# DIFFUSION BOARD CONTAINMENT CONCEPTS AND FOAM ENCAPSULATION STUDIES - A PROGRESS REPORT

L. Silverman, M. Corn, and F. Stein
Harvard School of Public Health

## ABSTRACT

This study presents preliminary results of progress on the development of two novel approaches to treatment of gases and particulates released from reactors or nuclear processes within containment or confinement structures.

Progress is reported on a diffusion board which will serve as a porous filtration and adsorption membrane for released particulates and halogens. This board must resist steam, pressure and shock as well.

Development of foam encapsulation of gases and particulates for use inside containment vessels is also described. Reductions of concentrations of released contaminants by factors of 10 or more were obtained with 0.074u and greater size aerosols. This reduction was also obtained with iodine vapor.

## INTRODUCTION

The purpose of this presentation is to describe two basic studies in progress at the Harvard Air Cleaning Laboratory which relate to the economic control of air contamination by both radioactive gases and particulates. Many reactor and chemical process plant designers have expressed the opinion that the cost of reactor containment and off-gas cleaning are high in relation to other types of power generation and chemical processing. Since the cost of containment and off-gas treatment may range from 5 to 15% of the total plant cost and in a few limited cases even higher, our research efforts have been directed toward less costly approaches without sacrificing equivalent safety and performance.

In the first project identified as the diffusion board concept the containment structure is a porous structure constructed of fibrous or filamentous media serving as both a gas and particulate removal surface. This approach follows the diffusion board concept considered for shelters

designed to protect occupants from toxic chemical warfare gases or smokes.

In the reactor accident or release confinement, it would be operating in reverse protecting the public from the possible consequences of an internal release which escapes into the containment or confinement zone.

The second study relates to a protective device which could be placed inside a containment or confinement structure. This device would generate high expansion foam which could be triggered to rapidly fill the vessel. This foam would then encapsulate air borne particulates and also react with halogen gases.

The two approaches reported in this paper are treated separately, and a brief discussion of each follows.

A. Diffusion Board Containment Concept

In this concept the ideal diffusion board is a cell-like structure which has the capability of resisting pressures encountered in postulated reactor accidents or releases. Since the commonest reactor accident postulated for a water reactor and some gas cooled reactors is the loss of coolant, the structure must resist the inherent steam pressure developed by its sudden release and any shock wave that might be created. It is our concept that a diffusion structure could be made strong enough to resist both forces. It could also act as an air cleaner and still not be as expensive as the present unfired pressure vessels made of steel plate. Such a structure would be able to function for both water and gas cooled reactors and could handle many types of releases including the most severe accident postulated.

As basic criteria for such a diffusion board structure we include the following essential items:

(The diffusion board should have the following properties.)

1. Be non-combustible and unaffected by normal atmospheres as to to deterioration and corrosion.

2. Mechanically resist steam pressures as high as 100 psi and temperatures to 250°F.

3. Resist shock waves with over-pressures not exceeding 3 inches of mercury.

4. Resist prolonged (several hours) of water vapor exposure and radiation (gamma).

5. Remove radioactive halogen gases with 99.9% efficiency.

6. Remove 0.3u and larger particulates with 99.9% efficiency.

7. Adsorb rare gases to a maximum extent if possible, but at least be completely permeable to them and air and water vapor.

8. Resistance characteristics should be such that diffusional velocities can readily take place at resistances below 6 inches of water.

9. Be inexpensive enough to show substantial reduction in costs of materials and labor for a reactor housing, or for an off-gas cleaning unit.

One material which meets the last 4 requirements is the carbon impregnated diffusion board presently under development by the U. S. Army Chemical Corps as a shelter structure material. Unfortunately this is a cellulosic wood fiber material impregnated with carbon. It will not resist thermal destruction and serious deterioration with steam. It could probably withstand the structural loads desired but may not meet the shock wave criterion.

We evaluated this material for its iodine removal and fine particle penetration with the excellent results shown in Tables 1 and 2. Particulate and iodine performance easily meet our initial criteria, showing results well over 99.9% for 0.2u particles and slightly less than this value for 0.05u Iodine -127 removal are also excellent as is the total capacity in terms of iodine reaction availability. I-127 performance may be compared with I-131.

After evaluating the CC diffusion board, we selected a fine porous carbon material for study. It was a 1/4 inch porous graphite aerator diffuser plate. Results obtained with this material are shown in Tables 3 and 4. Particulate removal and iodine efficiency while approaching 90% are not acceptable even at very low velocities. Good iodine removal was obtained for short periods. Since the resistance values are quite low, it is likely that much thicker sections would give acceptable results. This material, however, would be more costly than others and still may not meet the specified structural and non-combustible requirements.

Our laboratory spent considerable effort trying to develop a board constructed from slag on glass fibers, and combinations of these. This board also involves the use of silver surfaced silica gel porous glass, or silver plated copper turnings dispersed throughout the fibrous glass media as an iodine reactant. Further media developments are now under consideration with paper and fiber board manufacturers.

One promising approach we have under study is the fabrication of a diffusion board from honeycomb material, as shown in Figure 1. Honeycomb materials can be metal (aluminum or stainless steel) or plastic and the

## TABLE 1

## DIFFUSION BOARD STUDIES

Summary of CC Diffusion Board Efficiency Tests

A. Dautrebande $D_{30}16$ Tests - 0.1% Uranine
Mg = 0.05 u
$\sigma g$ = 3.5

| Run No. | Face Velocity fpm | Resistance Inches | Penetration % | Efficiency % |
|---|---|---|---|---|
| 1 | 0.1 | 0.72 "$H_2O$ | 4.47 | ? |
| 2 | 0.1 | 0.72 "$H_2O$ | 0.39 | 99.61 |
| 3 | 0.1 | 0.72 "$H_2O$ | 0.37 | 99.63 |
| 4 | 0.1 | 0.72 "$H_2O$ | 0.36 | 99.64 |
| 5 | 1.0 | 0.52 "Hg | 0.22 | 99.78 |
| 6 | 1.0 | 0.52 "Hg | 0.13 | 99.87 |
| 7 | 1.0 | 0.52 "Hg | 0.18 | 99.82 |
| 8 | 5.0 | 2.90 "Hg | 0.037 | 99.963 |
| 9 | 5.0 | 2.90 "Hg | 0.055 | 99.945 |
| 10 | 5.0 | 2.90 "Hg | 0.040 | 99.960 |

B. Peni-sol Generator + 2.G.S. Impingers - 2.35% Uranine
Mg = 0.2 u
$\sigma g$ = 2.4

| | | | | |
|---|---|---|---|---|
| 1 | 0.1 | 0.72 "$H_2O$ | 0.0027 | 99.9973 |
| 2 | 0.1 | 0.72 "$H_2O$ | 0.0025 | 99.9975 |
| 3 | 1.0 | 0.52 "Hg | 0.0018 | 99.9982 |
| 4 | 1.0 | 0.52 "Hg | 0.0020 | 99.9980 |
| 5 | 5.0 | 2.90 "Hg | 0.0011 | 99.9989 |
| 6 | 5.0 | 2.90 "Hg | 0.0011 | 99.9989 |

## TABLE 2

## DIFFUSION BOARD STUDIES

Summary of CC Diffusion Board Tests Using $I^{127}$

| Run No. | Face Velocity fpm | Resistance Inches | Penetration % | Efficiency % | Remarks |
|---|---|---|---|---|---|
| 1 | 0.1 | 0.68 "$H_2O$ | 0.31 | 99.69+ | 15 min. test ) $I_2$ was below |
| 2 | 0.1 | 0.68 "$H_2O$ | 0.13 | 99.87+ | 30 min. test ) detection thres- |
| 3 | 0.1 | 0.68 "$H_2O$ | 0.043 | 99.96+ | 60 min. test ) hold |
| 4 | 1.0 | 0.5 "Hg | 0.053 | 99.95+ | ) No $I_2$ detected downstream |
| 5 | 1.0 | 0.5 "Hg | 0.052 | 99.95+ | ) |
| 6 | 5.0 | 2.85"Hg | 0.081 | 99.92 | ) Total $I_2$ = 228.25 mg for |
| 7 | 5.0 | 2.85"Hg | 0.142 | 99.86 | ) 15.9 sq. inches Diff. board is |
| 8 | 5.0 | 2.85"Hg | 1.15 | 98.85 | ) getting saturated with $I_2$ |

## TABLE 3

## DIFFUSION BOARD STUDIES

Summary of Carbon Disc Tests

A. Using 2.3% Uranine in Pen-i-Sol Generator + 2 G.S. Impingers

$Mg = 0.2$
$\sigma g = 2$

| Run No. | Face Velocity fpm | Resistance in inches of water | Penetration % | Efficiency % | Remarks |
|---|---|---|---|---|---|
| 1 | 0.1 | 0.012 | 10.4 | 89.6 | |
| 2 | 0.1 | 0.012 | 6.5 | 93.5 | |
| 3 | 0.1 | 0.012 | 7.8 | 92.2 | |
| 4 | 1.0 | 0.112 | 42.7 | 57.3 | |
| 5 | 1.0 | 0.112 | 41.8 | 58.2 | |
| 6 | 1.0 | 0.112 | 41.3 | 58.7 | |
| 7 | 5.0 | 0.560 | 54.8 | 45.2 | |
| 8 | 5.0 | 0.680 | 40.4 | 59.6) | $\Delta p$ is increasing |
| 9 | 5.0 | 0.880 | 26.9 | 73.1) | |
| 10 | 5.0 | 0.92 | 22.0 | 78.0) | Plugging |

B. Using 0.1% Uranine in Dautrebande Generator

$Mg = 0.05$
$\sigma g = 3.5$

| Run No. | Face Velocity fpm | Penetration % | Efficiency % | Remarks |
|---|---|---|---|---|
| 1 | 0.1 | 5.25 | 94.75 | Collection mainly by diffusion |
| 2 | 0.1 | 4.02 | 95.98 | |
| 3 | 0.1 | 3.74 | 96.26 | $\text{Eff.} \simeq \left.\frac{1}{V}\right]_{0.1}^{1.0}$ |
| 4 | 1.0 | 33.9 | 66.1 | |
| 5 | 1.0 | 33.4 | 66.6 | |
| 6 | 5.0 | 37.3 | 62.7 | |
| 7 | 5.0 | 37.5 | 62.5 | |

## TABLE 4

## DIFFUSION BOARD STUDIES

Summary of $I^{127}$ Tests Using Carbon Disc

| Run No. | Face Velocity fpm | Resistance Inches of water | Penetration % | Efficiency % | Remarks |
|---|---|---|---|---|---|
| 1 | 0.1 | 0.012 | 0.136 | 99.86 | No $I_2$ detected downstream |
| 2 | 0.1 | 0.012 | 1.77 | 98.23 | |
| 3 | 0.1 | 0.012 | 1.23 | 98.77 | Total $I_2$ loading $\simeq$ 9.25 mg |
| 4 | 1.0 | 0.11 | 59.9 | 40.10 | Saturation with $I_2$ because Penetration should be 10 x 1.23 $\simeq$ 12.3% if collection by diffusion |

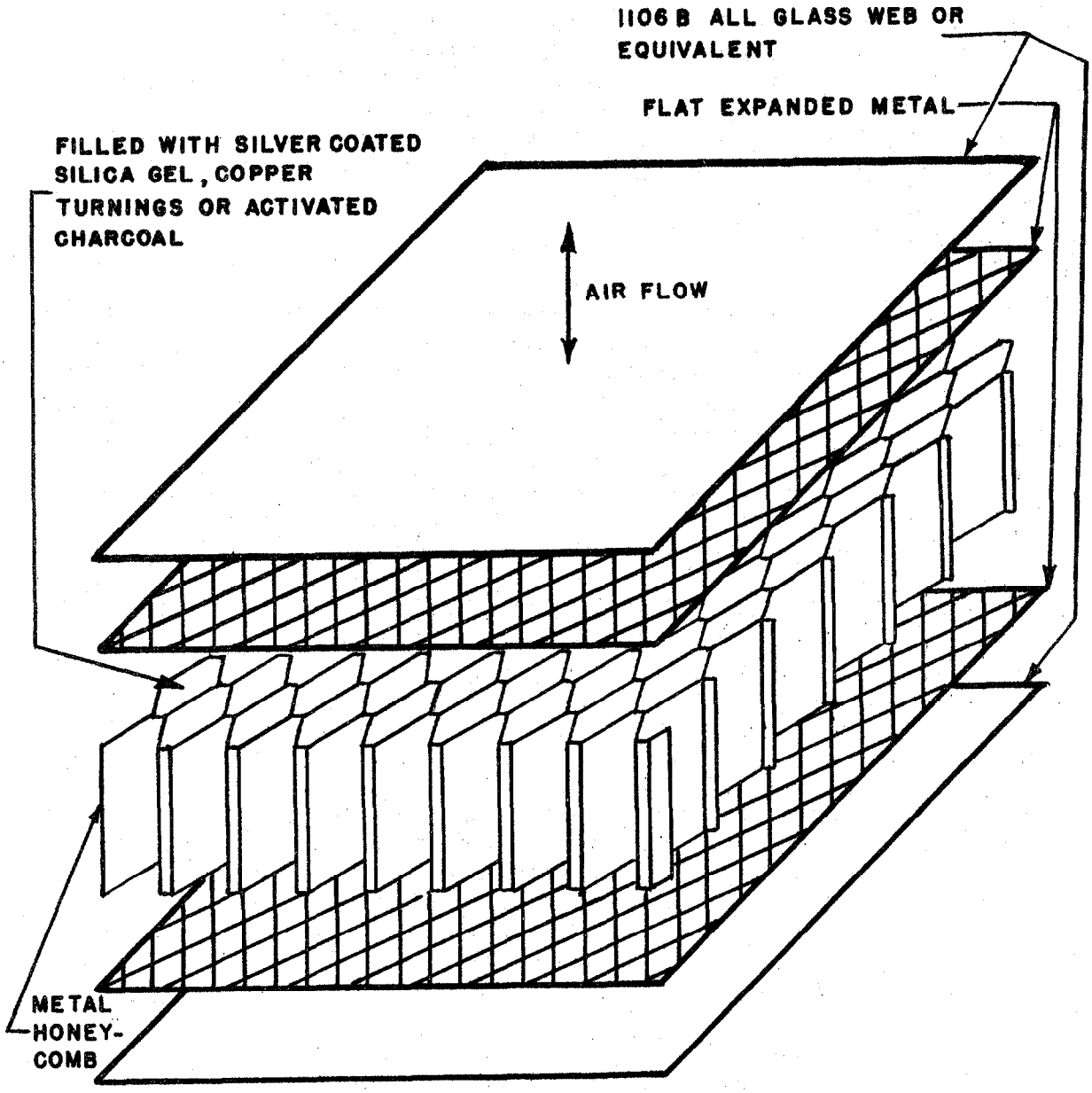

1106 B ALL GLASS WEB OR EQUIVALENT
FLAT EXPANDED METAL
FILLED WITH SILVER COATED SILICA GEL, COPPER TURNINGS OR ACTIVATED CHARCOAL
AIR FLOW
METAL HONEY-COMB

FIGURE I

honeycomb walls can be silver surfaced. The pores of the honeycomb can also be filled with a solid non-combustible adsorbent such as silver plated silica gel or copper turnings. The face sheets would be perforated, possibly corrugated, to obtain additional area and strength and have glass fiber media attached to the inside surface. Such a board is now being fabricated for tests at Harvard. We believe designed performance can be achieved close to predicted values.

