With the aid of mirroring or chemical silver plating, silica gel becomes a useful selection. Resistance losses of all granular adsorbents are comparable at a given mesh size.
13. For room temperature operation at relatively high velocity with low air flow resistance, activated carbon impregnated fibers appear to be a new and useful development (assuming that fire or high temperatures do not exist).
14. Activated carbons in general where fire or high temperature hazards are not involved are highest in performance for decontamination of iodine bearing off-gases. Resistance losses are significantly greater than coarse fibrous media.

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## Discussion

- Q. (B. L. Rich, PPCo.) We are rather concerned with the special problem in regard to Idaho production at this facility - once you dissolve a fuel element in a caustic mixture - may be - for anyone of a dozen filter medias - do you plan to extend your studies to the more practical side in reference to introduction at some of the sites?
- A. Planning to get some data on silver filters in regard to fuel element - air cooled reactor - as work in Oak Ridge when ruptures are a problem. We were looking originally for high volume, low pressure drop situation - using work done at Hanford with caustic scrubbers indicates silver is No. 1 in performance on dissolving. Also ran some bromine tests and got results comparable to normal iodine.

- Q. You said you had a lead shield and viewing window in which you determined the efficiency of the bed by close scanning. Can you elaborate on this further?
- A. we evaluate material deposited - collection gradient along the bed for more efficiency.
- C. (Sabo - PHS) To answer the question on the CPP we use both the silver fiber which is similar to what you had, as a matter of fact it was developed from that and the treated paper. The reason you prefer paper is because of continuous sampling. We found the efficiency varied from 40% to 90%. We have collected as high as 90% of the iodine on the CPP process. At other times we have been down as low as 40 so there is no question about it. What they do there has a great tendency bearing on what you are able to sample. We sample off-site so we are a half mile to six miles away where concentrations are low and one must sample for long periods of time to even count.
- C. Using a filter under those conditions, even silver nitrate, I think heating would be certainly recommended, because we find that the heating increases a collection of efficiency.

## SPECIAL INCINERATION STUDIES - INSTITUTIONAL DESIGN

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### Summary

The Harvard Air Cleaning Laboratory is currently engaged in designing incineration and gas cleaning apparatus for the disposal of low-level radioactive wastes from hospitals and biological laboratories. Previously, this laboratory had attempted to design a gas cleaning system for use with the BOMAEC-30 incinerator, developed by the U. S. Bureau of Mines. Operational and leakage problems, however, indicated that design changes would be necessary for practical application of the unit.

Tests on a small (10-15 lb. per hour burning rate) commercial home incinerator showed combustion characteristics which were nearly as good as those noted for the BOMAEC-30. Since the cost of the former unit was in the range of \$100.00, it appeared feasible to construct a small incinerator from a 55 gallon drum with provision for accurate gas flow and temperature measurements. Our first experimental model was designed for single inlet, tangential, over-fire air admittance (somewhat like the Bureau of Mines unit). However, the burning chamber was lined with a 2 in. layer of fire-brick rather than stainless steel. A charge pre-drying chamber located above the burning section proved unsuccessful as a means of handling high-moisture waste. Therefore, a single side charge door was installed with a sliding rack to support wet materials within the burning chamber while the previous charge was burning. This procedure enabled continuous charging of wet materials once the burning chamber was at temperature,  $>2000^{\circ}\text{F}$ . A secondary brick-lined cylindrical chamber located immediately above the burning area allowed for further high temperature combustion of unburned volatiles and particulates, since a secondary air inlet was located at the base of this section. Effluent gas was cooled by dilution air which entered tangentially at the top of this chamber.

Test results, based upon burning rate and volume of  $\text{CO}_2$  produced per lb. of charge, show that the over-all performance of the current incinerator design, ACL II, is superior to that of the BOMAEC, based on cost, simplicity of operation, and the fact that wet wastes, up to 50 per cent moisture can be burned satisfactorily without the need for auxiliary gas firing.

Gas cleaning apparatus consists of a basket type filter, 10 sq. ft. surface, composed of graded glass fibers. Our present intention is to filter hot (600-800°F) to avoid installation of cooling and reheating apparatus.

### Introduction

Earlier reports by this laboratory (1,2,3,4) furnish details on the evaluation of the stack effluent from a special incinerator, BOMAEC-30, designed by the U. S. Bureau of Mines, Combustion Research Section. The device was developed under contract with the U. S. Atomic Energy Commission for disposal of low-level radioactive waste materials from hospitals and research laboratories. Originally, this laboratory was requested by the Division of Reactor Development, U. S. Atomic Energy Commission to design a gas cleaning system that would prevent significant discharge of radioactive substances to the atmosphere. Our first approach was to establish the nature of the stack effluent under a variety of burning conditions. Initial studies (1,2) indicated that, under burning conditions deemed optimum by the Bureau of Mines personnel, the stack gas contained sufficient quantities of soot and condensable organics to make filtration by woven glass fabrics difficult. Further stack sampling after minor changes in incinerator design suggested by the first and second series of tests (3), showed no improvement in the stack effluent. Admission of secondary combustion air at the top of the burning chamber did not reduce significantly the amount of combustibles in the stack effluent although excess oxygen in the system was increased from nearly zero to 5 to 10 per cent. It appeared that the auxiliary air by-passed to the stack where temperatures were too low (about 1000°F) to initiate secondary burning. Mean stack temperatures dropped about 200 F° indicating that gas cooling was the major effect.

In the absence of auxiliary gas firing (which was installed for the third series of tests) wet rubbish containing >10 per cent moisture could not be burned. Furthermore, operational difficulties were encountered in the use of the auxiliary gas system which suggested that extreme caution and well designed (and costly) safety devices would be required for practical service.

Attempts to burn rubbish without auxiliary gas firing were unsuccessful even after eliminating most of the water. Stack temperatures dropped to low levels (600 to 800°F), a distinct odor of burning garbage was detected, and a sooty deposit appeared on the sampling filters.

Cooling of the gas stream by water sprays to about 400°F appeared to permit filtration through the glass bags without prohibitive increases in pressure loss. Although initial plugging caused a rapid rise from 1 to 5 inches of water (at 1.2 cu.ft. per min. per sq.ft. of cloth area) subsequent tests showed smaller increases, about 1 inch of water. Mechanical shaking reduced bag resistance to slightly less than 2 inches of water.

Although the bag effluent appeared to be free of soot particles, its moisture and condensable organic content was too high to permit final filtration through high efficiency AEC type filters. However, it is now our opinion that absolute filtration may not be required for many applications.

At the completion of the Pittsburgh field tests the BOMAEC-30 incineration unit was shipped to the Air Cleaning Laboratory so that extensive burnings could be made to establish the effective life of the glass bags. Past experience has indicated that these

fabrics, which are inherently brittle, tend to fail under flexure in much shorter periods than do those composed of synthetic resin or natural fibers. If the glass bags proved unsatisfactory our intention was to develop other cleaning techniques which would be suitable for typical effluents particularly those resulting from poor burning conditions.