B. Foam Encapsulation Studies

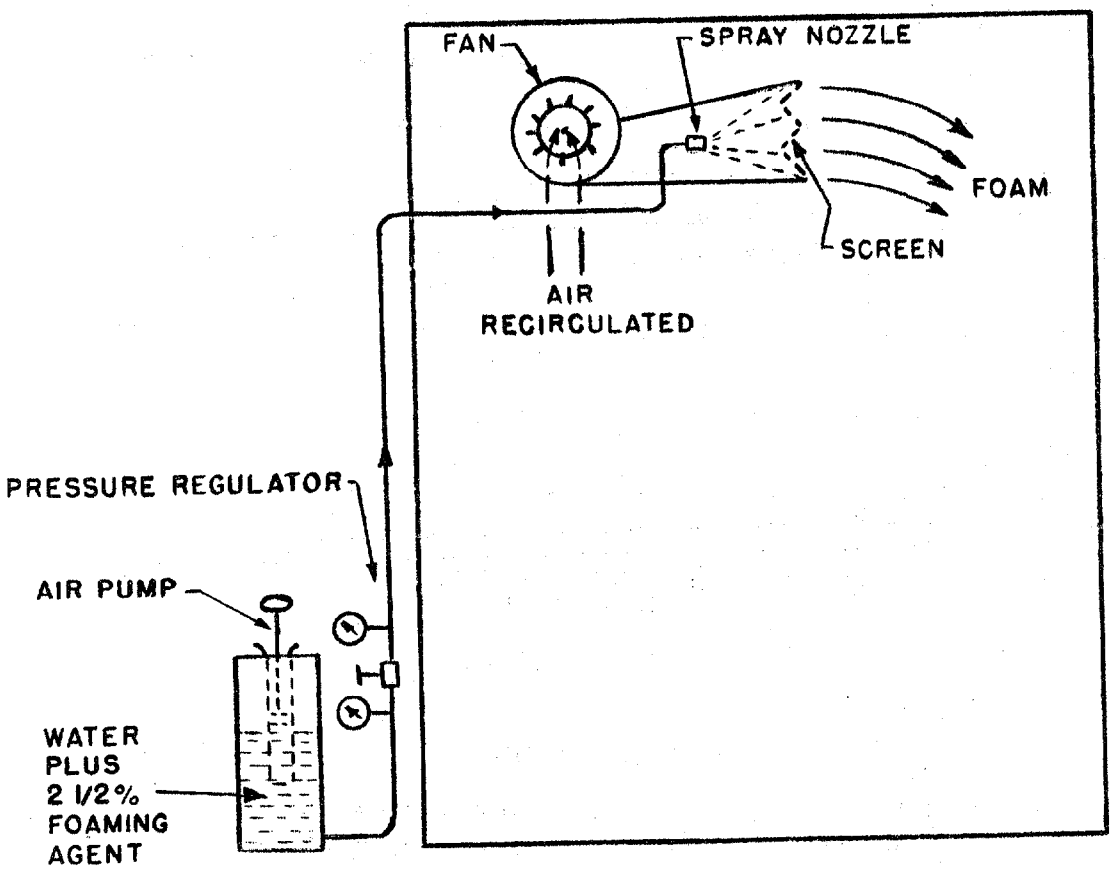
The foam encapsulation concept involves two possible applications. In one case this device will serve as a safety system which would be used to encapsulate halogens and particulates if a reactor accident should take place inside an existing containment shell. This entrappment will prevent the anticipated leakage of containment shells from occurring. It therefore could effectively reduce losses to the environment especially if the containment should be breached. In this concept, aqueous or in certain cases, plastic or rigid foams could be employed. They can be applied to the cases of rare gas removal as well as high concentrations of halogens which are in small gas volumes such as obtained directly or from stripped adsorbents or freezing traps. We conceive of using plastic or rigid foams (foamed concrete or plastics) as a means of producing capture and storage of rare gases for indefinite periods if necessary.

Studies have already been conducted (in a 43 cubic foot static chamber, see Figure 2) with 0.2 and 0.07 micron uranine aerosols, with iodine-127 and the hologen in combination with an aerosol. These results were obtained using a very high expansion foam (1000 to 1) producing device. The results of these particulate studies are shown in Figure 3. In the case of 0.2 and 0.07 u aerosols the decay rate is increased several fold. For example, 20 minutes after a 0.2 u cloud has been placed in the chamber, 95% of the initial concentration is still present. When foam is added less than 40% is air-borne after the same time interval. Comparable results were obtained with iodine vapor, Figure 4, and combinations of iodine and fine aerosols, Figure 5.

We have also exposed the foams used to radiation levels of 300 R without any visible deterioration being produced. These are shown by photographs in Figure 6.

Table 5 presents results of a study to determine particulate removal in a duct by a dynamic foam system. High expansion foam was injected continuously into a duct while the particulate was added simultaneously. To prevent loss of aerosol in the fan and foam generator unit aerosol was injected as shown in Figure 7.

Results of this study are of interest because nearly 90% removal with the




CABINET WITH FOAM GENERATOR

FIG. 2

## AEROSOL CLOUD DECAY FROM URANINE PEN-I-SOL GENERATOR

| | | | | |
|---|---|---|---|---|
| RUN I | x ONE SAMPLING PORT | 0.2μ PARTICLES | | |
| RUN II | "A" SAMPLING PORT | | $Y = 119\,t^{-0.0852}$ | $Y = 2460\,t^{-1.54}$ |
| | "B" SAMPLING PORT | | 1/2L = 26000 MIN. | 1/2L = 4.5 MIN. |
| RUN III | "A" SAMPLING PORT | 0.074μ | $Y = 117 \times t^{-0.06}$ | $Y = 2000\,t^{-1.17}$ |
| | "B" SAMPLING PORT | | $1/2L = 1.42 \times 10^{-6}$ MIN. | 1/2L = 10 MIN. |

A, AI WITHOUT FOAM  B, BI WITH FOAM

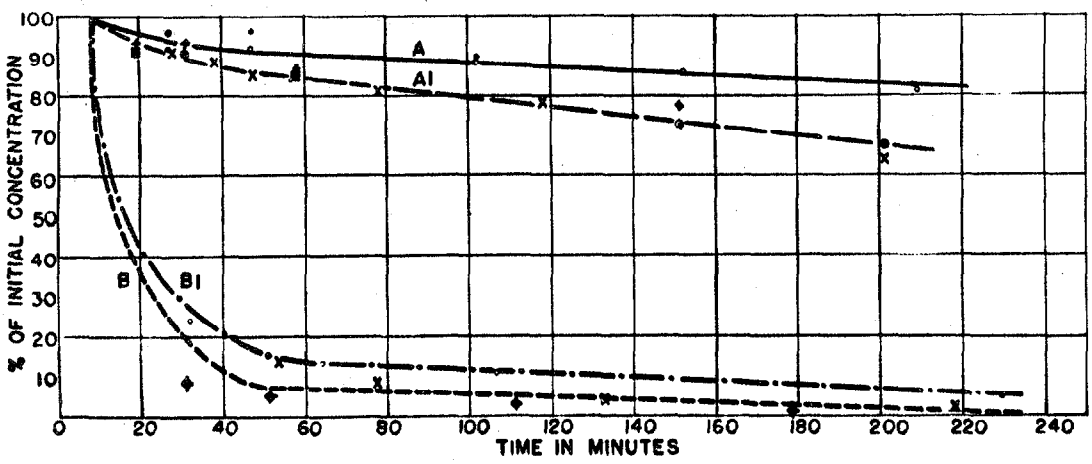



Figure 3

## $I_2$ DECAY CURVE

A) WITHOUT FOAM

$Y = 100E^{-0.00965(t-13)}$

1/2 L = 71.5 MIN.

B) WITH FOAM

$Y = 100E^{-0.0622(t-13)}$

1/2 L = 11 MIN.

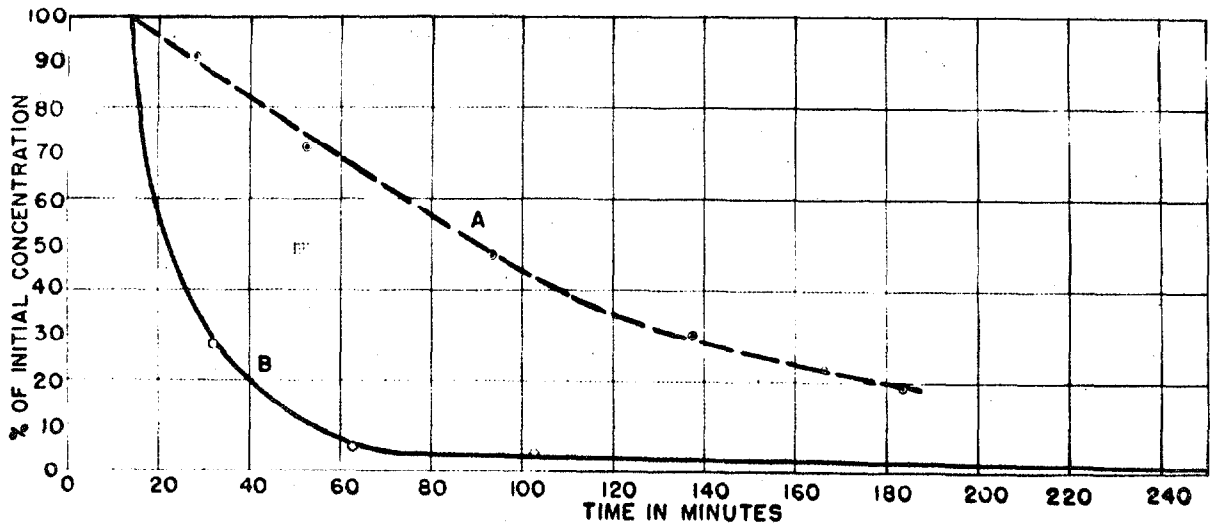



Figure 4

SIMULTANEOUS IODINE AND URANINE DECAY CURVES.

WITHOUT FOAM

A) 11.7 PPM $I_2$

$Y = 100E^{-0.0249(t-13.5)} \Big|_{13.5}^{\infty}$

1/2 L = 27.5 MIN

AI) $2.11 \times 10^{-8}$ G/L URANINE

$Y = 100 - 0.286(t-13.5) \Big|_{13.5}^{\infty}$

1/2 L = 174.5 MIN

WITH FOAM

B) 8.90 PPM $I_2$

$Y = 1850 \times t^{-1.115} \Big|_{13.5}^{\infty}$

1/2L = 11.8 MIN

BI) $2.67 \times 10^{-8}$ G/L URANINE

$Y = 100 - 3.05(t-13.5) \Big|_{13.5}^{\infty}$

1/2L = 16.4 MIN

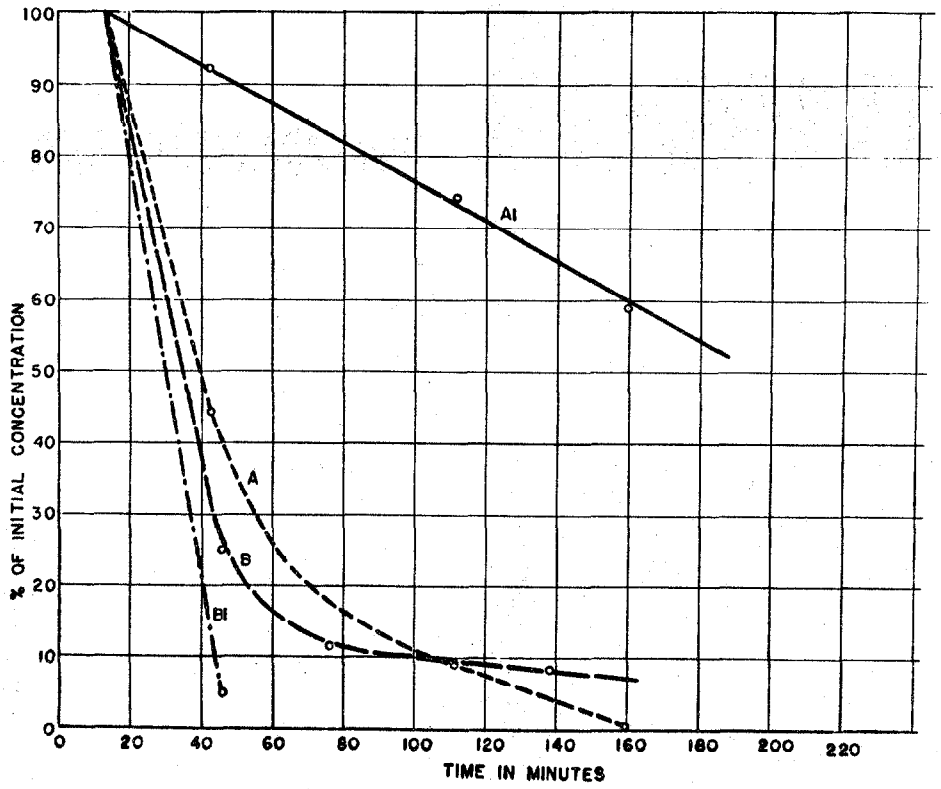
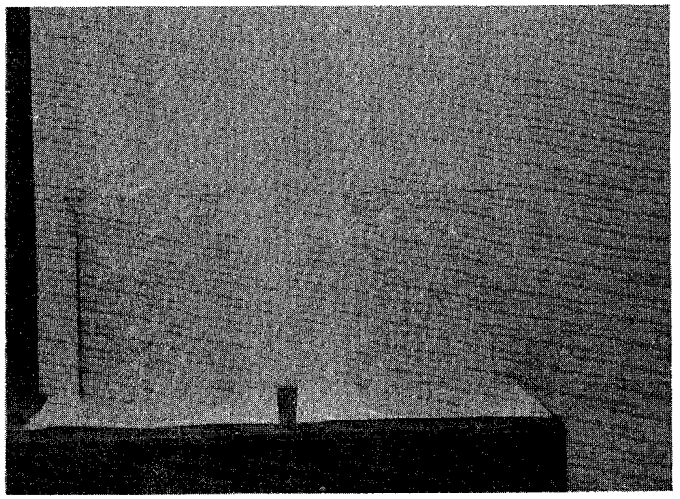
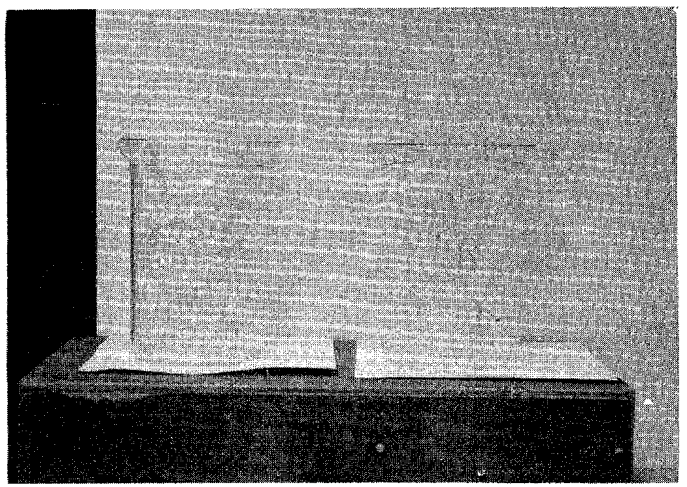



Figure 5

## FOAM IRRADIATION



0 Time - 0 Roentgens

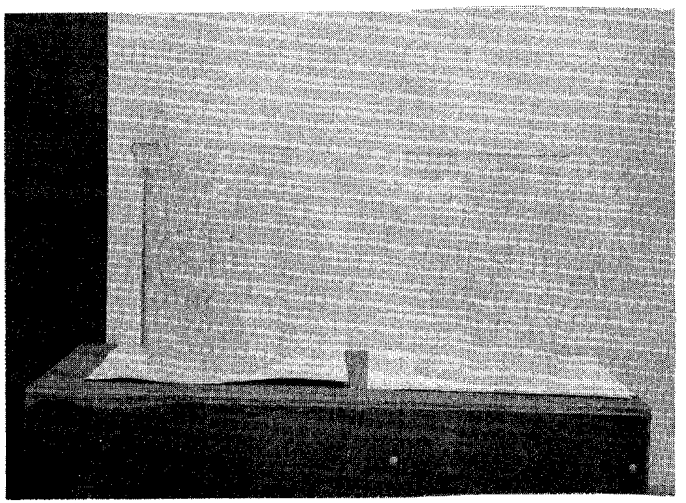


8 Minutes - 100 Roentgens

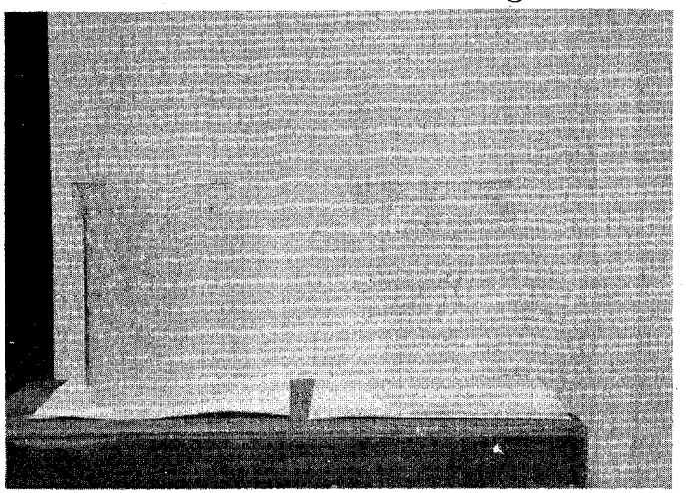
100 KVP
X-Rays

0.6 mm Al
Inherent
Filtration
2.0 mm Al
Added

Rate =
12.8 R/Min



16 Minutes - 200 Roentgens



24 Minutes - 300 Roentgens

Figure 6

## TABLE 5

## FOAM STUDIES

Results of Dynamic Foam Tests - Measurement in 8" duct -
Average duct velocity = 39 fpm

A. Distance between sampling ports = 40"

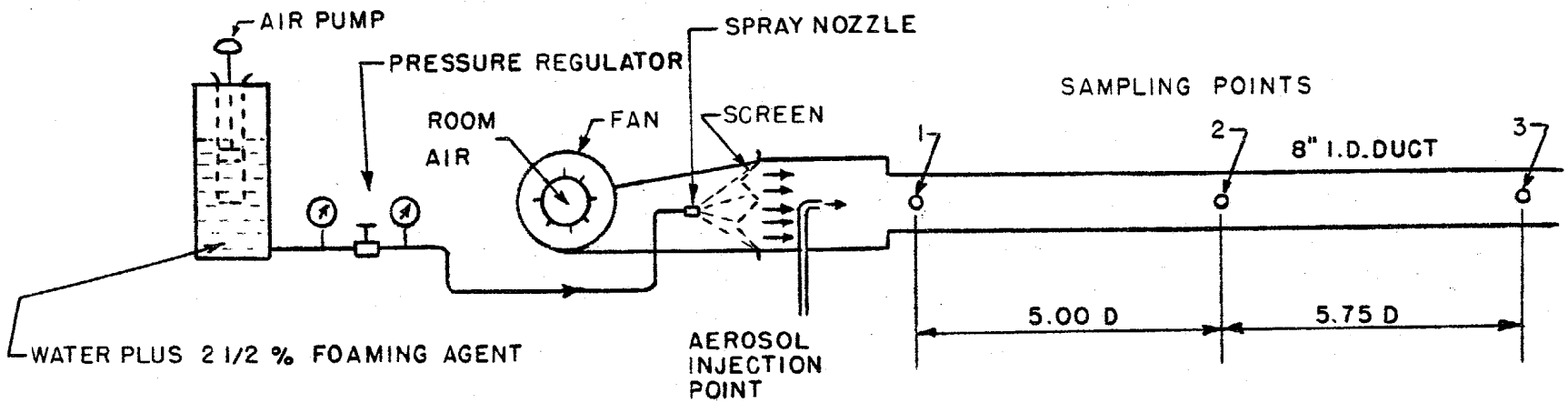
| Test | Aerosol | Efficiency % | Upstream Concentration mgs per cu. meter |
|---|---|---|---|
| 1 | Uranine 0.072u+ | 91.0 | $7.22 \times 10^{-3}$ |
| 2 | Uranine 0.072u+ | 82.6 | $2.12 \times 10^{-3}$ |
| 3 | Gentian Violet 0.26u* | 80.8 | $5.90 \times 10^{-2}$ |
| 4 | Gentian Violet 0.26u* | 84.0 | $1.23 \times 10^{-1}$ |
| 5 | Gentian Violet 0.26u* | 81.0 | $3.48 \times 10^{-1}$ |

B. Distance between sampling ports = 86"

| Test | Aerosol | Efficiency % | Upstream Concentration mgs per cu. meter |
|---|---|---|---|
| 1 | Gentian Violet 0.26u* | 88.2 | $4.25 \times 10^{-1}$ |
| 2 | Gentian Violet 0.26u* | 87.0 | $2.93 \times 10^{-1}$ |
| 3 | Gentian Violet 0.26u* | 70.4 | $1.73 \times 10^{-1}$ |

+ $\sigma g = 2.4$

* $\sigma g = 1.36$




DUCT WITH FOAM ADDITION

FIG. 7

0.07 u gentian violet aerosol was obtained in 5 diameters of duct length at a velocity of 39 fpm. Gentian violet was used as an aerosol because the large amount of foam trapped in the absorber from a dynamic system caused interference with the uranine aerosol fluorescence.

These results in general confirm the static tests and indicate possible applications to duct and other dynamic systems. At velocities above 40 fpm we were unable to maintain a complete filling of the cross section. We believe the foam could be treated to enhance iodine and halogen removal in each type of application (containment or duct). The rate of foam generation can be as high as needed. Up to 25,000 cfm production rates are possible.

The results reported here are only preliminary, but we are now completing a 1500 cfm generator for evaluations in our large dust cabinet to determine if there is any scaling factor.

## CONCLUSIONS AND SUMMARY

Two new approaches to aerosol and gas removal for reactor release control are described and their performance indicated. Preliminary results indicate that an effective diffusion board can be developed to function as a filtering structure to prevent contaminant release.. A high expansion foam generator has been demonstrated to produce both particulate encapsulation of very fine aerosols ($> 0.05$ u ) and iodine vapor removal. Reduction factors of 10 or more appear possible in each of these cases.

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

M.W. First, L. Silverman, J.J. Fitzgerald, C.E. Billings, and R. Dennis
Harvard School of Public Health

## ABSTRACT

The Harvard Air Cleaning Laboratory has been conducting an economic survey of AEC air cleaning costs over the past several years. The basic data to be supplied by the operating sites is still incomplete but a number of conclusions have been reached from the information already on hand.

From a practical standpoint, the designer of an air or gas cleaning system wants specific information on two points: (1) which type of equipment to select and (2) how to employ it with respect to air flow rate, pressure drop, etc., so as to achieve economy of operation. Equipment selection, once the nature of the problem has been understood, must generally be made from among a surprisingly few types of air cleaners; although in each category there may be multiple commercial sources offering identical or closely equivalent devices. Generally speaking, devices that are best for cleaning gases and vapors are different from those that are preferred for the removal of dry, particulate materials; and in the latter group, it is necessary to make a distinction between air cleaners suitable for heavily dust-laden process streams and those giving optimum performance with ventilation air containing light loadings of small dust particles. As the air cleaning task becomes more difficult (i. e. a greater decontamination factor), the types of devices from which a reasonable selection can be made becomes fewer and fewer. Since high performance cleaners are those highest in purchase price, opportunities for effecting substantial savings in the original installation cost are likely to be rather restricted. In most cases, however, the capital cost, distributed over the estimated life of the equipment, represents but a small part of the total annual cost. Therefore, it is in the operating phase that the greatest opportunity for minimizing air cleaning costs exists.

Analysis of annual operating costs for AEC filters, for example, shows that capitalization costs are less than 20% for most installations; but filter replacement costs (material and labor) represent 65% or more of the total. For the typical commercial throw-away air filter (Dust-Stop, Amer-Glas, etc.) that is frequently used as a prefilter for the AEC high-efficiency filter, annual capitalization costs are only 10-12% of the total; but labor costs for replacement of filter media average about 40% and the purchase of new filters, about 25%. Although the total material and labor cost for filter media changes is the same for prefilters and final filters

(65%), it is noteworthy that the purchase cost of the replacement media is 60% of the annual cost in the case of the AEC filter installations but only 25% for the prefilters; showing how completely a single expensive replacement item can dominate the total cost picture. Fractional cost breakdowns of this nature suggest ways in which annual air filtration costs can be minimized.

## INTRODUCTION

For the past several years, the Harvard Air Cleaning Laboratory has been collecting cost information on installed air and gas cleaning equipment at AEC sites. Information, in varying degrees of completeness, has been submitted on about 350 systems. Most of these systems are used for the removal of finely divided dry solids from unsaturated gases, usually air, but a few devices have been reported that are used for the removal of gaseous substances by adsorption or absorption.

Previous reports on the status of this study have emphasized data gathering (1), have discussed certain of the theoretical aspects of cost analysis and have presented some of the early information (2). The principal remaining task is to prepare a detailed analysis of all of the cost data.

### General Considerations

The first step will be to segregate the air cleaning devices into very homogeneous groupings based on aerosol characteristics (or on the nature of the gaseous component to be removed) rather than by a broad classification system based only on decontamination factor. For example, air and gas cleaning devices used for dust collection must be subdivided into a group suitable for process gas streams (i. e. heavy dust loadings) and one for ventilation air (i. e. very light loadings of fine dusts) because, generally speaking, collectors in one category can not be substituted for those in the other. Each type of collection device has been especially designed to function well under quite different conditions. The type of self-consistent and useful information that can be derived from this small group method of analysis is illustrated by Figure 1, taken from a recent paper of Silverman's (3), in which the dust collection efficiency of 13 different industrial process stream gas cleaning devices is measured with the same aerosol and then each is cost analyzed for the identical gas cleaning task. It is interesting to note that the analysis summarized in Figure 1 includes virtually all of the devices that can be used under the operating conditions specified and this illustrates the fact that in practical situations the number of useful devices is generally fairly limited. Further, as the specific air cleaning task becomes more difficult (i. e. when a greater decontamination factor is required) the types of devices from which a reasonable selection can be made become fewer and fewer.

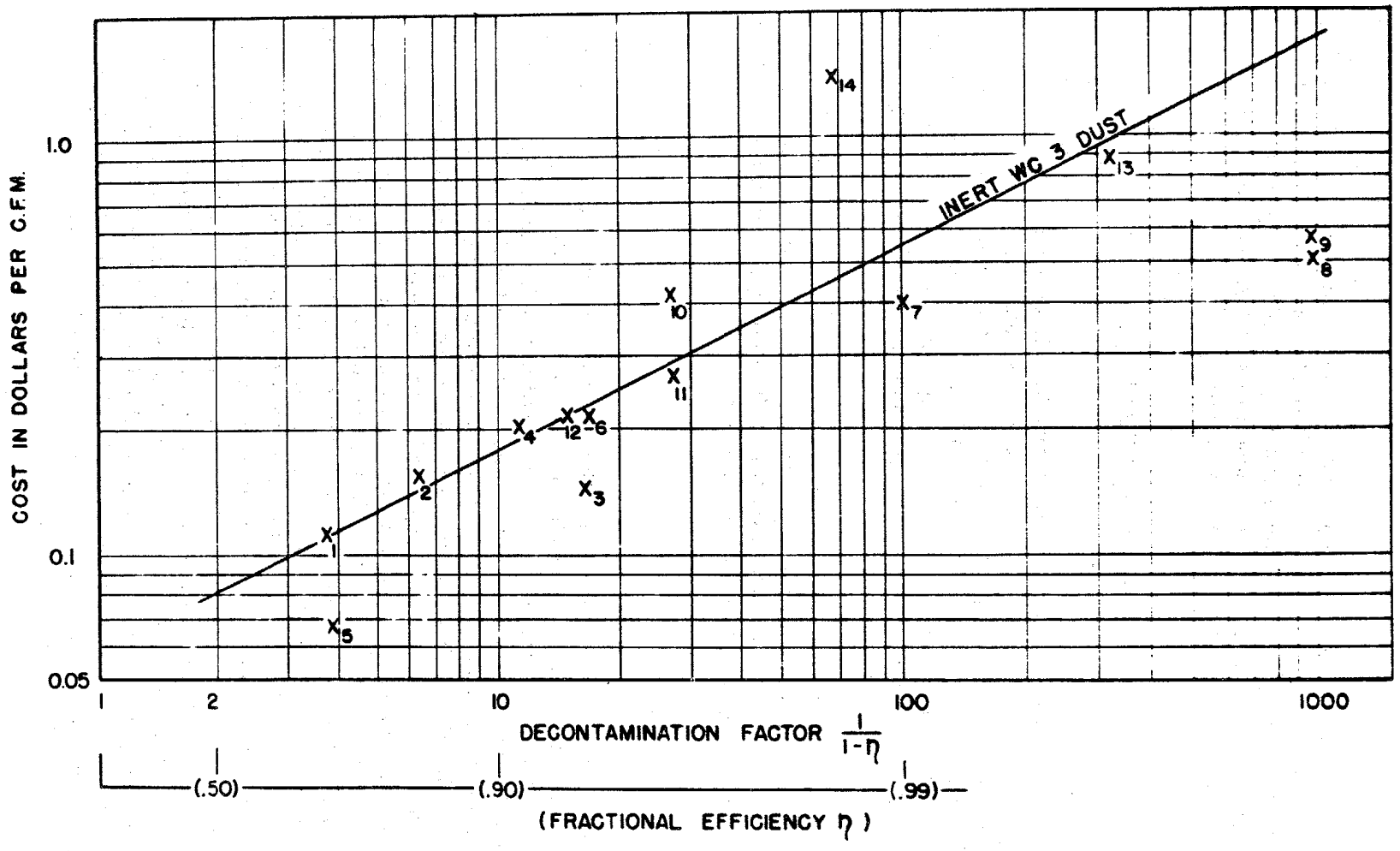



Figure 1 COST VS. DECONTAMINATION FACTOR FOR GAS CLEANING OF INERT DUSTS

Within each group of air cleaners capable of performing the same collecting task, analysis will reveal, on a quantitative basis, the principal factors that are of importance in determining costs. For example, it is generally recognized that the absolute size of an installation has an important bearing on both initial and operating unit costs, a large unit being more economical than a smaller one. Nevertheless, special factors enter into the design of many AEC installations and these tend to produce significant deviations from the general trend. For this reason, the greatest amount of useful information can be derived from this data by first analyzing it in broad order-of-magnitude groups (e. g. as systems of 100; 1000; 10,000; and 100,000 cfm capacity) and second, examining the reasons why certain installations deviate significantly from the norm.

Still another example of a factor which is likely to behave similarly within each of the homogeneous sub-groups is the influence of particle size on collection costs. While it is natural to assume that it is more difficult, and hence more costly, to collect small particles than large ones, there are difficulties in expressing this trend in a quantitative manner because of the diverse ways in which particle size and efficiency are customarily expressed. Once again, a small number of order-of-magnitude groupings is likely to reveal the broad trends in sufficient detail to lead to meaningful conclusions. A useful method for this purpose is to classify dust collectors on the basis of their ability to achieve a decontamination factor of 10 or greater for particles 10, 5, 2, 1, or 0.1 micron or less in diameter.

The application of these and similar analytical methods plus the nature of the information that can be obtained may be illustrated by specific examples taken from an analysis of a portion of the site data dealing with AEC ultra-high efficiency filters and with the type of prefilter commonly used with AEC filters.

## Cost Analysis of AEC Filter Installations

Table 1 summarizes cost information on 39 AEC filter installations on the basis of collector size. As anticipated, average annual unit costs decrease with increasing total capacity. Except for the group of largest sized units, the rate of decrease with size is seen to be exceedingly rapid. (Reasons why the largest units fail to conform more closely to this trend will be discussed below.)

The maximum and minimum cost figures for the two smallest size groups in Table 1 show considerable spread, whereas the cost range is rather narrow for units of 10,000 cfm capacity and greater. An examination of the type of air stream each of these installations is filtering indicates that all of the units having 10,000 cfm capacity or greater are handling ventilation air, either supply or exhaust, whereas many of the smaller capacity units are employed on special materials; high cost applications such as the decontamination of off-gases from incinerators and perchloric acid hoods. These materials cause rapid destruction of the filters or extreme radioactivity, leading to high disposal costs.

## TABLE 1

## EFFECT OF COLLECTOR SIZE ON TOTAL ANNUAL UNIT COSTS FOR AEC FILTERS

| Total Capacity CFM | No. Units | Total Fixed Plus Operating Cost $/1000 cfm/year | | |
|---|---|---|---|---|
| | | Average | Minimum | Maximum |
| $10^2$ | 4 | 935 | 175 | 2678 |
| $10^3$ | 22 | 359 | 152 | 1227 |
| $10^4$ | 10 | 175 | 152 | 216 |
| $10^5$ | 3 | 228 | 177 | 300 |

## TABLE 2

## COST BREAKDOWN FOR AEC FILTERS FOR EACH COLLECTOR SIZE GROUP

| Total Capacity CFM | Percent of Total Annual Unit Costs | | | |
|---|---|---|---|---|
| | Capitalization | Power | Replacement Filters | Labor |
| $10^2$ | 17.6 | 8.2 | 64.0 | 10.3 |
| $10^3$ | 15.5 | 14.7 | 60.3 | 9.5 |
| $10^4$ | 11.5 | 19.4 | 61.2 | 8.6 |
| $10^5$ | 66.0 | 11.0 | 15.0 | 8.0 |

## TABLE 3

## EFFECT OF COLLECTOR SIZE ON TOTAL ANNUAL UNIT COSTS FOR THROW-AWAY PREFILTERS

| Total Capacity CFM | No. Units | Total Fixed Plus Operating Cost $ / 1000 cfm/year | | |
|---|---|---|---|---|
| | | Average | Minimum | Maximum |
| $10^3$ | 17 | 44.50 | 21.30 | 99.30 |
| $10^4$ | 10 | 25.00 | 17.05 | 36.15 |

A question which often arises during the design of filters for highly radioactive particles is whether it is ultimately more economical to install an oversized unit at a higher than normal first cost in order to increase the interval between filter changes and thereby reduce certain operating costs? The amount of collector over- or under-sizing can be judged by comparing the actual flow rate with the manufacturer's rating and then actual costs can be compared on the basis of the "percentage of nominal capacity" that is utilized. This has been done in Figure 2 for the three largest size groupings. The data for the 22 installations in the 1000 cfm size group are the most revealing because they cover a wide range of costs and percentages of capacity. These points form a smooth curve which shows that when percentage of capacity is greater than 80% there is negligible effect on total unit costs but that as capacity drops below 80%, total unit costs increase very rapidly. The data for the 10,000 and 100,000 cfm groups cover only a segment of the 1000 cfm curve, but are, in all respects, consistent with it.

In Figure 2, it may be seen that the points for the 100,000 cfm group are all located between 20% and 33% of nominal capacity; figures associated with abnormally high total costs. This is believed to be an adequate explanation for the apparent break in the trend of lower average unit costs with increase in collector size that is shown in Table 1. Presumably, total unit costs would have been much lower than they were had these installations been employed at levels nearer their rated capacities.