Prior to the equipment transfer, we considered that the lack of a means for continuous charging was a poor design feature. In its original form, Figure 1, the cover of the burning chamber,

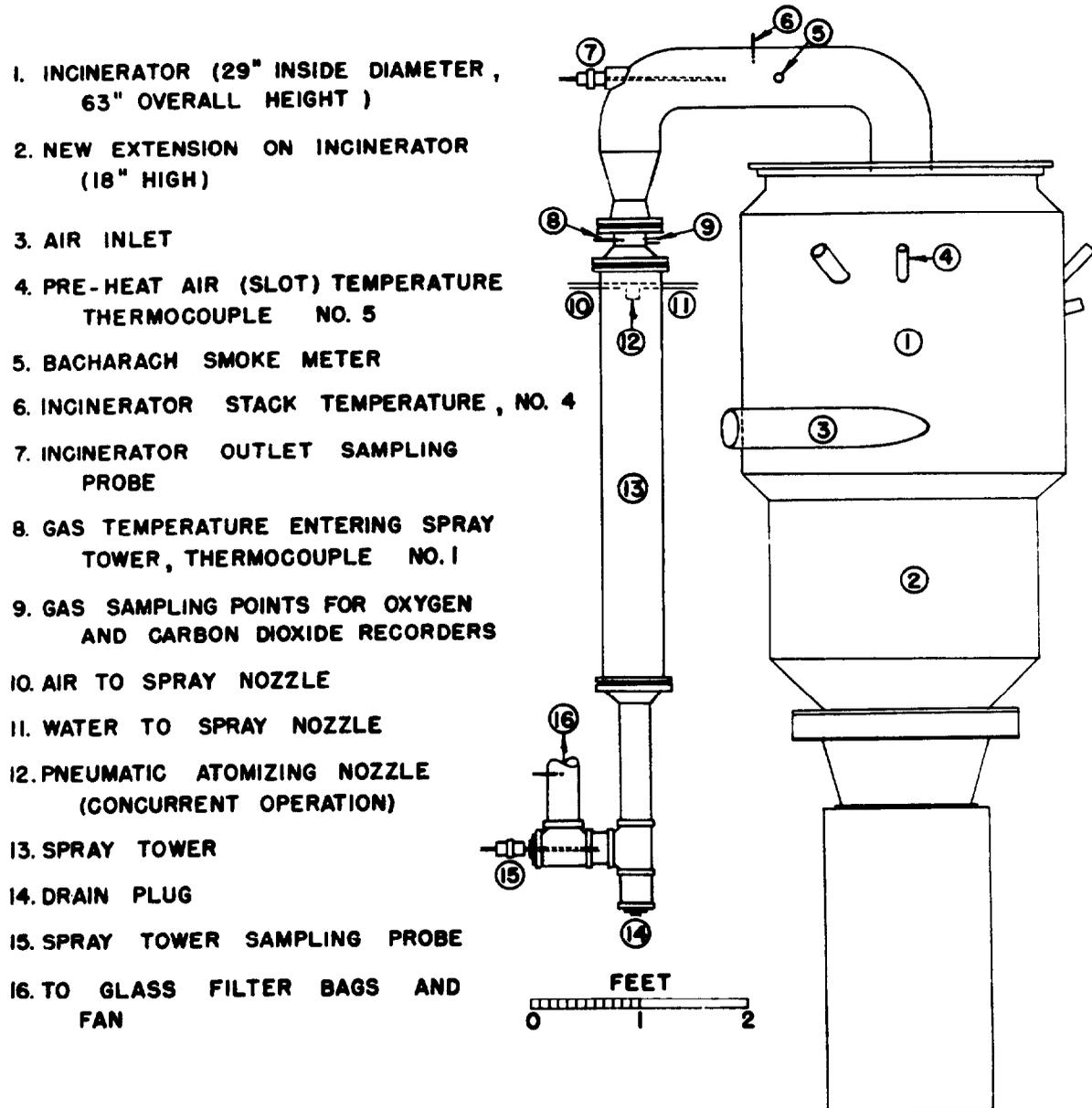


Fig. 1—Schematic drawing of revised institutional incinerator (BOMAEC-30) showing sampling points.

outlet pipe, heat exchanger, bag house, and exhaust fan were attached to a central hydraulic lift column. By elevating the above components about 6 inches and then rotating through a 90° arc, waste material could be dumped into the top of the combustion chamber. Therefore,

in order to charge the device safely, at least 30 minutes of cooling were required between burnings. Since dry, 25 lb. sawdust charges were burned completely in less than 30 minutes, the rated burning capacity (30 lbs. per hour) of the unit was essentially correct. Our tests with wet charges (15 to 50 per cent moisture) indicated much lower burning rates, 15 to 25 lbs. per hour, even with the use of continuous auxiliary gas firing. Allowing the unit to cool between burnings reduced its temperature such that the stack values seldom exceeded 1500°F and averaged 1200°F or less for the entire combustion period. We recognized that provision for continuous charging would ultimately be required if any improvement with single chamber combustion was to be attained.

### BOMAEC-30 Incinerator - Final Tests

#### A. Evaluation of Glass Filter Bags

Prior to shipping the BOMAEC-30 unit to this laboratory, the incinerator was altered so that charging could be accomplished without elevating accessory parts. A portion of the top cover was hinged to swing upwards and secured with dogs to provide a tight gas seal. Our laboratory tests, which were conducted with sawdust to simulate earlier Pittsburgh studies, produced an effluent which caused rapid plugging of the glass bags. Major difficulties appeared to be created by air leakage at several points in the system (at least 100 per cent of primary air flow). Stack gas temperatures did not exceed 800 to 900°F at any time, the gas flow within the burning chamber lacked the characteristic spiral pattern, and the flame color as observed through the view port was a dull, smoky orange.

Three glass bags ripped at the seams and with new replacements resistance could not be kept below 10 inches of water. At this point it appeared that glass bags would not be suitable unless some precleaning unit was used to screen out a good part of the carbonaceous material.

#### B. Evaluation of Slag Wool Filter

Our tests with various mineral and slag wool filters with open hearth fume (5) indicated that most of the particulates in the incinerator effluent could be retained without prohibitive resistance provided that tar formation was not excessive. Due to structure of most bulk fiber collectors cleaning by mechanical shaking is not effective. However, the low cost of mineral wool justifies fabrication of disposable units provided that sufficient filtration area can be used to allow a practical service life. Although no experimental evidence is yet available on the amount of activity that might penetrate the slag wool we think that this media alone may provide adequate gas cleaning.

The first test filter was constructed by placing two concentric expanded metal screens within a 55 gallon drum and sandwiching the slag wool filter between them. Side and bottom area of this basket device provided approximately 9.4 sq.ft. of filtration surface.

Two filters were prepared (4), the first by passing a wet slurry of the slag wool fibers through the screen and the second by making a dry hand-packed bed. Efficiency for the first filter (wet slurry) was low, 60 per cent, since drying of the bulk fibers led to channel formation and subsequent leakage.

The hand-packed filter was >90 per cent efficient in solids removal and showed moderate resistance, 1 inch of water at 3 to 5 ft. per min. face velocity. However, gas samples collected downstream of the filter showed large quantities of condensed tars which had passed through the filter in the gaseous phase (500 to 600°F). Further testing of this cleaning system in conjunction with the BOMAEC incinerator was discontinued since it became impossible to control the burning conditions. Gradual warping of the heated surfaces of the incinerator shell produced variable leakage which could not be corrected with high temperature sealing compounds. An attempt to evaluate the slag wool media by using a small experimental incinerator, 3 to 5 lbs. per hour, was unsuccessful apparently due to scale down effects on gas flow patterns.

### "Inciner" - Home Type Incinerator

#### A. Test Apparatus

Since available incineration apparatus was not amenable to good combustion control it was decided to investigate the utility of home type incinerators as a means of generating a reproducible effluent. A small unit, the "Inciner" (34 in. high and 20 in. outside diameter) was purchased for about \$100.00. In its original form the burning chamber was cylindrical in shape, constructed of steel, and surrounded by a concentric outer steel shell with an inner fiber glass lining. A gas burner was located above the grate for igniting purposes and also for drying damp charges. Supply air was a combination of under- and overfire air with no specific entry pattern. Normally, the exhaust gases discharged at the rear wall of the combustion chamber and vented by natural draft into the flue.

The following design changes were made prior to conducting any tests:

- a) A two-inch thick, fire brick liner was installed in the combustion chamber.
- b) An inlet pipe was attached to the base of the unit so that underfire air could be metered.
- c) Provision was made to meter total volume of effluent gas so that the amount of overfire air could be estimated.
- d) A rectangular drying chamber was placed on top of the incinerator for predrying wet charges prior to dumping into the combustion chamber, Figure 2.
- e) A filter unit, Figure 3, consisting of a circular 2 inch bed (2.8 sq.ft. of filter surface) of slag wool fiber, 6.5 lbs. per cu.ft. packing density, and housed in half of a 55 gallon drum was connected to the incinerator outlet pipe about 8 ft. downstream of the incinerator. An 8 inch layer of 1/4 inch gravel was placed in the bottom of the drum so that coarse particulates could be screened from the effluent gas prior to passing upward through the slag wool bed.
- f) An exhauster was installed downstream of the filter housing so that the entire system could be operated under negative pressure.
- g) A water cooled condenser was placed in the hot gas line coming from the incinerator so that bed temperatures could be varied in the slag wool filter unit.

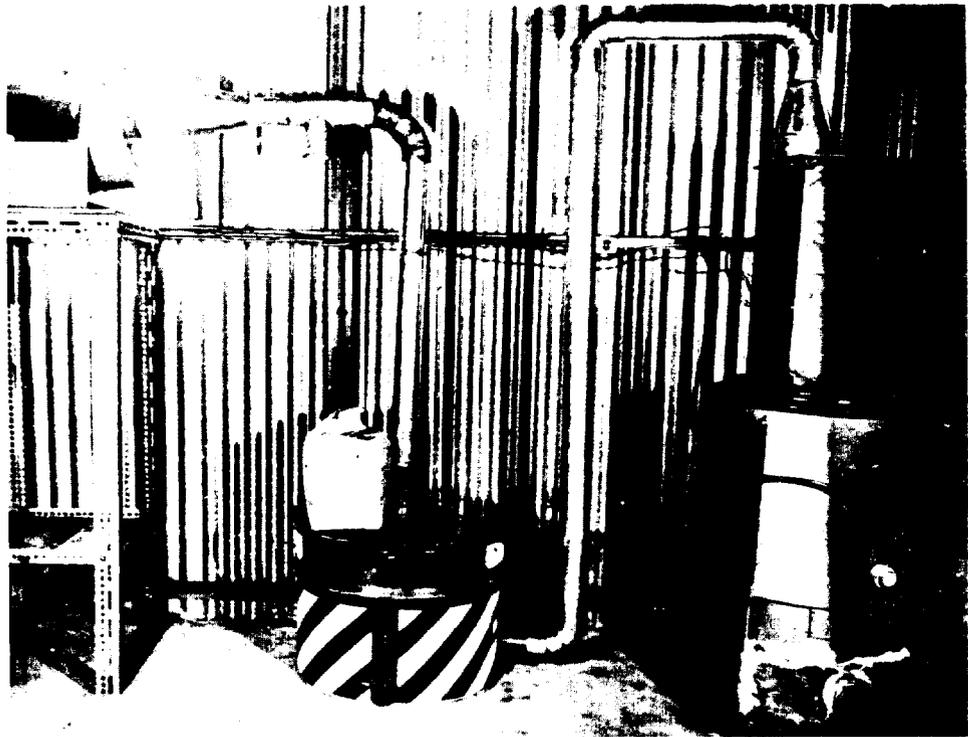


Fig. 2—Incineror general arrangement of unit and filter holder.

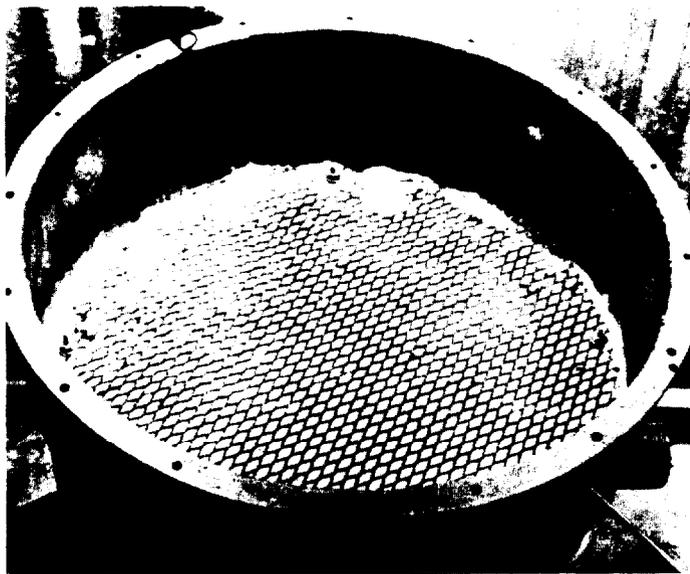


Fig. 3—Slag wool filter—ACL Incinerator I and Inconor (packing density,  $6.5 \text{ lb/ft}^3$ ; bed depth, 2 in.; area,  $2.78 \text{ ft}^2$ ).

h) Sampling ports were provided for determining dust loadings before and after the filter. Provision was also made for estimating gas composition ( $O_2$ ,  $CO_2$ , and combustibles reported as CO) and gas temperatures throughout the system.

## B. Stack Sampling Procedures

Sampling equipment was designed to furnish a distinct cut between particulates (mineral or carbon) and condensation products. This was accomplished by passing the stack effluent through an all-glass filter disc (MSA 1106B paper) followed by a condenser and an A.C. electrostatic precipitator. Cooling to ambient temperatures removed water which condensed in a trap and permitted capture of any condensed volatiles (tars) in the glass precipitator tube. Tar products were estimated quantitatively by dissolving in acetone and comparing the color photometrically with that obtained with standards prepared from the tar extract.

In the case of filter samples collected upstream of the slag wool unit, a distinction was made between the coarse, readily captured material entrained in the gas stream and finely divided carbon particles. Separation was accomplished by lightly tapping the filter which dislodged gross particles.

## C. Test Results

Preliminary testing on the "Inciner" consisted of burning 5 lb. sawdust charges, packed in paper bags, using underfire and overfire air flow rates of 30 and 20 cu.ft. per min., STP, respectively. Sawdust was again selected as the combustible charge so that some comparisons could be made with previous BOMAEC-30 performance. From a test viewpoint there were two advantages in using this material: 1) the effluent contained a high volatile loading which presented a filtration problem, and 2) the sawdust charge was reasonably uniform and amenable to convenient packaging.