In Table 2, costs for each size group are broken down into four major items: prorated capital or amortization cost (including installation labor), power cost, filter replacement cost, and operating labor charges. The percentages of total cost found in each of the four categories are quite similar for the three smallest size groups. The cost of filter replacements is the major cost, accounting for somewhat more than 60% of the total, in each case. The cost distribution is distinctly different in the case of the largest units; here filter replacements account for only 15% of the total cost. However, capital costs were disproportionately large because of the very low percentage of the rated capacity that is used. When taken together, the figures in Tables 1 and 2 suggest that the high amortization costs of greatly oversized installations are not easily offset by economies in power costs, filter replacements, and labor charges.

The low power costs and high filter replacement costs of the three smallest size groups suggest that lower total costs can be achieved by running the filters to a higher resistance before changing. This may be impossible in existing installations because of limitations in exhaust fan or blower capacity or requirements for better shielding, but it should be considered in design for new construction. For the most part, these filters are being discarded when air flow resistance reaches 2 inches of water gage, although the filters will withstand much higher pressures successfully. By contrast, the filters in the largest size group are permitted to reach 4 inches resistance before replacement.

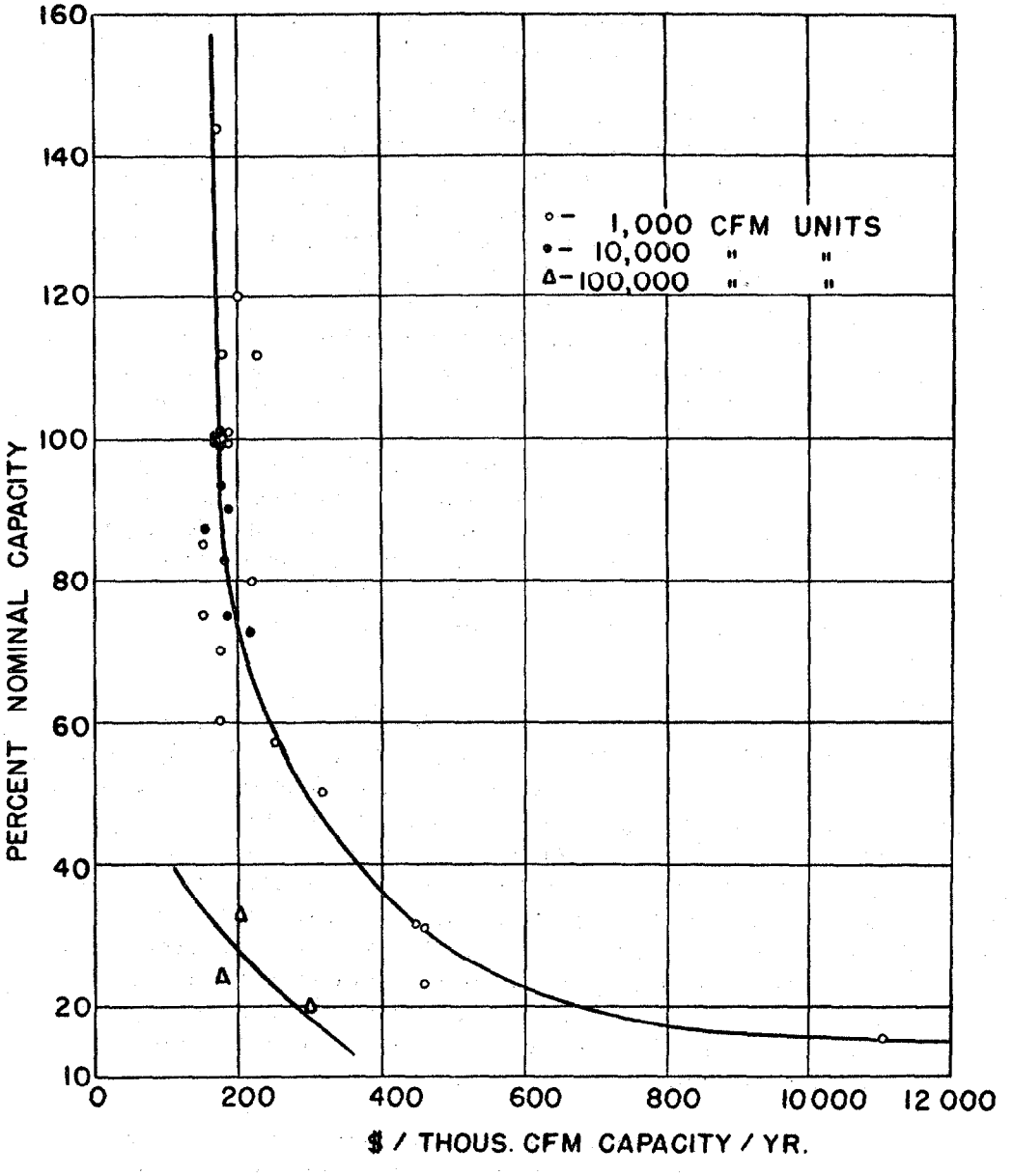



FIGURE 2
INFLUENCE OF PERCENT OF NOMINAL CAPACITY UTILIZED ON TOTAL FILTER COSTS

## Cost Analysis of Prefilter Installations

Two inch deep throw-away filters containing porous mats of resin-bonded glass fibers in the 125-250 micron diameter range (Dust-Stop, Amer-Glas, etc.) are used throughout AEC establishments as ventilation air filters and as prefilters for more efficient units. Table 3 shows the total average cost and range of costs for 27 installations in the 1000 and 10,000 cfm capacity ranges. Just as for the AEC filters, unit costs show a marked decrease with increasing size of the installation and, in addition, the range of costs (maximum to minimum) is less for the larger units.

Comparing costs of prefilters and AEC filters, it may be seen from Tables 1 and 3 that the ultra-high efficiency filters cost 7 to 8 times as much as the prefilters. For this cost differential, the AEC filters are capable of a decontamination factor of 10 for particles 0.1 microns in diameter, whereas the prefilters attain this decontamination factor only on particles 5 microns and larger.

In Table 4, the cost data for prefilters are broken down into 4 major categories, as in Table 2 for the AEC filters. For the prefilters, the major cost item is labor charges for maintenance and filter charging (in contrast to the AEC filters for which labor charges amount to only 8-10% of the total cost). This shift in the distribution of cost items does not imply greater labor requirements for the prefilters as much as it reflects lower filter purchase costs; a prefilter costs only 1/25th, or less, the cost of an AEC-filter cartridge.

A few prefilter installations of the cleanable type (Kleen-flow) have been analyzed, also, and the summaries are shown in Table 5. Total annual costs are less than for the throw-away type (Table 3) but not greatly so; and against this slightly lower cost must be balanced the somewhat lower dust collection efficiency of the cleanable filters. These data are still too few to permit a detailed analysis, but are included primarily to illustrate the types of correlations that will be sought when all of the site information has been received and processed.

## SUMMARY

Analysis of annual operating costs for AEC filters shows that capitalization costs are less than 20% for most installations; but filter replacement costs (material and labor) represents 65% or more of the total. For the typical commercial throw-away air filter types (Dust-Stop, Amer-Glas, etc.), frequently used as a prefilter for the AEC high-efficiency filter, annual capitalization costs are only 10-12% of the total, but labor costs for replacement of filter media average about 40% and the purchase of new filters, about 25%. Although the total material and labor cost for filter media changes is the same for prefilters and final filters (65%), it is noteworthy that the purchase cost of the replacement media is 60% of the annual cost in the case of the AEC filter installations but only 25% for the prefilters, showing how completely a single expensive replacement item can dominate the total cost picture. Fractional cost breakdowns of this nature suggest ways in which annual air filtration costs can be minimized.

TABLE 4

COST ANALYSIS FOR THROW-AWAY PREFILTERS FOR EACH COLLECTOR SIZE GROUP

| Total Capacity CFM | Percent of Total Annual Unit Costs | | | |
|---|---|---|---|---|
| | Capitalization | Power | Replacement Filters | Labor |
| $10^3$ | 11.4 | 18.0 | 24.7 | 45.9 |
| $10^4$ | 10.9 | 29.7 | 24.7 | 34.7 |

TABLE 5

UNIT COSTS FOR CLEANABLE PREFILTERS

| Total Capacity CFM | No. Units | Total Fixed Plus Operating Unit Cost $/1000 cfm/yr. | Percent of Total Annual Unit Costs | | | |
|---|---|---|---|---|---|---|
| | | | Capitalization | Power | Replacement Filters | Labor |
| $10^4$ | 2 | 21.50 | 38.2 | 30.9 | - | 30.9 |
| $10^5$ | 2 | 16.30 | 16.3 | 42.8 | - | 40.9 |

## REFERENCES


1. Proceedings of Fifth Atomic Energy Commission Air Cleaning Conference, Harvard Air Cleaning Laboratory, June 24-27, 1957. TID-7551, issued April 1958. Office of Technical Services, Washington, D. C.

2. Proceedings of the Sixth Atomic Energy Commission Air Cleaning Conference, Idaho Falls, Idaho, July 7-9, 1959. TID-7593, issued October 1960. Office of Technical Services, Washington, D. C.

3. Silverman, L., Economic Aspects of Air and Gas Cleaning for Nuclear Energy Processes. Disposal of Radioactive Wastes, pp. 137-78. International Atomic Energy Agency, Vienna 1960. (Proceedings of International Atomic Energy Agency, Monaco Conference, November 16, 1959).

# RADIOACTIVE WASTE INCINERATOR DESIGN AND OPERATIONAL EXPERIENCE - A REVIEW

R. Dennis and L. Silverman
Harvard School of Public Health

## ABSTRACT

Since 1950 several attempts have been made to design incineration and gas cleaning equipment for the disposal of solid, combustible radioactive wastes. The main objective has been to reduce the total volume of contaminated wastes so that over-all cost for incineration, ash disposal, and ultimate storage would be less than existing costs for handling, storing, transporting and burying the bulk waste. However, recovery of fissionable materials has also led to special incinerator design.

This paper reviews incineration experience at several AEC sites, including basic design requirements, operational problems, and economic considerations. Failure of most devices to compete economically with other means of waste disposal was due principally to the high cost of gas cleaning systems although structural failings in incinerator design and erratic combustion were also trouble sources.

Performance data are also furnished for two incineration systems in current use and reportedly operating successfully in terms of their respective applications, (a) plutonium recovery, and (b) waste volume reduction of uranium oxide contaminated materials.

Basic research on institutional type incinerators is reviewed including (a) U. S. Bureau of Mines studies, (b) joint studies of the U. S. Bureau of Mines and the Harvard Air Cleaning Laboratory, (c) Harvard studies, and (d) joint development by Harvard and the U. S. Army Chemical Center of a 50-lb. per hour incineration-gas cleaning system.

## INTRODUCTION

The safe disposition of solid radioactive waste from production, research, and reactor operations is a necessary and frequently costly procedure. Methods of collection, sorting, packaging, interim storage, transportation,

and ultimate disposal by land or sea burial are major contributing cost factors.

There is no way to alter the absolute quantity of radioactive material arising from particular operations. However, effective process containment and segregation of contaminated materials afford two means of reducing the bulk of waste requiring special handling. In the case of solid wastes which have been sorted to a maximum practicable degree, costs associated with all handling procedures subsequent to collection are largely determined by the waste bulk volume. Therefore, techniques appearing to offer a significant volume reduction in contaminated waste have been under continuous investigation within the AEC and contractor groups for several years. The practice of compression and baling represents one method of reducing volume anywhere from 6 to 100 times depending upon the composition and packing density of the original material. The presence of large or rigid objects (pipe, tubing, miscellaneous metal, boards or glass) along with papers, rags, plastics, rubber, etc., obviously restrict compaction.

Incineration of combustible solid wastes appears to be a convenient method of attaining maximum volume reduction. However, review of past and present experience with experimental or operative field installations indicates clearly that many problems remain to be solved before incineration techniques can be applied effectively.

In this paper, we discuss briefly AEC site incineration projects at Mound (MLM), Knolls (KAPL), Los Alamos (LASL) and Argonne (ANL) laboratories, which were discontinued for the following reasons - poor combustion, mechanical failures, gas cleaning problems, or excessive cost relative to other means of waste treatment. Development of the U. S. Bureau of Mines institutional type incinerator is also included. Field performance of incinerators at the Rocky Flats Plant, Colorado, of the Dow Chemical Co. and the General Electric (APED) San Jose, California site are reviewed with special emphasis on the gas cleaning problems.

Current studies of the Harvard Air Cleaning Laboratory relating (a) to the performance of a small 25 lb. per hour incineration-gas cleaning system and (b) to the design of a 50 lb. per hour prototype unit for evaluation by the U. S. Army Chemical Corps, Nuclear Defense Laboratory are also described.

## INCINERATION PLANTS NO LONGER IN SERVICE

The equipment described in this section is representative of early attempts (1950-1954) on the part of various AEC contractor groups to reduce the bulk volume of solid radioactive wastes by incineration. Although hindsight indicates that some approaches were extraordinarily complex or perhaps overly optimistic, it should be remembered that high level decontamination of process off-gases was a major target. Furthermore, information relating to

the proper application of gas cleaning techniques and reliable field performance data were not common knowledge then.

The general design of combustion apparatus was based largely on the studies of the Combustion Research Section of the U. S. Bureau of Mines with regard to the tangential overfire concept and stainless steel linings in the burning chamber. Although steel liners were originally proposed to eliminate activity accumulation on firebrick (and also to eliminate a source of particulate loading due to spalling) their use imposed temperature restrictions within the burning chamber and required special air or water cooling which did not always prevent warping of metal structures. The immediate effect of maintaining temperatures in the 1200 to 1500 F range was to produce an incinerator effluent containing partially burned solids, soot and a wide variety of condensable volatiles or tars. In many cases, service life of high efficiency filters was reduced to a matter of days or even hours.

1. Mound Laboratory (MLM)

In Table 1, design features and operating characteristics have been summarized for several early incineration systems. The 15 lb. per hour MLM pilot device was constructed to furnish design criteria for a 120 lb. per hour unit. It was reported (1) that extrapolation of test data showed that operation of a full scale unit would result in an estimated $14,000 yearly saving in comparison with existing shipping and burial costs. Decontamination studies based on scrub water analyses showed values of $10^8$-$10^9$. In view of the complexity of the gas treatment system, it appears that effluent gas measurements might have indicated the same decontamination levels. It was stated that high efficiency filter life was expected to be very long based on the fact that 17 hours testing showed no apparent change in filter resistance (1). However, a rigorous examination of the gas cleaning system suggest that estimated values were far too low. No prototype unit was constructed.

2. Knolls Atomic Power Laboratory (KAPL)

The gas cleaning system installed in the KAPL pilot incineration plant (20 lbs. per hr), Table 1, was developed with the object of reducing the stack effluent to a minimum volume. Water vapor was to have been removed by a condenser and excess $0_2$ converted to $S0_2$ to prevent interference with $C0_2$ removal in a diethanolamine Raschig ring tower. Use of pure oxygen for combustion eliminated nitrogen from the circuit. Steam nozzles, contrifugal scrubbing, FG-25, 50 media, and high efficiency AEC filters were installed for particulate removal. Unfortunately, the equipment failed to operate as a result of erratic burning (furnace pressure varied from $\pm$ 20 in. water) and rapid fouling of system components with soot and tars (2). The above system was abandoned and the entire project scheduled for re-examination and redesign. Review of the KAPL studies emphasizes the fact that combustion of heterogeneous mixtures presents unique problems not enountered with conventional fuels.

TABLE 1

PILOT AND PROTOTYPE INCINERATORS FOR DISPOSAL OF SOLID, COMBUSTIBLE RADIOACTIVE WASTES (Devices no longer in Use)

| | MLM* 1950 | KAPL 1950 | LASL 1951 - 1953 | ANL 1951 - 1954 | BOMAEC 30 | BOMAEC 100 |
|---|---|---|---|---|---|---|
| Burning Capacity | 15 lbs/hr | 20 lbs/hr | 100-200 lbs/hr | 100 lbs/hr | 30 lbs/hr | 100 lbs/hr |
| Burning Chamber | Cylindrical Downdraft | Cylindrical | Cylindrical | Cylindrical | Cylindrical | Cylindrical |
| Charge Packaging | 3-5 lbs bag | - | Cardboard box, 13"x13"x 24": 8-20 lbs | Fiber drums 1 cu. ft | Bulk | Cardboard boxes 5 lbs/box |
| Combustion Air | 20 cfm STP | Pure oxygen 7 cfm STP | 2000 cfm STP | 300 cfm STP | 60 cfm STP | 155 cfm STP |
| Air Inlets | Tangen-tial | Over-fire | Tangential Overfire | Tangential Overfire and under-grate | Tangential Overfire | Tangential Overfire |
| Gas Treatment | (a) Spray Washer (b) Pease Anthony wet washer (c) Nash pump (d) Steam nozzles and ex-pansion chamber (e) 2nd Pease Anthony wet washer (f) CWS #6 Filter | (a) Water jacketed condenser (b) sulfur burner (c) steam nozzles (d) $CO_2$ absorber diethan-olamine Raschig rings (e) Pease Anthony centrifugal washer (f) Reheater (g) FG-25-50 media (h) CWS #6 filter | (a) Cyclone dust collector (b) Spray cooler (c) Pease Anthony Venturi scrubber and separator (d) 2 stage deep pocket, dry fiberglass filter (FG25-50) | (a) Vane plate scrub tower (b) Pease Anthony Venturi scrubber (c) Peabody scrubber (d) Reheater (e) AEC high efficiency filter | (a) Spray cooler (b) all-glass bags (c) proposed final stage AEC filters | Proposed system (a) water condenser (b) electrostatic p recipitator (c) high efficiency roughing filter (d) final - AEC filters |
| Ignition | Kerosene jet | | Gas | Gas | Gas | Gas |

(Continued)

TABLE 1 (Continued)

| | MLM* 1950 | KAPL 1950 | LASL 1951 - 1953 | ANL 1951 - 1954 | BOMAEC 30 | BOMAEC 100 |
|---|---|---|---|---|---|---|
| Overall Decontamination Factor, Penetration or Efficiency | $10^9$ | $10^9$ | 0.005% penetration | $3.4 \times 10^7$ | Unknown | Unknown |
| Equipment Details and Operating Characteristics | 200 lbs/hr of 50-60 psi steam 285 gal/hr. wash water 10 H.P. Nash pump | Poor combustion regulation Furnace static pressure varied from ± 20 in. water. Tar and soot plugging in 1 hr. | Generally low combustion gas temperature 800°F Erratic burning | Short AEC filter life 8 to 40 hrs. Warping of stainless steel | Cumbersome charge mechanism Sooty effluent short bag life warping of stainless steel, air leakage | No data on cleaning equipment |
| Comment | Excessive Cost operations suspended | Excessive cost unsatisfactory burning operation suspended | Unsatisfactory burning, costly operation suspended | Unit operable estimated disposal costs $1.60 - $2.68/ft.$^3$ > land burial cost, operation discontinued | | |

| | |
|---|---|
| * MLM | Mound Laboratories |
| KAPL | Knolls Atomic Power Laboratory |
| LASL | Los Alamos Scientific Laboratory |
| ANL | Argonne National Laboratory |
| BOMAEC-30 | Bureau of Mines |
| BOMAEC-100 | Bureau of Mines |

3. Los Alamos Scientific Laboratory (LASL)

During the period 1951-53, pilot testing was performed on a comparatively large, 100-200 lb. per hour, incineration and gas cleaning system at LASL (3)(4). The basic design of this device was quite similar to that of the BOMAEC-100 unit (see section 5). However, the ratio of overfire air to burning rate was very high resulting in low combustion temperatures, 500-800°F. Unofficial comments indicated that it was (a) difficult to maintain a fire and (b) that the effluent contained considerable tars and soot. The project was discontinued when another means of waste disposal became available.

4. Argonne National Laboratory (ANL)

The Argonne National Laboratory incinerator (5)(6) designed by A. D. Little Company, Cambridge, Massachusett was in field operation for over a year. Service was discontinued when it became cheaper to store, ship, and bury the waste than to process it. Two major failings were evidenced; warping of the stainless steel jacket and short life, 8-40 hours, for AEC high efficiency filters. Auxiliary gas firing was used for charge ignition and final burnup of residual grate material. Although not specifically stated, the short filter life appeared to be caused by a combination of condensation and unburned combustion products. Since design temperatures were in the order of 1500°F for the combustion chamber the presence of soot and tars might be suspected.

In general, the four incinerators discussed above were designed to burn typical low level wastes - mixtures of paper, rags, wood, rubber gloves, and plastics with variable moisture content. All were single chamber devices with no provisions for secondary combustion or continuous use of auxiliary fuel. Venturi scrubbers or other wet gas washing devices performing the dual function of cooling and partial cleaning were used in every case since liquid waste handling facilities were available. It should be noted that Venturi scrubbers are not 100 per cent efficient against tar fogs produced during incomplete combustion. Ekman and Johnstone (7) for example, report 95 per cent efficiency against tar and acetic acid from a wood distillation plant. Furthermore, decontamination values based on radioactivity may be far different than those relating to actual particle or mist removal.

5. U. S. Bureau of Mines Studies

The BOMAEC-30 and 100 incinerators, Table 1, were the outgrowth of pilot studies on a small 10 lb. per hr. unit (8)(9) developed to investigate the principal factors governing combustion with single chambered, tangential overfire incinerators. Corey et al (9) cited the following advantages to this technique:

(1) Elimination of gas flow fluctuations caused by passage of underfire air through a diminishing mass of charge and variable open grate area.

(2) Increased gas stream turbulence which causes better mixing of

combustibles with air and more rapid heat transfer from heated walls to gas stream.

(3) Increased combustible retention time due to vortical or cyclonic gas flow which permits greater burning efficiency in a single chamber combustion unit.

(4) Increased solids retention time in the burning chamber as a result of centrifugal forces exerted on particles entrained in the rotating gas stream.

Under AEC contract, the Bureau of Mines constructed a 30 lb. per hr. prototype unit for the disposal of low-level radioactive wastes originating from hospitals and research laboratories. It was stipulated that (a) only dry gas cleaning methods should be used and (b) that the unit be simple to operate. The Harvard Air Cleaning Laboratory conducted an extended stack sampling program on this device at Pittsburgh (10) and later in Boston (11) to determine criteria for design of gas cleaning apparatus. It was established that (a) charges of sawdust or miscellaneous office wastes containing more than 10 per cent moisture could not be burned without continuous auxiliary gas firing, (b) that tars and soots present in the stack gas led to eventual rupture of woven glass fabric bags, and (c) that the bag effluent contained tar products impossible to collect on AEC high efficiency filters. The charging technique presented mechanical problems, fire hazards, and led to inefficient combustion. Testing was abandoned when warping of the steel cover caused uncontrollable leakage.

Stack sampling of the BOMAEC-100 unit indicated the same type of effluent noted for the smaller BOMAEC-30 incinerator. This laboratory did not observe the BOMAEC-100 cleaning system in operation although plugging problems were cited by Bureau personnel.

Aside from charging difficulties which could be corrected, the major defect in the BOMAEC devices was the temperature limitation, $< 1500°F$, imposed by the all steel construction. Furthermore, the heterogeneous composition of most waste charges led to preferential distillation of volatile components which reduced excess oxygen to near zero levels during parts of the combustion cycle. The combination of insufficient heat and oxygen produced an effluent which although clean in appearance contained sufficient condensable organics to present a difficult cleaning problem.

In the design and development of the ACL-I and ACL-II incinerators by this laboratory (11) (see heading, Harvard Air Cleaning Laboratory Studies, section 1) firebrick linings and a secondary air supply and combustion chamber were incorporated with the tangential overfire concept to attain improved combustion.

## INCINERATION PLANTS IN CURRENT USE FOR DISPOSAL OF SOLID RADIOACTIVE WASTES

### 1. Dow Chemical Company (Rocky Flats Plant, Colorado)

A standard commercial design incinerator* with minor modifications to the combustion unit proper (see Table 2) has been installed at the Rocky Flats site for disposal of 50 to 70 lb. per hour of miscellaneous combustibles. Waste materials are sorted to separate non-combustibles and then packaged in polyethylene bags (roughly 6 in. x 6 in. x 6 in., 3 lbs. per bag). These operations are conducted within a large glove box enclosing two sides of the incinerator. Waste composition is varied and may include rags, paper, PVC, rubber gloves (some lead bearing), ion exchange resins, and miscellaneous laboratory and process chemicals. Combustion air (a combination of over- and under-grate supply totaling 200 cubic ft. per min. STP) is drawn from the glove box enclosure which is currently equipped with four - 50 cu. ft. per min. capacity high efficiency AEC filters. The primary purpose of these filters is to prevent area contamination should the normal hood negative pressure, - 1 in. water, accidently become positive.

Furnace construction is a three chamber design consisting of a rectangular burning chamber and two secondary combustion chambers. Auxiliary gas firing is provided in (a) the main burning chamber, 75,000 BTU per hr. and (b) the second combustion chamber, 150,000 BTU per hr. By charging every 3 minutes effluent gas temperatures are maintained within an average range of 1600-1700°F. A six inch thick, firebrick lining is used throughout the incinerator.

Effluent gas passes first through an air to gas reheater which heats about 120 cu. ft. per min. of room air (filtered with high efficiency AEC units) for subsequent dilution of the incinerator effluent. An air to gas fin cooler reduces temperature to approximately 800°F prior to effluent passage through slag wool particulate prefilters.

Since a negligible resistance increase was reported during extended burning tests, it is the opinion of the authors that considerable edge leakage or channeling occurred. Installation of slag wool filters was made at the recommendation of this laboratory on the basis of apparently successful use in our testing operation. However, it was later found that improved packing and edge sealing methods led to rapid plugging (11). Consequently, previously reported performance was attained at the expense of leakage.

There followed further temperature reduction in a third heat exchanger to about 370°F. A tar sump was installed at this point to separate condensed organics and moisture. Prior to entering the final high efficiency filter stage, the gas stream was diluted with 120 cu. ft. per min. of reheat air to maintain temperatures well above the dew point, 430°F filter inlet temperature.

Although moisture itself appeared to be excluded as a major plugging source, filter life was short due mainly to tar and soot deposition. Eight,

* Plibrico Sales and Service Co., 5750 Pacoe Street, Denver 21, Colorado.

TABLE 2

INCINERATION PLANTS FOR DISPOSAL OF SOLID RADIOACTIVE WASTES
(1 9 6 1)

| | Dow Chemical Company<br>Rocky Flats, Colorado | General Electric Company<br>Atomic Power Equipment Department<br>San Jose, California |
|---|---|---|
| Incinerator Design | 3-chamber, rectangular overall 4' x 3' x 5'3"<br>6 in. firebrick lining | 3-chamber, rectangular overall 4' x 3' x 5'3", 4 in. firebrick lining |
| Burning Capacity | 50-70 lbs/hr | 100 lbs/hr |
| Combustion Air | 200 cfm, STP overfire and underfire | 300-400 cfm, STP overfire and underfire |
| Auxiliary Fuel | Natural Gas (continuous)<br>150,000 BTU/hr - Burning Chamber<br>150,000 BTU/hr - Combustion Chamber | Natural Gas (continuous)<br>75,000 BTU/hr - Burning Chamber<br>75,000 BTU/hr - Combustion Chamber |
| Charge Composition | Rubber, plastics, rags, paper, ion-exchange resins - 20-50% $H_2O$ | About 90% kraft paper, 10% stray rubber, plastics - No lab acids or reagents |
| Incinerator Outlet Temperature | 1600-1700°F | 1400-1500°F (estimated |
| Charge Packaging | Polyethylene bags, approx. 6"x6"x6"<br>3 lbs/bag | Cardboard boxes - 2' x 2' x 18"<br>10 lbs/box |
| Gas Treatment System | (a) Air to gas reheater 120 cfm 70°F to 900°F<br>(b) Air to Gas Fin cooler<br>(c) Slag Wool Roughing Filter 12.5 $ft^2$ - 1 ft. deep, 3 $lbs/ft^3$, T = 800°F, Resistance = 0.4 in. $H_2O$<br>(d) Air to gas fin cooler<br>(e) Tar trap<br>(f) Mixer - gas and reheat air<br>(g) AEC filters - 8-1000 cfm units | (a) Baffled spray chamber recycle spray, through 5 20-30 psig nozzles outlet temperature $< 500 >$ 300°F<br>(b) 2 high efficiency precleaner filters - 1000 cfm cap./filter<br>(c) 2 AEC filters, 1000 cfm cap./filter |
| Special Features | Entire operation glove box controlled. Ash processed for plutonium | Protective half mask type respirator - manual ash handling, ash contains $< 0.01\%$ uranium |
| Filter Life | 8 AEC filters changed after 16 hours - equivalent to 1000 lbs of waste burned | 2 AEC filters changed when resistance $> 2$ in $H_2O$ - equivalent to 1000-1400 lbs waste burned |
| Comment | System reported feasible based on plutonium recovery and reduced storage costs | Base on 28 weeks operation.<br>Reported Total Cost:<br>Offsite disposal - $108,000<br>Incineration - 25,900<br>Saving $ 82,100 |

1000 cu. ft. per min. AEC filters were replaced after 1000 lbs. of waste were burned. Although gas cleaning costs would appear to be prohibitive, Dow personnel claimed significant savings resulting from (a) elimination of storage and burial costs and (b) the recovery value of heavy metals reclaimed from the ash (estimated as 95 per cent of that in raw waste).

Except for the unusual situation, general application of the Dow incineration system would probably be too costly in view of frequent filter changes. In recent discussions with the Rocky Flats personnel, it was pointed out that some improvement in combustion should be attainable by increasing combustion temperatures. Plans have already been made to replace the present gas burner in the main burning chamber with a 150,000 BTU per hr. unit. Since wet scrubbing was excluded as both a cooling and collecting medium because of large water demands by other operations, there appear to be few alternatives for the treatment of the present off-gas. Studies by this laboratory (see heading Harvard Air Cleaning Laboratory Studies, section 2) indicate that typical incinerator effluents tend to cause rapid plugging of filters composed of fibers fine enough to furnish effective pre-cleaning. Electrostatic precipitation was suggested as a possible means of decreasing tar and soot loadings to high efficiency filters, thereby permitting some reduction in the estimated $90,000 per year replacement cost (based on a burning rate of 500 lbs. per day). Further details on the Dow over-all incineration process may be obtained by contacting the Rocky Flats plant.*

2. General Electric Company (APED) San Jose, California

The General Electric Company (APED) San Jose, California employs an incineration unit (Table 2) very similar to the Rocky Flats device, a Plibrico Model No. 1-100 natural gas combustion furnace differing only with respect to thickness of firebrick lining and method of charging. However, the G. E. waste was principally uranium contaminated paper and disposable clothing which constituted 90 per cent of the combustible load. Equipment was located outdoors with a corrugated steel rain cover overhead and no protective hooding was used except for the charging lock. Conventional half mask type respirators and protective clothing were the only safeguards required.

Incinerator combustion temperature was estimated to be in the 1400-1500°F range according to the fabricator's tests. The gas treatment system was comparatively simple, consisting of a baffle spray chamber for cooling and partial scrubbing of coarse material followed by high efficiency precleaning and AEC filters in series. Cooling spray rate was adjusted manually to maintain 300-500°F temperatures in the final filtration stage. High efficiency filter life was not much longer than that experienced with the Rocky Flats system although two, rather than 8 filters were replaced after burning

* Mr. D. D. Balls, Ass't Dept. Supt., Production "C", The Dow Chemical Company, Rocky Flats Plant, P.O. Box 2131, Denver, Colorado.

1000 to 1400 lbs. waste. It appears that the policy of excluding insofar as possible all non-cellulose combustibles was the main reason for slightly longer filter life.

According to G. E. personnel, the reported savings in disposal cost amounted to $82,000 for a 28 week period. Since previous sea burial in concreted drums was quoted as $6.50 per cu. ft., it is easily seen why the present incineration system is well accepted despite frequent filter replacements.

The following cost figures were furnished by Thorburn and Chandler (12) for the 28 week period:

| | | |
|---|---|---|
| Total over-all cost for disposal of 6747 boxes waste by previous system | | $108,000 |
| Total filter cost | $5,200 | |
| Total labor cost | 2,700 | |
| Total incinerator cost including testing | 18,000 | |
| | $25,900 | $108,000 |
| | | - 25,900 |
| | Net Savings | $82,100 |

Currently, the incinerator is operated about one day a week since the backlog of waste has been burned. Assuming 100 lbs. per hour burning capacity (10 boxes at 10 lbs. per box) the yearly volume incinerated would be about 5000 boxes (50,000 lbs.). Using the data tabulated above, over-all disposal by burial would cost $80,000 per year. At the present frequency of operation, it appears that the comparative yearly incineration cost would be less than $10,000 if the incinerator and testing charge is amortized over a ten year period. The actual cost per cu. ft. of waste depends upon the degree of compaction of the material. If packing densities of 5, 10, and 15 lbs. per cu. ft. are assumed for the cellulose waste, the respective disposal costs by incineration are in the order of 1, 2 and 3 dollars per cu. ft. Evaluation of the G. E. (APED) incinerator in this light does not appear to indicate any unusual economies.

## HARVARD AIR CLEANING LABORATORY STUDIES

### 1. Review of Incineration Studies

This laboratory was originally requested to design and evaluate the gas cleaning equipment for use with the U. S. Bureau of Mines BOMAEC-30 incinerator. In earlier reports (10)(11) details of stack sampling tests have been presented for effluent evaluation under a variety of operating conditions. Initial tests were conducted at the Pittsburgh laboratory over the period Dec. 1954 through March 1956. Final tests, which were completed at the Air Cleaning Laboratory during May 1957, indicated that major design changes

were essential. In addition, our inability to control the BOMAEC-30 combustion process, required that we obtain incineration equipment capable of generating a reproducible effluent. This was a necessary step in the development of a suitable gas cleaning system. Preliminary tests on a modified domestic type incinerator "Incinor" indicated that combustion rates in the order of 20 to 25 lbs. per hour were readily obtainable. By lining the burning chamber with ordinary oil burner-type firebrick, gas exit temperature was increased to 1600-1800°F. Waste charges containing as much as 50 per cent moisture were also completely burned. Since the Incinor design was not amenable to revisions which would allow measurement of supply air characteristics (volume, velocity, and location), it was decided to construct our own incinerator. The following factors were considered in the new design:

(1) Tests on the BOMAEC-30 and Incinor units indicated that tar production was minimized when overfire air alone was supplied. Combustion rate, however, was increased when the proportion of undergrate air was increased.