Burning rates for sawdust charges averaged 20 to 25 lbs. per hour exclusive of the time required to load and seal the predrying chamber. Incinerator exit temperatures ranged from 1600 to 1800°F and filtration temperatures within the slag wool bed varied from 200 to 800°F depending upon the amount of gas cooling employed. During the test period required to burn 300 to 400 lbs. of sawdust, no significant rise in filter resistance above the initial value of 1 in. water was noted. However, at bed temperatures less than 200°F, resistance increased to 1.7 in. water during one test as a result of water condensation. When gas cooling was reduced so that bed temperature exceeded 300°F, the slag wool filter resistance returned to about 1 in. water.

The incinerator effluent prior to filtration contained approximately 0.05 grains per cu.ft. of solids of which 25 to 40 per cent were acetone-soluble tar products. The filter effluent appeared to be composed primarily of tar products which either passed through the filter as a fine mist or fog or condensed beyond the filter as a result of lowered gas stream temperature.

It was possible to burn a synthetic charge composed of 3 lbs. of sawdust and 2 lbs. of shredded cabbage without resorting to gas firing. Moisture content of this mixture was estimated to be greater than 40 per cent. However, burning rates were reduced to 15 lbs. per hour and incinerator effluent temperatures were considerably lower, 1200 to 1300°F in contrast to 1600 to 1800°F for sawdust alone.

## D. Discussion

Perhaps the most obvious conclusion to be drawn from the above tests is that the over-all performance of a relatively simple commercial incinerator design was better in many respects to that of the BOMAEC-30 unit. A scale-up of the "Inciner" or similar device to the size needed for disposal of 30 lbs. of bulk waste per hour should cost much less than the BOMAEC-30.

Resorting to a firebrick liner permits light weight construction with mild steels and allows much higher temperatures in the combustion chamber. It is emphasized that stainless steel construction was used in the BOMAEC-30 unit to eliminate the possibility of contamination of firebrick and its attendant problems as well as possible erosion and subsequent entrainment of contaminated firebrick in the gas stream. We do not think that this problem should exist with customary low activity waste material. Unfortunately, stainless steels limit incinerator temperatures to levels inadequate for good combustion and ultimately led to warping in the case of the BOMAEC unit. (This was also observed in the Argonne incinerator when over-heating took place.)

We were not completely satisfied with the "Inciner" as an experimental unit since it was not possible to determine gas flow distribution or precisely where overfire air entered the unit. In addition, the device was designed for batch charging from the top which also was not desirable for continuous burning. It did permit production of a reproducible effluent and, most important, furnished the basis for a new experimental unit.

## ACL I - Experimental Incinerator

### A. Design Considerations

In formulating the design for a new incinerator the following factors were taken into consideration:

1) Tests on both the BOMAEC-30 and "Inciner" units indicated that tars and combustible gases in the incinerator effluents were minimized when overfire air alone was supplied. Although underfire air in various proportions produced higher burning rates the resulting stack gas was more difficult to filter due to the increased volatile and solid loading.

2) From the point of view of simplicity, the single chambered unit with overfire, tangential admission of supply air appeared to be the best design for a compact unit. In this respect we confirmed the Bureau of Mines evaluations assuming that a scale-down of a double chamber municipal incinerator would not be acceptable for disposal of low level wastes.

3) The ultimate design of the new incinerator should provide a simple safe means of charging the unit continuously since under these circumstances the combustion chamber is maintained as hot as possible.

4) Ceramic liners should be installed to maintain high combustion temperatures and allow use of ordinary construction steels.

5) The design of covers, doors, etc., should be such that warping caused by high temperature does not cause air leakage in critical locations.

6) It should be possible to burn high moisture wastes (up to 50 per cent moisture either by constructing a practical predrying device or by charging directly to the combustion chamber.

## B. Description

Figure 4 shows the first model of an incinerator (ACL I) which was constructed according to the above design principles. A 55 gallon steel drum was lined with 2 inches of firebrick to provide a burning chamber 29 inches deep and 18 inches in diameter. An ash pit, 6 inches deep, was located immediately below the grate and provided with a clean-out port which also could be used if necessary as an underfire air inlet. A single tangential overfire air inlet was located about 10 inches below the top of the burning chamber. By inserting ceramic wedges the width of the entry air slot could be varied according to test requirements. Except for the fact that we employed a single, rather than multiple entry (4 symmetrically spaced inlet ports in the BOMAEC-30 unit) the external geometry of the ACL-I model was similar to that of the Bureau of Mines' unit.

A charging and predrying section, 24 in. high and 12 in. x 12 in. square was placed directly above the burning chamber. The bottom of this hopper, located about 8 inches above the incinerator proper, was hinged to the sidewall so that by swinging downward its contents were dumped into the combustion chamber. In the open position the hopper bottom partially blocked the opening to the 3 inch diameter flue pipe which connected to this chamber 3 inches below the hinged bottom. This served to prevent any by-passing of unburned materials to the incinerator outlet pipe during the dumping process.

In order to eliminate leakage, the incinerator cover and predrying hopper were fabricated as a single piece. The lower rim of the cover rested in a 4 in. deep, sand-filled circular channel section which was an integral part of the incineration chamber. This construction permitted ready access for repair or internal modifications and reduced air leakage to insignificant quantities (1 to 2 cu.ft. per min. or <5 per cent).

The top of the predrying hopper was gasketed and held in place by metal clamps during testing to eliminate stray leakage at this point. The incinerator stack effluent passed through approximately 8 ft. of 3 in. diameter duct prior to entering the base of the slag wool filter unit. The latter device was the same one that had been used during tests on the "Incinerator".

Test procedures for the ACL-I incinerator were the same as those reported for the "Incinerator".

## C. Test Results

Results of several combustion tests on the ACL-I incinerator are summarized in Table 1. The major variables were the quantity and type of air supply, i.e. overfire or underfire. Data for several air flow conditions, Tests 1-7, represent average conditions for the combustion of 6 to 10 separate 5 lb. sawdust charges. Each charge was allowed to burn nearly to completion (based upon return of O<sub>2</sub> levels to 18 per cent in the stack effluent) before the next charge was introduced. Indicated burning rates do not include the time required to open and close securely the predrying hopper (about 5 minutes) since no such delay in charging would exist in the final model.