(2) A single chambered, cylindrical burning chamber with tangential overfire air supply appeared to be the simplest design for a compact unit.

(3) Ceramic liners should be installed to maintain high combustion temperatures and allow use of mild construction steels.

(4) Charge ports or doors should be readily accessible, and gasketed tightly to prevent air infiltration in critical locations.

(5) The ultimate design should provide a simple, safe means of continuous charging since under these circumstances the combustion chamber is maintained as hot as possible.

(6) It should be possible to burn high moisture wastes (up to 50 per cent moisture) by charging directly to the combustion chamber.

An experimental incinerator, ACL-I, was developed on the basis of the concepts outlined above and subjected to extensive testing. Waste charges were admitted through a rectangular hopper placed directly above the burning chamber. Preliminary drying of wet waste took place in this hopper prior to dumping (by swing damper) into the burning chamber.

Several operational problems evolved from the combined pre-drying, overhead charge system which led to extensive modifications. In the final design ACL-II described in previous reports (11) a simple, well gasketed charge door six inches above the grate. A cylindrical after-burner (combustion chamber) 20 in. high and 12 in. I.D. was placed directly above the burning chamber. Provision was made to admit secondary combustion air (and auxiliary gas if desired) at the chamber base. All interior surfaces were firebrick lined to permit burning temperatures in the range of 2000°F.

Preliminary evaluation of a slag wool fiber filter for high efficiency precleaning of the ACL-II effluent indicated favorable results (>90 per cent efficient, 0.7 in. water resistance increase for 1000 lbs. of sawdust burned). However, removal of the filter showed that by-passing caused by edge leakage and channelling was responsible for extended filter life. Installation of a new

edge seal prevented all leakage and resulted in rapid (2-3 hour) slag wool plugging. Therefore, a new filter design was proposed which would provide larger filtering area and increased holding capacity.

2. ACL-II Incinerator - Gas Cleaning Studies, Fiber Filtration

A "basket" type filter was fabricated which contained graded glass fiber media in lieu of the slag wool. The new design consisted of a housing (55 gallon drum) into which was inserted two concentric cylinders of expanded metal screening 17-1/2 inches diameter O.D. and 17 inches diameter, I.D., respectively. Cylinder depth was approximately 22 inches. The two grades of fiber used were (a) roughing media Type "G" Airmat*(17 micron diameter glass fiber), and (b) Type FG-25* resin bonded glass fiber (2.5 microns) both obtained in rolls 24 inches wide for easier assembly. The media when sandwiched between sides and bottoms of the two concentric baskets provided 9.0 sq. ft. of filter surface. The inner cylinder was filled with "Vermiculite" (expanded mica) in order to remove any coarse particles from the entering gas. To reduce the gas temperature at the filter inlet (media designed for a maximum temperature of 750°F) an air to gas heat exchanger was placed in the line between the incinerator and the filter. The filter housing, originally designed with a top inlet and side outlet, required change since the hot gases short-circuited through the upper 2 inch portion of filter, fusing the fiber and burning holes. Due to leakage average collection efficiency was less than 75 per cent by weight. (Table 3, tests MB-1 to MB-5). A 55 gallon drum with tangential inlet and outlet was placed in the line downstream of the heat exchanger and upstream of the filter to provide increased gas cooling. The inlet and outlet of the filter were reversed and a baffle plate 18 inches x 12 inches was installed in front of the gas inlet to prevent hot spots. The baffle also forced the gas to contact the walls which aided in reducing the gas temperature. Because of the change of inlet location, the filter media was wrapped about the outer screen. An additional 2 inch band of media was wound about the top and bottom of the filter and then squeezed tightly with a 1 inch band of sheet metal to prevent leakage. The first bed consisted of 3 layers of FG-25 and 3 layers of Type G Airmat, respectively. The bottom of the basket was closed off with a Transite gasket plate. Initial resistance across the bed was 0.25 inches $H_2O$ at 10 fpm. After burning 41 charges (144 lbs. sawdust) resistance rose to 16 inches $H_2O$ at 10 fpm (Tests MB 6-7) and efficiency rose from 83 to 96 per cent. The reason for the rapid increase in resistance was very apparent when the filter wad disassembled. A bluish-black, low porosity, cake had formed which was evenly distributed over the surface of the Type "G" Airmat paper. Subsequent cake analysis indicated that 77 per cent was organic material. The residual ash in the ash pit represented 0.450 per cent of the total charge weight and the average upstream loading to the filter was 22.4 grains per 1000 cu. ft. (STP). Filter inlet and exit temperatures were 890 and 680°F, respectively,

* American Air Filter Corporation, Louisville, Kentucky.

while average maximum stack temperature was 1835°F. Although the efficiency of this filter approached the desired range, its holding capacity was low. Consequently, other types of fiber media and variations in burning techniques were investigated. It was decided to run screening tests with a small scale device which could be quickly assembled and disassembled.

A 6 in. diameter conical filter holder was connected to a sampling line so that a metered aliquot of the incinerator effluent could be drawn through the experimental filter at velocities in the range of 20 ft. per min.

The first such filter, C-1, was formed by compressing three layers of 1 in. Dust Stop media (35-40 micron curled glass fibers) to an average thickness of 0.5 in. During the burning of 35 lbs. of sawdust a small resistance increase was noted, 0.011 to 0.013 in. water. Examination of this filter after testing showed little dust retention. (Tests MB-8 through MB-10).

To attain better collection another filter, C-2, composed of 3 layers of Type G Airmat paper 17 micron diameter fiber was placed in the test circuit. Resistance rose from 0.013 in. to 0.40 in. water following combustion of 141 lbs. sawdust. Collection efficiency based on staining tests was less than 40 per cent. (Tests MB-11 through 13).

A third filter, C-3, similar in construction was tested with slight variation in total system air flow, that is, cooling or dilution air was reduced from 95 to 78 cu. ft. per min. No significant change in filtration was noted. (MB-14 to 15). Tests were not continued on filters C-2 and C-3, since extrapolated curves of resistance vs. operating time indicated that rapid plugging would ensue with further operation.

Following the above tests a 22 in. long cast refractory core was centered within the incinerator afterburner to provide an annular passage 2-1/2 in. wide. The purpose of this device was to divert all gas flow to the hot chamber walls to permit better mixing with secondary air.

Filter, C-4, composed of 3 layers of Type "G" Airmat paper and 3 layers of Dust Stop Media (See Filter C-1) was rated during the combustion of 124 lbs. sawdust. The rapid rise in resistance, 0.018 to 2.28 in. water, indicated that insertion of the core led to higher dust loadings, presumably due to lowered gas retention time and higher entrainment velocities.

After removing the core, filter C-5 was installed, this unit containing 3 layers of Type "G" Airmat and 1 layer of FG-25 bonded glass fiber. Resistance characteristics were consistent with earlier large scale tests with the same media combination (MB-6 and MB-7), i.e., resistance increased from 0.037 to 1.23 in. water with only 21 lbs. of sawdust burned.

It was decided at this point that fiber filtration alone would not suffice

unless much lower face velocities could be accepted. Data reported in Table 3 showed initial and final resistance as measured at 70°F at 10 ft. per minute. These values necessarily increase by a factor of 3 to 4 for the same mass flow due to changes in gas density and viscosity when the gas temperature is in the range of 600-800°F.

3. Electrostatic Precipitation

A small DC electrostatic precipitator (Figure 1) was, therefore, placed upstream of a graded glass fiber filter similar to C-5. The E. S. P., which consisted of a 1.5 inch I. D. steel pipe, 35 inches long was connected to the top of a 5 gallon solvent can. The top portion of the pipe was tee'd to permit suspension of a 0.0625 inch diameter steel wire (the central positive electrode) and to provide a gas outlet to the filter. The wire was pulled taut and insulated at both ends to prevent shorting. The applied potential was 15 kv. at 0.8 milliamps. The secondary cleaner was a 6 inch cone filter (C-6) with 3 layers of Type "G" Airmat and 1 layer of FG-25. During these tests (MB-19-21) 175 lbs. of sawdust were burned and the filter resistance rose from 0.037 inches water clean to 0.088 inches water. The resistance increase appeared to be linear with respect to weight of charges burned.

Stain samples collected up and downstream of the electrostatic precipitator indicated efficiencies greater than 99 per cent. Estimated gas velocity through the precipitator was 300 ft. per min. based on a gas inlet temperature of 500°F. In comparing tests MB-19-21 with MB-18, it should be noted that although nearly 8 times as much sawdust was burned the resistance of filter C-6 was about 15 times lower than C-5 (no E. S. P. in system).

Based upon the encouraging results obtained with the preceding cleaning equipment, plans were made to fabricate and test a larger precipitator for handling approximately half of the effluent gas stream, Figure 1. A 6 inch square stainless steel duct, 39 in. long, provided the housing into which were suspended four 1/8 inch diameter cold rolled steel electrode rods. The duct was divided by a sheet of 20 gage galvanized sheet metal to form two, 3 inch x 6 inch passages. The steel rods were suspended by means of a special "H" shaped harness such that each electrode was equidistant from the walls and from each other. To each end of the rectangular housing, 5 gallon solvent containers (10 1/2 inch diameter x 14 inches long) were attached to provide an inlet and outlet for the gas stream. Static and dynamic cold tests showed no arcing even with voltages upwards of 15 kv. at 0.8 milliamp (our voltmeter was limited to a maximum of 15 kv.). In the first test (run MB-22) 25 lbs. of sawdust were burned. Simultaneous stain samples collected up and downstream of the E. S. P. (average gas velocity 400 ft. per min., inlet temperature 930°F, outlet temperature 570°F) showed comparatively high efficiency, 95 per cent. However, as burning progressed, it was necessary to reduce voltage to values ranging from 8.5 to 11.4 KV in order to prevent arcing. Weight collection efficiency during the later tests (MB-23 and MB-24)

TABLE 3

ACL-II INCINERATOR - SUMMARY OF COMBUSTION AND GAS CLEANING TESTS

| Test Number | Gas Cleaning System | Filter Resistance In Water at 10 fpm, 70°F Initial | Filter Resistance In Water at 10 fpm, 70°F Final | Weight Sawdust Burned lbs. | Inlet Dust Loading grains/ft$^3$ | Weight Coll. Eff. % | Combustion Air CFM-STP Primary | Combustion Air CFM-STP Secondary | Dilution Air CFM-STP | Burning Rate lbs/hr |
|---|---|---|---|---|---|---|---|---|---|---|
| MB1-MB5 | 2 layers Type G Airmat 3 layers FG-25 | 0.15 (Filter ruptured) | 0.054 | 249 | 0.025 | 68-75 | 50 | 8 | 50 | 23 |
| MB6-MB7 | As above | 0.25 | 16.0 | 144 | 0.022 | 83-96 | 50 | 8 | 50 | 25.5 |
| MB8-MB10 | C-1 3 layers Dust stop Media | 0.011 | 0.013 | 35 | 0.021 | <10 | 42 | 18 | 113 | 26 |
| MB11-MB13 | C-2 3 layers Type G Airmat | 0.015 | 0.40 | 144 | - | Stain <40 | 42 | 18 | 95 | 26 |
| MB14, MB15 | C-3 As above | 0.011 | 0.27 | 113 | 0.020 | Stain <50 | 40 | 15 | 78 | 26 |
| MB16, MB17 | C-4 3 layers Type G Airmat 1 layer Dust Stop | 0.018 | 2.3 | 124 | 0.023 | - | 55 | 18 | 85 | 26.5 |
| MB18 | C-5 3 layers Type G Airmat 1 layer FG-25 | 0.037 | 1.2 | 21 | - | Stain 80 | Variable | | - | 18 |
| MB19-MB21 | 1-1/2" E.S.P. plus filter as above (C-5) | 0.037 | 0.08 | 175 | 0.024 | Stain 99 E.S.P. | 55 | 18 | None | 26 |
| MB22-MB24 | 6" E.S.P. No filter | - | - | 74 | 0.024 | 78 avg | 49 | 20 | None | 26 |

NOTES:

Type G Airmat - Fiber Diameter 15-20 microns, Packing Density = 4 lbs/ft$^3$ 1/16 in. thick

FG-25 - Fiber Diameter 3 microns, Packing Density = 0.5 lb/ft$^3$ 1/2 in. thick

Dust Stop - Fiber Diameter 40 microns, Packing Density = 0.35 lb/ft$^3$ 1 in. thick (nominal)

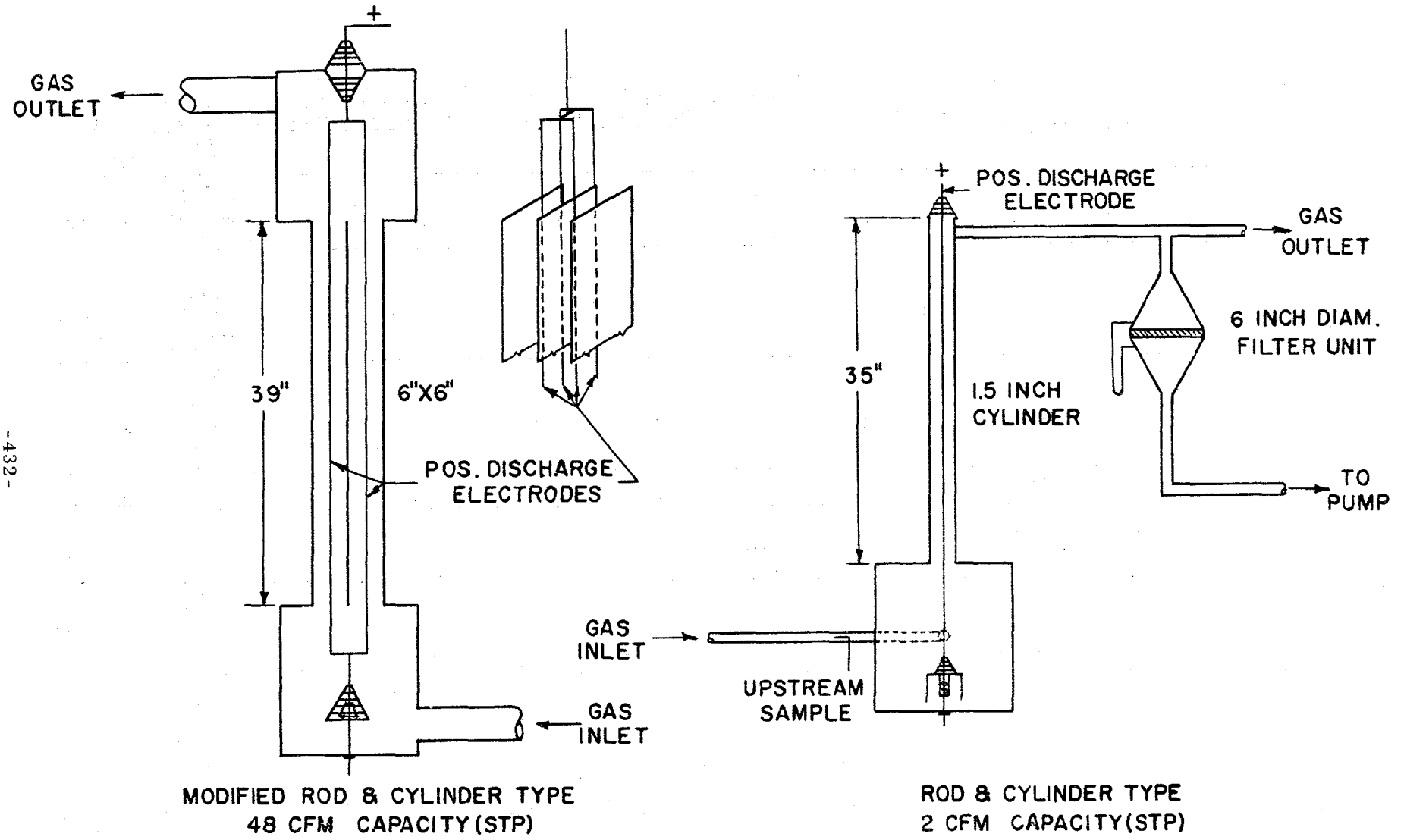



FIG. 1 EXPERIMENTAL ELECTROSTATIC PRECIPITATORS

dropped to lower levels than expected, 78 per cent.

Theoretically, electrode spacing should have permitted voltages in excess of 15 KV with our system. However, thermal distortion of electrodes plus both mechanical and electrical oscillation of the center electrodes disturbed the system geometry. Furthermore, by reversing the polarity of the discharge electrode, (negative rather than positive) higher potentials and more stable operation would be expected. Positive central electrodes were used in our tests to simplify shielding and insulation problems. Gas velocities were also higher (400 ft. per min. average) than those for the small E. S. P. unit tested previously. With the proper materials of construction fabrication of a unit capable of at least 99 per cent weight collection appears entirely feasible.

Inspection of the interior of this collector showed a gray to black deposit on the ground electrodes, some of which could be dislodged by rapping and all of which was removed by brushing or gently scraping the wall. It is recommended that cleaning of collecting electrodes be performed only during unit shut-down to avoid unnecessary dust entrainment. Based upon long period testing, it appears that average solids emission from the incinerator will be in the order of 0.25 lbs. per hour (4 lbs. per 8 hour burning day). Since this quantity of dust could lead to excessive electrode deposition, it may be necessary to operate two collectors in parallel with one on standby.

During all incineration tests, gas temperature measurements were recorded at various sections of the system; i.e., incinerator stack, inlet and outlet of gas cleaning devices, and at flow metering locations. Representative values for incinerator outlet temperature are plotted in Figure 2 for a one hour combustion test (MB-22).

Continuous analyses of stack gas composition were also made with respect to per cent oxygen, carbon dioxide, and per cent combustibles. Variation of $O_2$ and $CO_2$ concentrations are shown for one hour's testing in Figure 3. Instantaneous values of $CO_2$ and $O_2$ did not necessarily check since the former device reports an integrated CO value. However, graphical integration of the areas under these curves indicates good correlation with the quantity of solids burned.

Based upon the research of this laboratory and that of the U. S. Bureau of Mines, tentative specifications were prepared for a combined incineration-gas cleaning system.

These were sent to several manufacturers of incineration equipment or electrostatic precipitators with the request that tentative cost estimates be submitted for fabrication of a prototype incineration-gas cleaning system. These specifications are presented in their original form under the headings, Specifications for Small Institutional Type Incinerator for Disposal of Low-Level Radioactive Waste and Specifications for Gas Cleaning Equipment for

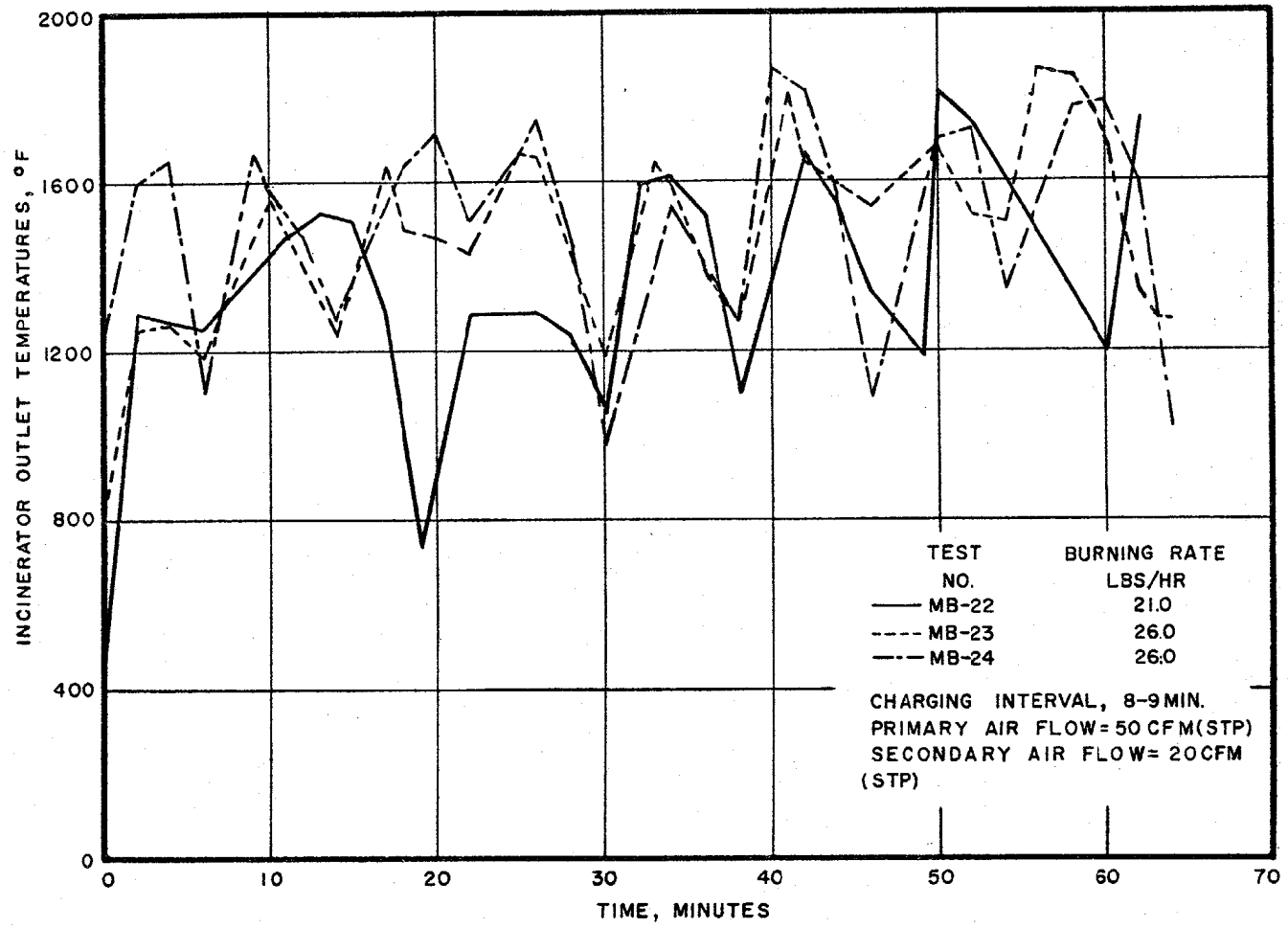



FIG. 2 GAS TEMPERATURES AT A.C.L. II INCINERATOR OUTLET WITH COMBUSTION OF BAGGED SAWDUST CHARGES (3.5 LBS/BAG)

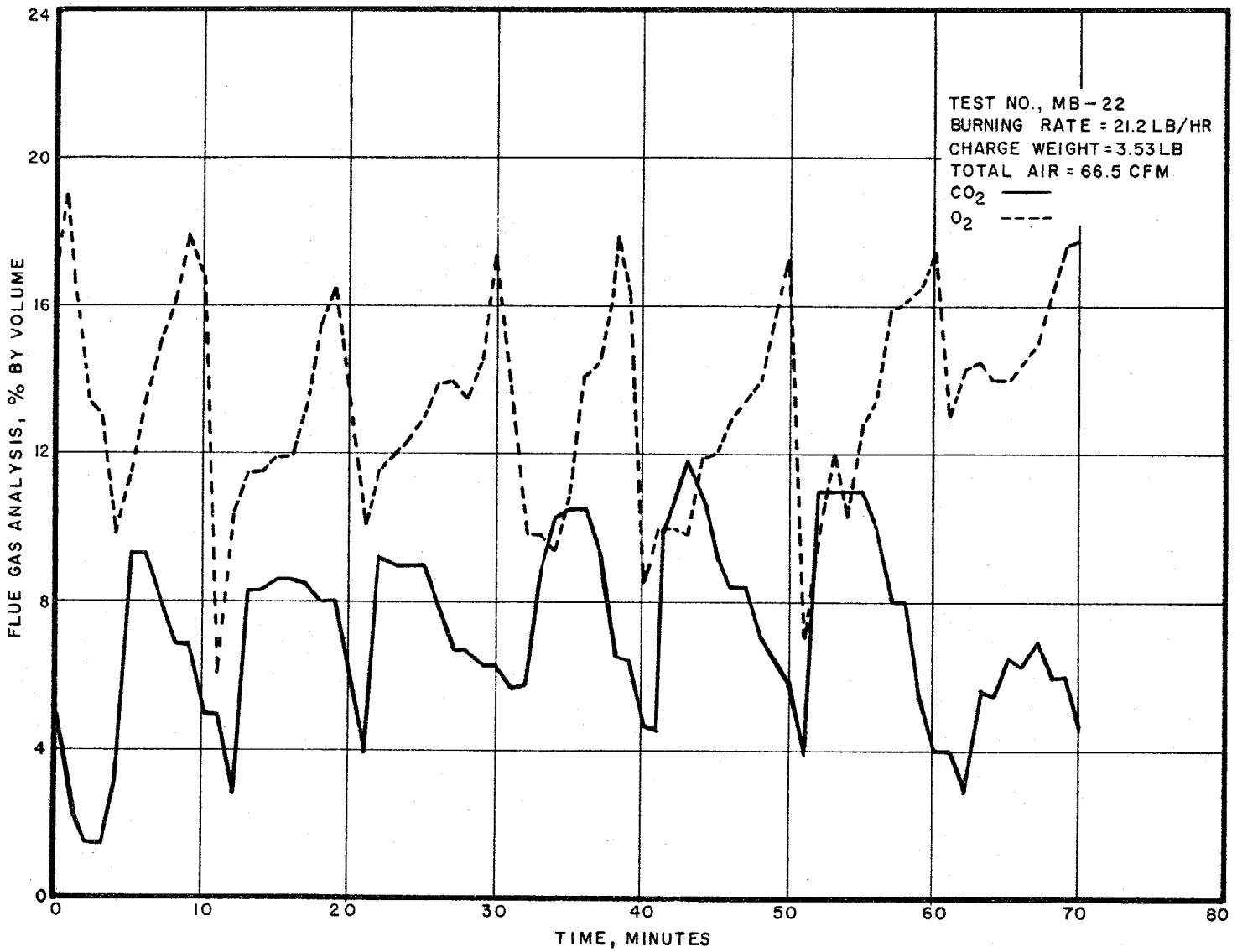



FIG. 3 A.C.L. II INCINERATOR FLUE GAS ANALYSIS

Use with Small Institutional Type Incinerator for Disposal of Low-Level Radioactive Waste.

## SPECIFICATIONS FOR SMALL INSTITUTIONAL TYPE INCINERATOR FOR DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE

### Legal Notice

This specification was prepared by the Harvard Air Cleaning Laboratory in conjunction with Government sponsored work. Neither the United States, nor the United States Atomic Energy Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this specification, or that the use of any information, apparatus, method, or process disclosed in this specification may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this specification.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

The following specification is for a small institutional type incinerator which can be used by hospitals and laboratories for the disposal of combustible low-level radioactive wastes ( $\leq$ 200.0uc per kilogram of charge).

Gas cleaning equipment, which will be necessary in most cases in conjunction with use of the incinerator to prevent excessive release of radioactivity to the atmosphere, is described in a separate specification.

Facilities and special equipment for storage of unburned waste and final disposal of ash residues are not included in this specification.

### 1. Basic Incinerator Design - Combustion Principle

Incinerator specifications are based upon evaluations of a full scale

experimental unit, ACL II, developed by the Harvard University Air Cleaning Laboratory*. Design criteria for this unit with respect to combustion method only were based upon the earlier studies of the U. S. Bureau of Mines, Combustion Research Section**. Corey, et al of that group concluded that (a) uniformity of combustion rate and maximum combustion efficiency for single chambered incinerators designed for burning typical laboratory wastes (low bulk density, low ash, and relatively high volatile content) was best achieved with an overfire air supply, and (b) that the mass flow rate and direction of overfire air could be best controlled by admitting air tangentially to a cylindrical combustion chamber.

Advantages of this combustion system were as follows:

(1) Elimination of gas flow fluctuations caused by passage of underfire air through a diminishing mass of charge and variable open grate area.

(2) Increased gas stream turbulence which causes better mixing of combustibles with air and more rapid heat transfer from heated walls to gas stream.

(3) Increased combustible retention time due to vortical or cyclonic gas flow which permits greater burning efficiency in a single chamber combustion unit.

(4) Increased solids retention in the burning chamber as a result of centrifugal forces exerted on particles entrained in the rotating gas stream.

The method of combustion air supply (tangential overfire) and the relative proportions of the cylindrical burning chamber, both developments of the U. S. Bureau of Mines, are incorporated in the ACL II incinerator design.

The installation and construction of an after-burner section and the method of waste charging are developments of this laboratory.

2. General Description of Incinerator

The incinerator described in this specification (see Drawing HU-1) consists of a single, cylindrical combustion chamber (23 in. O.D. and 27-1/2 in. high) with a cylindrical after-burner chamber (16 in. O.D. and 23 in. high) mounted directly above. Both chambers are constructed from mild steel and lined with 2 in. thick refractory (oil burner type) to maintain high wall and combustion gas temperatures (2000°F range). Primary overfire air, 50 cu. ft. per min.,

* Dennis, R., Muller, F. L., Kristal, E., Silverman, L.: Special Incineration Studies - Institutional Design. Proceedings of the 6th AEC Air Cleaning Conference, July 7-9, 1959. TID-7593.

** Corey, R. C., Spano, L. A., Schwartz, C. H. and Perry, H.: Experimental Study of Effects of Tangential Overfire Air on the Incineration of Combustible Wastes. Air Repair 3:1-8 (1953).

is admitted tangentially through a single rectangular inlet (1 in. wide x 2 in. high) located 15 in. above the grate in the combustion chamber. Secondary combustion air, 20 cu. ft. per min., is admitted tangentially about 2 in. above the base of the after-burner section.

Both air supply lines should lead from a common plenum in which metal screen and glass fiber filters are placed to guard against blow back.

Waste material is introduced as packaged charges (3 to 5 lbs. at a time) through a side loading door, 14 in. wide and 10 in. high, the bottom of which is located 6 in. above the grate. A two pronged sliding fork inserted through the loading door permits temporary suspension of wet packaged charges above the grate (1 min.) to facilitate rapid drying. Burning rates vary from 15 to 25 lbs. per hour depending upon the charge composition.

Hot combustion gases exit tangentially from the top of the after-burner so that the spiral gas flow pattern can be maintained throughout the entire unit. The effluent gas is cooled by addition of dilution air shortly after leaving the after-burner. The volume of cooling air required is approximately equal to that of the total combustion air. Exact cooling volumes selected will depend upon the type of gas cleaning equipment used.

The incinerator grate, located 7 in. above the conical ash receiver, can be rotated 340° about centerline to dislodge any ash or debris not falling through the bar type grating. The conical ash receiver flanged to the bottom of the combustion chamber discharges to a 30 gallon drum used for final storage of ash. A butterfly damper is placed at the bottom of the conical section to prevent ash spillage during change of ash drums.

3. Specifications

1.00 Operating Specifications

1.10 Burning Requirements

1.11 The incinerator shall be capable of burning dry combustible wastes, i.e. less than 10 per cent moisture, at a rate of no less than 20 lbs. per hour.

1.12 The incinerator shall be capable of burning wet combustible wastes (i.e. up to 50 per cent moisture, bone dry basis) at no less than 15 lbs. per hour.

1.20 Charge Composition

1.21 The incinerator shall be capable of handling combustible waste charges containing any or all of the following

materials: waste paper, towels, swab rags, surgical dressings, small animal carcasses, human or animal organs, rubber gloves, rubber or plastic tubing, animal pen debris, i.e. sawdust, feces, vegetable matter.

1.22 Charging of broken glass, metal scraps, or other non combustibles to the incinerator shall be avoided. No materials known to burn with explosive violence shall be charged to the incinerator.

1.23 The incinerator shall not be used for burning any non-radioactive waste except for the purpose of preheating the combustion chamber.

1.30 Waste Charging

1.31 The incinerator charge door shall be designed so that waste may be charged in sealed combustible leakproof bags (plastic or treated cellulose) approximately 11 in. x 8 in. x 7 in.

1.32 A manually operated protective slide baffle in conjunction with a semi- or totally enclosed charging lock shall be used when loading the incinerator. This equipment prevents accidental release of dust or fume under normal operating conditions and protects the operator from violent puffs or blow back. Dwg. HU-2 illustrates two possible charge door and lock constructions.

1.33 Provision shall be made to provide rapid venting of moisture when charges are placed in the incinerator. A tear tab which covers perforations in the package and which can be peeled back while the package rests in the loading hopper is the recommended method to provide vent holes.

1.34 Waste packages shall be charged to the incinerator at fixed intervals, approximately every 3-4 minutes in the case of typical miscellaneous waste charges.

1.35 If burning time is erratic due to variability in composition of bagged charges, the charging cycle shall be determined by the change in temperature of the stack effluent. Nearly complete combustion is indicated when effluent gas temperatures drop to a value 2/3 that of the maximum temperature ( $>$ 1800°F for dry waste, less than 10 per cent moisture and $>$ 1200°F for wet waste, up to 50 per cent moisture). Recharging is therefore indicated at temperatures of about 1200° and 800°F, for dry and wet wastes,

respectively. See Section 1.83 for temperature instrumentation.