- LEGEND-
- A- INCINERATOR (55-GAL DRUM)
  - B- CHARGING DOOR - 9" x 12" OPENING
  - C- ASH PIT GLEANOUT PORT
  - D- STEEL GRATE
  - E- FIREBRICK LINER
  - F- TANGENTIAL INLET (2" PIPE) PRIMARY AIR
  - G- SAND SEAL
  - H- TANGENTIAL INLET (3/4" PIPE) SECONDARY AIR
  - I- AFTERBURNER SECTION
  - J- TANGENTIAL EXIT (3" GALV. DUCT)
  - K- TANGENTIAL INLET (2" PIPE) COOLING AIR
- TC- THERMOCOUPLE  
FM- FLOWMETER

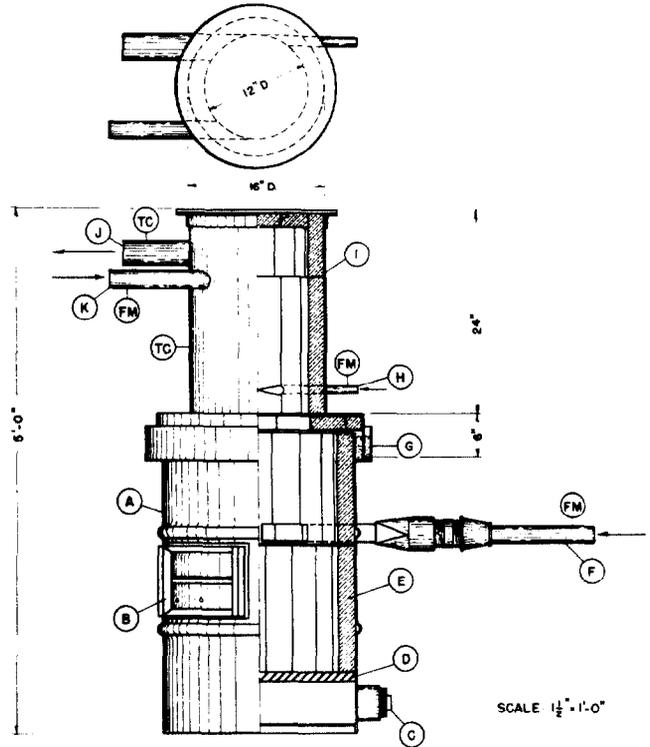


Fig. 4—Institutional type incinerator and gas cleaner for disposal of low level activity wastes, ACL-I.

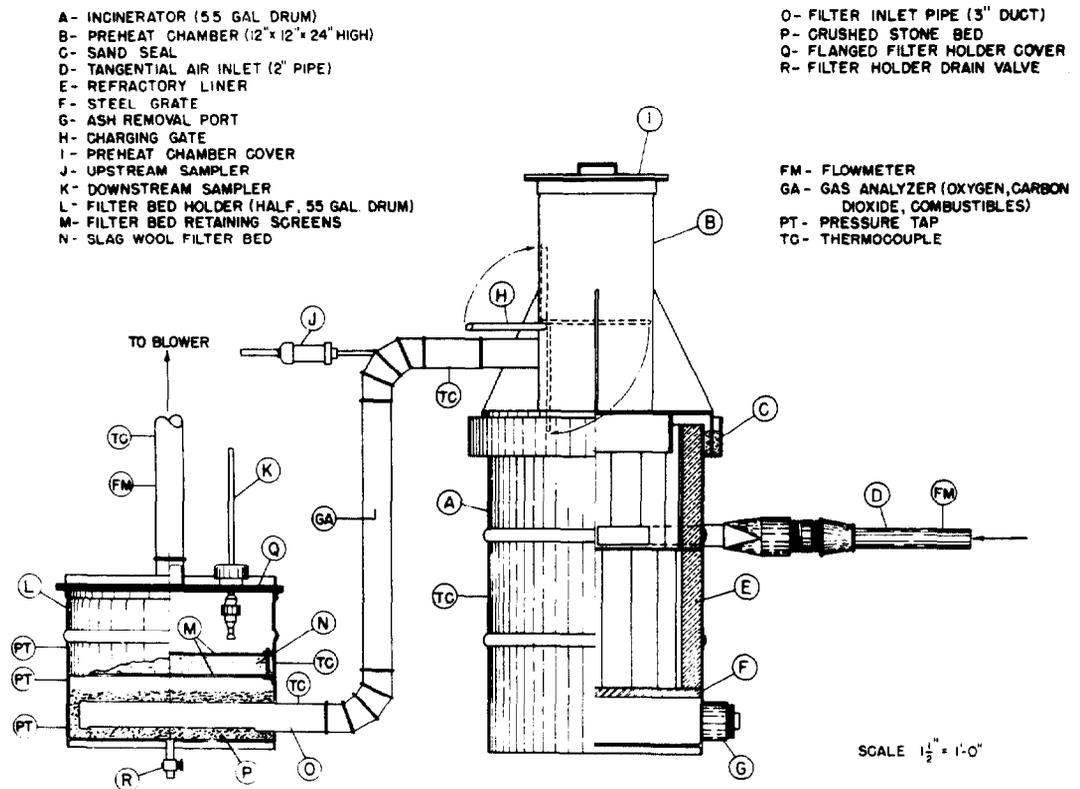


Fig. 5—Institutional type incinerator for disposal of low level activity wastes, ACL-II.

Overfire air entered the burning chamber tangentially whereas underfire air was admitted from below the grate area with no particular flow pattern. In both cases the air rates were adjusted to constant STP flow conditions. The volume of CO<sub>2</sub> and CO produced per pound of sawdust was obtained by graphical integration of the gas

TABLE 1

ACL-I INCINERATOR - TYPICAL COMBUSTION TESTS

Test No.	Supply Air cu.ft./min.		Flue Gas cu.ft./lb. of sawdust		Burning <sup>a</sup> Rate lbs./hr.	Stack Temperature Maximum °F
	Overfire	Underfire	CO <sub>2</sub>	CO		
1	50 <sup>b</sup>	0	14.8	2.6	15.0	1600
2	50	0	15.1	1.3	16.0	1450
3	10	30	12.3	1.1	13.6	1430
4	30	10	12.9	0.8	12.0	1260
5	30	0	-	0.4	9.5	1260
6	0	30	11.4	3.3	12.6	1380
7	0	50	12.7	1.9	15.0	1570

- a. 5 lb. dry sawdust charges in paper bags.
- b. Tangential inlet area = 4 sq. in. for Test 1, 2 sq. in. for Tests 1 through 7.

percentage versus time curve with respect to the instantaneous air flow rate and the amount of sawdust burned during the test period. The following relationships are indicated in Table 1.

- 1) The burning rate increased with total air flow (overfire plus underfire) from average values of 11 lbs. per hour at 30 cu.ft. per min. to 15 lbs. per hour at 50 cu.ft. per minute.
- 2) Burning rates also were generally higher for underfire air supply than for overfire air.
- 3) Average CO<sub>2</sub> production per lb. of sawdust was highest with overfire air supply.
- 4) The quantity of combustibles in the effluent gas were generally higher with underfire than with overfire air supply.
- 5) Stack temperatures were higher with underfire air supply.

In addition to the above items, it was noted that the unfiltered stack effluent was more smoky whenever underfire air was used. This condition was also observed during previous tests on the BOMAEC-30 incinerator.

#### D. Discussion

The selection of optimum operating conditions was based primarily on burning rate and combustion efficiency. On the basis of burning rate, no distinction could be made between 50 cu.ft. per min. overfire or underfire air flow. However, the volume of CO<sub>2</sub> produced, 15.1 and 12.7 cu.ft. per lb. of sawdust, respectively, indicated more complete combustion for overfire air supply. The amount of combustible gases in the effluent gas stream (reported as CO) did not furnish a reliable measure of combustion efficiency, unless correlated with other system characteristics. For example, in all tests made with underfire air supply, combustible gas concentrations noted during the first 10 minutes of operation were significantly higher than those determined for overfire air tests. Simultaneously, stack samples and visual observations of the incinerator effluent indicated much heavier smoke formation. It appeared that rapid distillation of resins and oils resulted in partial combustion only so that the percentage converted to low molecular weight volatiles, organics, or CO was lower than that detected for overfire burning. Although distillation also occurred in the latter case, the skimming action of the rotating air stream tended to produce more uniform burning of the cellulose and tar components of the sawdust.

A comparison of Tests 1 and 6 indicates that the relative CO emission was about the same. However, the CO<sub>2</sub> production with 30 cu.ft. per min. underfire air was much lower, 11.4 vs. 15.1 cu.ft. per lb., and the presence of soot and tars in the stack effluent very pronounced. The CO discharge in this case was not due to partial combustion of tar products so much as to the low oxygen levels in the burning zone.

We did not consider it worthwhile to attempt further correlation of the data in Table 1 since there were some variables which could not be controlled. Although burning rates were fairly uniform for the first 15 to 20 minutes of identical tests, erratic combustion was noted during the final phase, depending upon the position and degree of spread of the charge on the grate. Occasionally some sawdust fell into the ash pit and continued to burn at a slow rate. This extended the apparent burning period when CO<sub>2</sub> and O<sub>2</sub> concentrations were used as a measure of operating time.

There were also variations in sawdust composition even though the same grade was specified for all tests. However, based upon these data and visual observation of the stack effluent we concluded that use of 50 cu.ft. per min. overfire air would provide adequate burning capacity and highest stack temperatures without excessive smoke production.

When the area of the tangential overfire air inlet was reduced from 4 to 2 sq. in. a reduction in soot formation was observed, Test 2. Although CO<sub>2</sub> production appeared slightly higher, the total volume of combustion gases were not altered appreciably. Burning rate, however, was slightly higher and the CO concentrations were lower than those in Test 1 with a 4 in. sq. inlet and uniform throughout the burning period.

#### E. Slag Wool Filter Rating

It was intended to operate the incinerator at 50 cu.ft. per min. overfire air flow while burning several sawdust charges so that the filter life of the slag wool filter could be estimated under typical burning conditions. However, since there was not adequate fan capacity for this procedure, air flow rates were reduced to 30 cu.ft. per min. overfire. The only previous objection to the

above flow rate was that the burning rates were considerably lower, about 9.5 lbs. per hour. Double charging, 10 lbs. instead of the previous 5 lb. package, increased the burning rate to nearly 22 lbs. per hour. The average of several stack sampling tests indicated that total particulate loadings in the incinerator effluent were about 0.15 grains per cu.ft. Half of the collected material dissolved in acetone indicating the presence of condensed tar products. Previous tests on the BOMAEC-30 unit showed incinerator stack loadings ranging from 0.02 to 2 grains per cu.ft. and averaging 0.25 grains per cu.ft.

At the start of the loading tests the filter resistance was approximately 0.5 in. water. After burning 150 lbs. of sawdust resistance rose to 0.66 in. water but showed very little increase during the subsequent combustion of 750 lbs. (Final resistance, 0.7 in. water). According to downstream sampling measurements the slag wool media varied from 90 to 98 per cent efficient on a weight basis. It appeared that the material collected on the downstream sampling filter was primarily condensation products which had passed through the filter in vapor form. Upon firing these filters (all glass media) negligible amounts of mineral ash remained. Examination of the slag wool filter showed evidence of edge leakage which probably contributed to the passage of some carbon particles. Our present opinion is that the mineral wool fibers, although constituting an effective filter, should be prepared as a bonded preformed bed to improve sealing characteristics. Furthermore, it appeared that a thinner filter with a lower packing density than that used with the current unit (2 in. depth, 6 lbs. per cu.ft.) would furnish satisfactory cleaning. When this filter was removed from its holder it was found that actual dust and soot penetration was confined to a very thin layer, 1/2 to 1/4 inch.

#### F. Charging Device

Although better combustion and proportionately greater burning rates were realized with the ACL I incinerator than those attained with the BOMAEC-30 and Incinor units, the overhead predrying and charging system presented operational problems. Dumping of the bagged sawdust charges into the burning chamber occasionally extinguished the flame. Since residual chamber heat was sufficient to distill volatile materials, re-ignition at times produced minor explosions. A second difficulty was the premature ignition of charges stored in the predrying chamber. Although we believe that the above charging system could have been made operable, it appeared that the necessary modifications would lead to additional cost and complexity. Therefore, the overhead charging technique was discarded in lieu of a simple charge door located on the side of the cylindrical burning chamber. Our previous objection to the latter method of charging was based upon the expected interference with the vortical gas flow pattern within the burning chamber. However, in the design discussed in the following section, minimal disturbance with flow pattern was attained by careful control of air leakage through the door.

### ACL II Incinerator

#### A. Description

Our second incinerator design, Figure 5, incorporated the same burning chamber used in the ACL I model. A side charging door, 13 in. x 8 in. was located 6 in. above the grate and lined with firebrick so that the inner cylindrical contouring was maintained. "Thermoflex"\* gasketing reduced stray air leakage to sufficiently

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\* Johns-Manville, New York 16, N.Y.

low levels, <10 per cent primary air flow, such that the spiral gas pattern was not altered significantly.

A two pronged sliding fork was inserted in the door, Figure 6, so that wet charges (up to 50 per cent moisture) could be supported along the wall of the combustion chamber. By means of this device, wet material exposed to high radiant temperatures and hot swirling gases was dried in less than one minute provided that the incinerator was heated to operating temperature. When the fork was withdrawn the dried charge fell to the grate and burned completely. This drying method did not disturb the already existing fire in the burning chamber and eliminated the need for auxiliary preheating facilities. Removal of the overhead charging unit allowed space for an afterburning section which we believed would afford some advantage over the single burning chamber. A cylindrical, brick-lined chamber, 20 in. high and 11 in. inside diameter, was mounted directly above the burning chamber. Entry to the afterburner from the burning

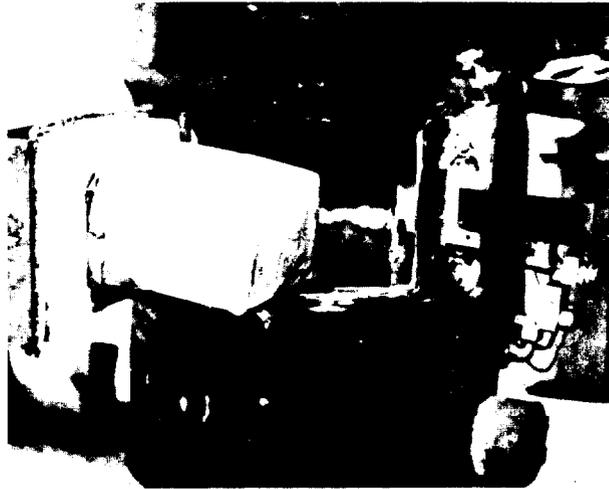


Fig. 6—ACL Incinerator II, charging door open with charge in drying position.

chamber was made through a short brick-lined conical section. A tangential inlet was provided at the base of the afterburner so that auxiliary combustion air or gas could be admitted. A tangential exit was placed at the top of the afterburner so that the spiral gas flow pattern could be maintained in the system. Since exit gas temperatures were in the range of 2000°F, it was necessary to use either special heat resistant ducting or to provide some means of gas cooling. We choose the latter method and installed an extra air inlet pipe at the top section of the afterburner. Under present operating conditions dilution air, about 50 cu.ft. per min., enters tangentially and mixes within the afterburner to produce an effluent which can be handled with ordinary ventilation piping.

Valves were provided for all air inlets so that optimum flow rates could be determined experimentally. Although facilities were available for admission of auxiliary gas to burn materials not oxidized in the combustion chamber itself we preferred to avoid this system in view of the cost and potential hazards. Since the temperatures in both combustion and afterburning chambers were greater than 2000°F it was postulated that a secondary air supply to the zone of oxygen depletion (<2 per cent by volume during the initial distillation phase of sawdust tests) would be a simple and practical method of soot and tar reduction.

## B. Combustion Characteristics

Preliminary combustion tests on the ACL II incinerator were similar to those made on the ACL I unit. Over-all performance was estimated in terms of the volume of CO<sub>2</sub> produced per pound of charge, the volume of combustible gases reported as CO, the burning rate, and average stack temperature.

Two standard charges were used, the first consisting of 3.5 lb. packages of sawdust and the second a mixture of 2.3 lbs. of sawdust and 1.2 lbs. of shredded cabbage. The 7 lb. (double charge) listed in Table 2 consisted of two of the above 3.5 lb. bags.

TABLE 2  
ACL-II INCINERATOR - TYPICAL COMBUSTION TESTS

Test No.	Type of Charge <sup>a</sup>	Flue Gas		Burning Rate lbs./hr.	Stack Temperature °F		
		cu.ft./lb. of Sawdust CO <sub>2</sub>	CO		Maximum	Minimum	Mean
A. Primary Air Flow - 48 cu.ft./min. STP, No Dilution (Cooling) Air							
1	S, 3.5 lbs.	12.2	1.0	21.1	1790	1250	1500
2 <sup>b</sup>	S, 2.3 lbs. C, 1.2 lbs.	14.3	0.6	17.6	1350	770	1130
3	S, 7.0 lbs.	11.5	1.8	21.1	2010	1250	1590
4 <sup>b</sup>	S, 7.0 lbs.	9.5	0.7	21.2	2110	1340	1730
B. Primary Air Flow - 48 cu.ft./min. STP, Dilution Air - 50 cu.ft./min.							
5	S, 3.5 lbs.	14.9	0.3	19.3	1600	960	1260
6	S, 2.3 lbs. C, 1.2 lbs.	11.5	0.7	19.7	1000	780	870
7 <sup>c</sup>	S, 2.3 lbs. C, 1.2 lbs.	15.8	1.1	17.6	1130	790	950
8	S, 7.0 lbs.	13.3	1.2	21.3	1710	910	1270
9 <sup>b</sup>	S, 7.0 lbs.	13.7	<0.1	20.1	1720	910	1280
10 <sup>b</sup>	S, 4.6 lbs. C, 2.3 lbs.	17.1	0.6	21.2	1210	890	1040

a. S = Dry sawdust (<10 per cent moisture); C = Shredded cabbage.

b. Secondary (auxiliary) air admitted - 10 cu.ft./min. STP

c. Auxiliary gas firing.

The major variables investigated with the ACL II incinerator were the size and type of charge, the quantity and point of admission of primary and secondary combustion air, and the amount of the cooling air.

1. Size of charge. Comparison of several tests in Parts A and B of Table 2 indicated that the amount of charge placed on the grate had very little effect on the burning rate (Tests 1,3,5,8). This conformed to previous studies which showed that the volume of overfire air appeared to be the controlling factor in combustion rate for a constant inlet velocity. These results were not surprising since, with tangentially admitted air, the major burning occurs in the peripheral zone of the grate. With typical loading procedures the main part of the charge is centered on the grate such that burning is initiated at the outer edge.

A noticeable effect of increased charge was the greater amount of combustible gases (reported as carbon monoxide) in the effluent gas stream. Generally, the appearance of filter samples collected in the stack correlated with combustible gas concentrations, i.e. a distinguishable soot deposit with increased combustible gases. When double sawdust charges were placed on the grate there was sufficient heat in the chamber to distill most of the volatile fraction of the charge. However, with a constant air supply, the oxygen demand of the increased volatile loading was exceeded which caused less efficient combustion.

Measurement of carbon dioxide concentrations in the effluent gas were consistent with carbon monoxide results for Test pairs 1-3 and 5-8, i.e. less CO<sub>2</sub> with more CO. However, some data with respect to CO<sub>2</sub> values were inconsistent with other test observations, i.e. Test 4, wherein burning rate, stack temperature, and CO emission showed generally improved combustion.

Mean stack temperatures appeared to increase slightly with double charges which should have indicated increased burning rate. However, mean values were based upon operating time and did not reflect changes in supply air volume with temperature variation. In Test 3, for example, the double charge produced higher peak temperatures during the distillation phase of the combustion. As a result the supply air volume was somewhat lower than that reported for a single charge, Test 1. Therefore for identical combustion rates of 21.1 lbs. per hour in Tests 1 and 3, one would expect to find a higher stack temperature in the system having the lower total gas flow.

2. Type of charge. Burning rates of mixed charges of sawdust and shredded cabbage (about 50 per cent moisture on a dry basis) were slightly lower than those for sawdust under most conditions, Tests 2, 6 and 7. Since the burning rate was based upon total charge the amount of dry sawdust burned was actually about 40 per cent less in these tests. Combustion products, which were based on sawdust weight only, were essentially the same as those for sawdust alone. Since the sawdust burning rate was much lower and the air volumes were unchanged, the stack gas temperatures were correspondingly lower for these wet charges. Lowered values did not reflect poor combustion. When secondary combustion air and dilution air were admitted to the afterburner (Test 10) the combustion efficiency for wet charges appeared higher than for dry sawdust based upon CO<sub>2</sub> emission. We think that the presence of moisture retarded the volatilization of tar products thus affording a better chance for more uniform burning.

3. Air supply.

a. Auxiliary (secondary) air. Admission of secondary (auxiliary) air at the base of the afterburner reduced soot formation in the stack and resulted in lower carbon monoxide emission, Tests 3, 4-8, 9. Although no significant change in burning rate was attained, higher gas temperatures were observed in the stack. These data

indicated that the introduction of secondary air to a zone of depleted oxygen supply was a definite adjunct to better combustion. Since the gas temperature exceeded 2000°F in the afterburner there was no chance for the auxiliary air to dilute and cool the main gas flow to temperatures below the ignition point of partially burned combustibles.

b. Cooling air. The chief reason for admitting cooling air at the top of the afterburner was to cool the effluent gas to temperatures within the practical operating range of mild steel piping. It was also presumed that with a tangential entry the vortical gas flow pattern within the afterburner would be accentuated. This would result in less entrainment of gross particles and increased gas retention time. According to our tests however, cooling (dilution) air improved incinerator operation assuming that a reduced CO emission indicated better combustion (Part B, Table 2). This could be attributed to two factors: a) the cooling air acted in part as a secondary air supply, and b) the increased vorticity within the afterburner extended down to the main combustion chamber. In the latter case, changes in the gas flow pattern and the ensuing turbulence might have improved burning in this region. Comparison of the following test pairs in Table 1 (1-5, 3-8 and 4-9) shows better combustion when cooling air was employed.

4. Gas temperatures. We have pointed out certain limitations in the use of gas temperature alone as a measure of combustion efficiency. The range between maximum and minimum temperature was largest when distillable components of the charge were readily volatilized. For example, although average burning rates were similar in Tests 1 and 3, the effect of double charging was to release volatiles at a higher rate during the first part of the burning. Thus, temperature ranges (maximum to minimum) were about 550 and 750F°, respectively, for Tests 1 and 3.

Mean temperatures, unless correlated with instantaneous gas flow rate did not necessarily reflect the total heat output (which was related directly to combustion efficiency). Since our fan speed was not changed during a combustion test the air supply rate decreased to a minimum at maximum temperature and gradually approached the initial values as the run progressed. Therefore, in comparing Tests 1 and 3, and 5 and 8 (and the slightly higher mean temperature values reported for Tests 3 and 8) one must take into account that total gas volumes were lower in the latter case.

However, the temperature increases noted for Test pairs 3-4 and 8-9, appeared to be associated with a real improvement in combustion efficiency since with Tests 4 and 9, addition of secondary air led to increased gas volumes. Similarly the rather low mean temperatures shown for wet charges were caused by the decreased heating value of the charge (about 66 per cent of that for the dry sawdust charge) and not by poor combustion. In addition, during wet tests a significant fraction of the heating values were utilized in evaporating the moisture load.

It was found that the mean stack temperatures reported in Part A, Table 2, were in reasonable agreement with predicted values (based upon a heating value of 7000 BTU per lb. for sawdust). However, it was noted that the indicated stack temperatures were actually higher than predicted values for most tests wherein cooling air was used. We believe that this inconsistency was caused partly by radiation to the stack thermocouple from the afterburner section. This effect was much more pronounced when cooling air was added. It was also possible that gas mixing was not complete such that the thermocouple did not record true average temperature in the duct cross-section.

### C. Gas Cleaning

Our tests indicated that the slag wool filter employed in previous studies did not provide adequate filtration area when cooling air was added to the system. Pressure loss rose to prohibitive values after the combustion of relatively little sawdust <500 lbs. Examination of the slag wool media showed a sooty surface coating to be responsible for the high resistance. Actually, the plugging was restricted to less than 1/4 in. of the 2 in. filter depth. We think that the only possible way to make dry cleaning feasible is to employ increased filtering area with a gradation in fiber diameter. A "basket" type filter having more than 8 sq. ft. of filtering surface is now under construction, Figure 7. In order to eliminate leak problems associated with hand-packed bulk fiber



Fig. 7—ACL Incinerator II, filter unit.

we intend to experiment with two fiber sizes of bonded glass fiber, FG-25 (2 to 5 microns) and Type G Airmat (10 to 20 microns).

### D. Discussion

Comparison of average burning conditions for the various incinerators tested by this laboratory, Table 3, indicates that the latest model, ACL II, provides the best combustion in terms of flue gas composition and stack temperature. The burning capacity of the ACL II was proportionately greater than that of any previous unit tested on the basis of effective burning rate. Aside from the above improvements, the ACL II model was the only device that could be used to incinerate wet charges without using auxiliary gas firing. This was impossible to accomplish with the BOMAEC-30 unit. Furthermore, by resorting to a simple side charge door and a loading fork, waste materials could be introduced wet or dry without disrupting the combustion process. The actual time required to open the incinerator door and place a charge on the loading fork amounted to less than 5 seconds. During the open period air motion through the door may be insufficient to prevent occasional release of gas to the loading zone. Therefore, auxiliary hooding should be provided to protect personnel involved in charging operations.

Our test data appeared to show a significant improvement in the quality of the stack effluent as a result of using secondary air and cooling air. However, increased air volumes present a problem in restricting dry filtering units to a practical size. There is no simple way of reducing gas temperatures to levels that will not damage filter media other than dilution cooling since the use of water sprays or wet scrubbers are not considered acceptable for the present system. For typical applications in hospital or research laboratories, it is unlikely that facilities will be available for liquid radioactive waste disposal. Although some gas cooling may be achieved through the use of extended surface heat exchangers (fins, coils, etc.) we believe that complete cooling by the above methods would be too expensive.

TABLE 3  
COMPARISON OF BURNING CONDITIONS IN VARIOUS INCINERATORS

	Lbs. Sawdust per chg.	Burning Rate lb./hr.	Volume CO <sub>2</sub> cu.ft./lb. chg.	Max. Stack Temperature °F
BOMAEC-30	25	45-60 <sup>a</sup>	9.09	1455
Inciner	5	20-25	-	1832
ACL Incinerator I	5-10	14-22	10-13.6	1256-1800
ACL Incinerator II	3.5-7	17-26.5	9.5-17.1	1000-2112

a. Effective burning rate approximately 30 lbs./hr. allowing for charging time.

#### E. Future Plans

The major problem at present is to develop an efficient and economical filter unit to clean the incinerator effluent. Tests are scheduled to evaluate FG-25 and Type G Airmat media under typical burning conditions to determine filter life characteristics. A major requirement in collector design is that fabrication cost be low since the entire unit including housing will be disposed of once the rated resistance has been exceeded. In view of this fact it appears that special temperature resistant fibers, i.e. aluminum oxide, would be excluded.

### Conclusions

#### A. BOMAEC-30 Incinerator

1. Our tests on the BOMAEC-30 incinerator indicated that several design changes would be necessary before this unit could be used successfully in the field. These included the following:

- a) Provision for continuous charging and burning of wet materials.
- b) Installation of secondary burning chamber.
- c) Use of ceramic liners to maintain high temperatures and minimize warping of metal surfaces.

- d) Construction features which would minimize stray air leakage.
- e) Development of a gas cleaning system that would collect particulate materials at reasonable resistance and have a useful service life under high temperature operation.

2. It was not practical to reconstruct the BOMAEC-30 unit in order to incorporate design changes indicated above.

#### B. ACL II Incinerator

1. An experimental incinerator, ACL II, designed by this laboratory and including the tangential overfire air supply system of the BOMAEC-30 unit, appears to overcome many of the disadvantages of the BOMAEC device.

2. A charging door on the side of the burning chamber permitted continuous loading of the incinerator so that high combustion temperatures could be maintained.

3. A sliding loading fork inserted through the door provided support for packaged wet materials. Waste containing up to 50 per cent moisture dried rapidly in the chamber and did not delay the combustion process.

4. A firebrick lining within the combustion chamber permitted temperatures greater than 2000°F which improved the combustion process.

5. A cylindrical afterburner mounted vertically above the burning chamber reduced the amount of tar products in the effluent when secondary air was admitted tangentially at the base of this section.

6. Use of a sand seal rather than a bolted flange reduced air leakage to negligible quantities at the connection between the main burning chamber and the afterburner.

7. Admission of dilution air at the top of the afterburner appeared to reduce tar concentrations in the effluent as well as affording a partial precooling facility for the effluent gas.

8. Combustible particulate loadings in the incinerator effluent were lower than those obtained with the BOMAEC-30 unit and comparable to those reported for two chamber municipal type incinerators.

9. A gas cleaning device consisting of a basket type filter containing bulk or preformed graded mineral or glass fibers appeared to be the most practical method of cleaning the effluent gas provided that inlet gas temperature did not exceed 750°F.

10. Absolute filtration of the effluent will be an expensive operation since cooling and reheat facilities must be provided to remove moisture and condensed tar products. Ordinarily these substances will pass through mineral fiber filters in the gaseous phase and cause no filter plugging.

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