1.40 Combustion Air

1.41 Primary combustion air shall be supplied at a rate not to exceed 50 cu. ft. per min.

1.42 Secondary (auxiliary combustion air) shall be supplied at a rate not to exceed 20 cu. ft. of air per min.

1.43 Air leakage through the charge door shall not exceed 10 per cent of the primary air flow.

1.50 Preheating

1.51 Preheating of the combustion chamber to proper operating temperatures shall be accomplished by burning approximately 15 to 20 lbs. of any dry, compacted cellulose type waste containing a negligible amount of ash and distillable organic materials, i.e. unsized, uncoated paper.

1.60 Auxiliary Fuel

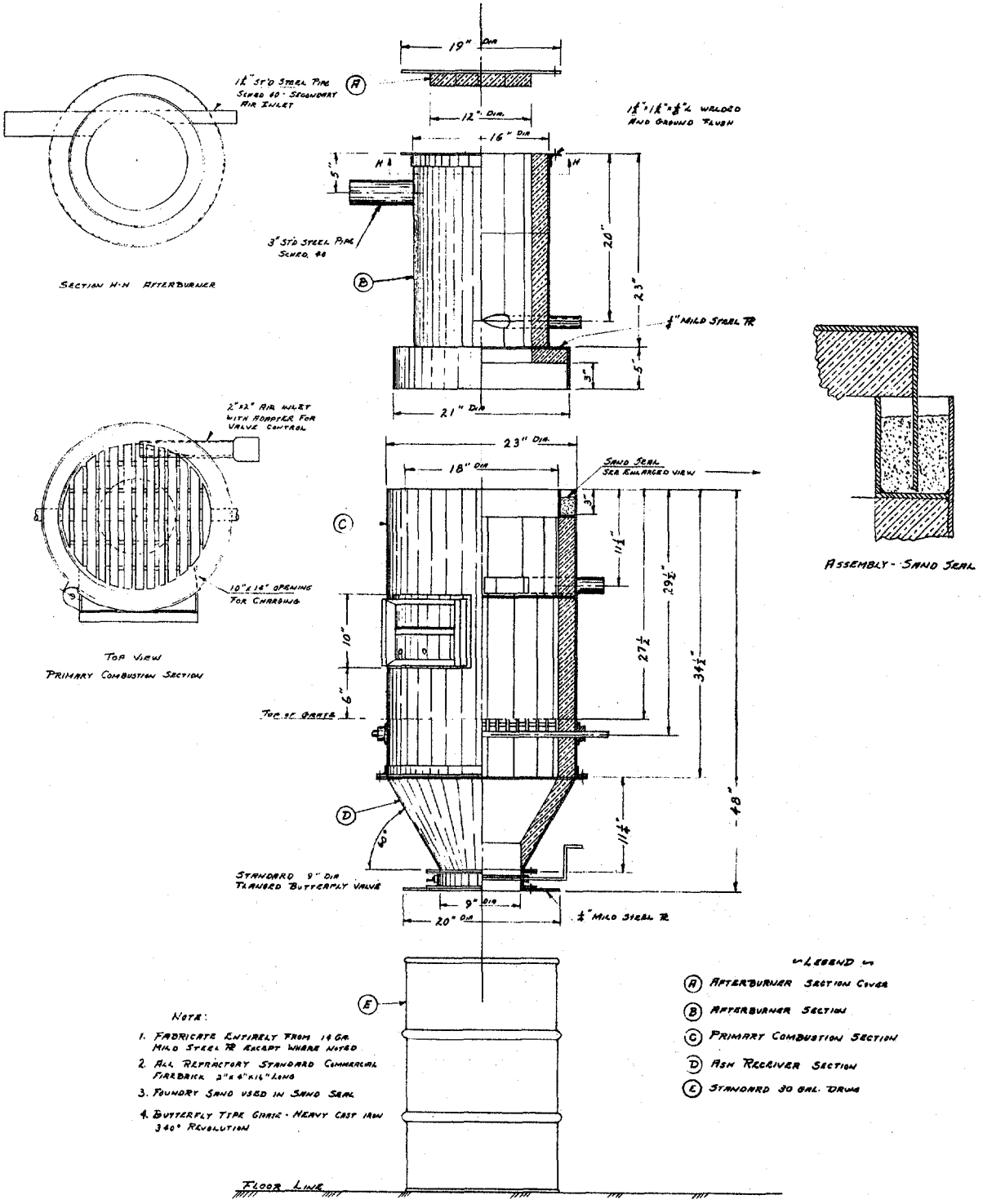
1.61 Provisions for use of continuously or intermittently-operated auxiliary gas or oil firing shall not be included in the incinerator design. Although the use of auxiliary fuels for after-burning can improve the quality of effluent, i.e. less soot, their use introduces hazards which can only be safely controlled by the use of expensive control and safety devices.

1.70 Space Requirements

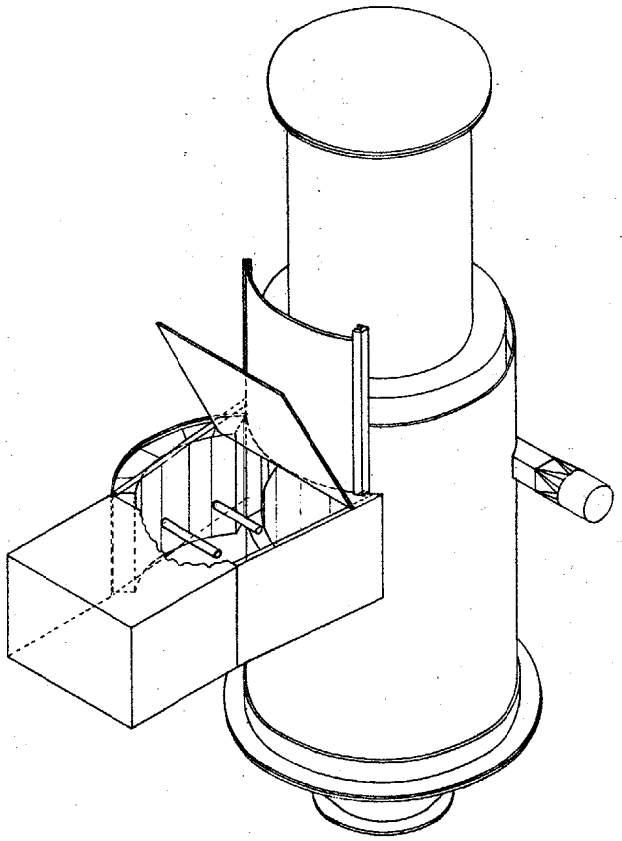
1.71 The over-all space requirement of the incinerator proper and the gas cleaning equipment used in conjunction with the incinerator shall not exceed 8 ft. x 10 ft. floor area. This restriction is necessary since additional storage space for unburned waste and ash storage drums will also be required, approximately 5 ft x 8 ft. Floor space requirements may be reduced if it is feasible to install incineration and gas cleaning equipment in a vertical orientation at two elevations.

1.80 Operating Requirements and Control Devices

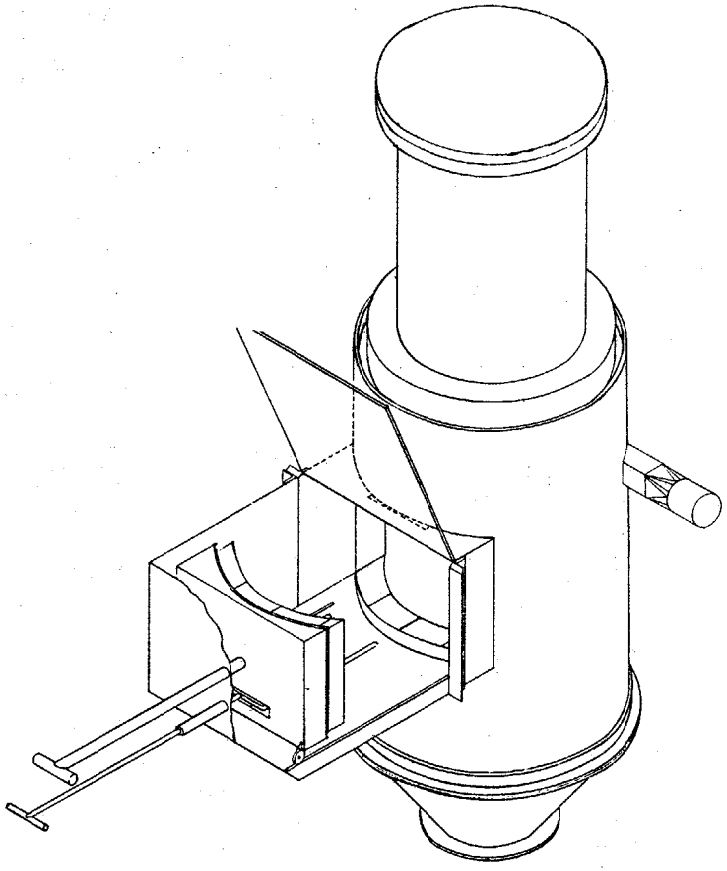
1.81 The incineration unit shall be capable of continuous operation by personnel such as those trained for typical heating plant or incinerator firing and maintenance duties.




INSTITUTIONAL TYPE INCINERATOR
FOR
DISPOSAL OF LOW LEVEL RADIOACTIVE WASTES



METHOD 1



METHOD 2

SCHEMATIC

PROPOSED CHARGING MECHANISM FOR INSTITUTIONAL INCINERATOR

1.82 Provision shall be made to meter and regulate separately primary and secondary combustion air. Both flow rates should be measured by conventional orifice meters to indicate flow rate on a direct reading scale. Resistance loss through the flowmeters shall not exceed 1 in. water.

1.83 Provision shall be made to measure incinerator effluent gas temperature and average temperature of the refractory lining of the combustion chamber. Effluent gas temperature shall be measured by a shielded dial thermometer (500°F to 2500°F range) located 8 in. from the after-burner outside wall in the center of the discharge pipe. Average refractory brick temperature shall be measured by a dial thermometer (500° to 1000°F range) inserted halfway through the refractory lining at a point 16 in. above the grate and directly opposite the primary air inlet.

1.90 Combustion Products

In order to obtain optimum gas cleaning the gaseous effluent from the incinerator shall meet the following minimum specifications.

1.91 Gas Volume. Total undiluted gas volume discharged from the incinerator shall not exceed 80 cu. ft. of gas per min. (measured at 70°F and 29.92 in. Hg) when wet charges containing 50 per cent water are burned and shall range between 75 and 80 cu. ft. per min. for wastes containing less than 50 per cent moisture.

1.92 Gas Temperature. The maximum temperature of the total gas volume leaving the incinerator, i.e. combined primary and secondary air shall fall within the range of 1700° to 2100°F for dry wastes ($<$10 per cent moisture) and shall be no lower than 1200°F for wastes containing up to 50 per cent moisture (bone dry basis). Temperature regulation in the stack shall be controlled by adjustment of the primary supply air.

1.93 Refractory Brick Temperature. Incinerator wall temperature as measured by a dial thermometer imbedded at a point 1 in. from the metal incinerator shell at the midpoint of the 2 in. thick refractory lining shall show a temperature of not less than 450°F after one hour after preheating (approximately 15-20 lbs. of preheating charge).

1.94 Dust Concentration and Composition. The following criteria shall be based on combustion tests with a wood sawdust (No. 5 grade,

Kiln dried, hardwood-maple or birch, 4 to 8 mesh, 10 per cent moisture, bagged to 15 lb. per cu. ft. packing density) with a burning rate of 25 lbs. per hour.

1.941 Average total stack loadings shall not exceed 0.05 grains per cu. ft. of gas (STP) based upon a total combustion air flow of 75 cu. ft. per min. (50 cu. ft. per min. primary overfire, 20 cu. ft. per min. secondary, and 5 cu. ft. per min. leakage through charge door).

1.942 Maximum stack loading shall not exceed 0.5 grains per cu ft. on the basis of 75 cu. ft. per min. total combustion air.

1.943 Stack loadings shall not exceed average loadings for more than 25 per cent of the combustion cycle.

1.944 Average solid stack effluent composition for a complete sawdust cycle shall not contain greater than 70 per cent combustibles. Total solids emission on a weight basis shall not exceed a value of 0.00125 lbs. of total ash per lb. of sawdust charge. All stack effluent measurements will be made at a point no further than 3 ft. from the incinerator exit and in accordance with the ASME Power Test Code.

Specifications for Gas Cleaning Equipment for Use with Small Institutional Type Incinerator for Disposal of Low-Level Radioactive Waste

## Legal Notice

This specification was prepared by the Harvard Air Cleaning Laboratory in conjunction with Government sponsored work. Neither the United States, nor the United States Atomic Energy Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in the specification, or that the use of any information, apparatus, method or process disclosed in the specification may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in the specification.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

This specification has been prepared for gas cleaning equipment to be used in conjunction with a small, institutional type incinerator designed to burn low level, $\leq$ 200uc per kilogram, radioactive wastes.

Composition of charges will necessarily be variable and may include such items as paper toweling, rags, surgical dressings, rubber gloves, small animal carcasses, animal pen debris (sawdust, feces, vegetable matter, etc.). Waste moisture content may run as high as 50 per cent on a bone-dry basis.

It is expected that the gaseous effluent from the incinerator will contain condensable organic substances, fine soot particles, and a variable mineral dust loading dependent upon the waste charge composition. In other respects the gaseous components of the effluent will be essentially those of a typical heating plant flue gas, i. e. principally air (deficient in oxygen), carbon dioxide, and water vapor.

Since the incinerator is proposed for use in locations where liquid radioactive waste handling facilities are probably not available or are not

often desired, gas cleaning should be accomplished by dry collection methods. Hence, wet scrubbing techniques, which can cool as well as partially clean the gas, are excluded.

Since gas cleaning will be restricted to dry methods the following factors must be given special consideration.

1. Incinerator effluent gas must be cooled by heat transfer units (fin cooling, extended air-gas surfaces) or by dilution with ambient air to temperatures consistent with the corrosion resistance and collection characteristics of the gas cleaning devices.

2. Gas temperature at all times must be kept above its dew point to minimize water condensation in the heat exchanger and prevent it within the collecting system.

3. High boiling point volatiles which can condense to form a tar fog should be collected by equipment not subject to plugging so that collector resistance will not be excessive. High efficiency precleaner or absolute type AEC fiber filters are excluded as primary cleaners since it has been shown that typical incinerator effluents rapidly plug these media.

1. Incinerator Effluent Description

Basic data for design of the gas cleaning equipment is furnished in the following section.

A. Gas Volumes

1. Total gas volume discharging from the incinerator combustion chamber will not exceed 80 cu. ft. per min. at STP (70°F and 29.92" Hg).

2. Total volume of dilution air used to cool the incinerator effluent (80 cu. ft. per min. STP) will be at least 80 cu. ft. per min. STP to reduce temperature to 1000°F or lower.

The volume of dilution air may be increased, if desired, to provide lower gas temperatures in the gas cleaning apparatus. Two conflicting factors must be balanced - increased dilution lowers the dew point of the gas so that moderate temperature fiber filtration, 100 to 150°F, without moisture condensation can be carried out with available commercial filter design. However, such dilution may lead to intermediate gas temperatures, 250° to 350°F, in an electrostatic precipitator. In this temperature range collection efficiency may not be optimum.

B. Gas Temperatures

Gas temperature of the undiluted incinerator effluent will be

approximately 2000°F. The temperature of the combined incinerator and dilution air mixture, 160 cu. ft. per min., STP, will be approximately 1000°F (100 per cent dilution).

C. Dust Loadings

Average incinerator effluent loadings will be approximately 0.025 grains per cu. ft. in the diluted (cooled) gas stream (160 cu. ft. per min., STP) when low ash material is burned such as sawdust. Dust loadings may occasionally attain values as high as 0.5 to 1 grain per cu. ft. if high ash material is charged to the incinerator, i. e. heavily sized paper, bones, mineral filter aids, etc.

D. Solids Discharge Rate

The solids discharge rate will average 0.035 lbs. per hour as combustible organics (soot and volatiles, when low ash, $<$ 1 per cent) waste is burned.

The solids discharge rate may occasionally rise to levels as high as 1 lb. per hour when high ash waste is burned, i. e. heavily sized paper, bones, etc. Average solids emission for typical wastes should not exceed 0.25 lb. per hour on the basis of long term burning.

E. Gas Composition

Carbon dioxide will be the major acid gas component in the incinerator effluent. Corrosive acid vapors (nitric, hydrochloric, sulfuric, hydrofluoric, etc.) may occasionally be present in the gas stream.

Water vapor will be present in percentages ranging from that of power plant flue gases (about 4 per cent) to values as high as 7 per cent.

The dew point of the effluent gas will be in the range of 150°F based upon a total gas flow of 160 cu. ft. per min., STP

2. General Performance Specifications

1.0 Components of Gas Cleaning System

The gas cleaning system shall be composed of three basic units:

a. Cyclone collector to remove coarse particulate carryover and reduce gas temperature by approximately 200°F.
b. Electrostatic Precipitator - Cottrell type - to furnish a minimum collection efficiency (weight basis) of 95 per cent and average efficiency of 97 per cent with the inlet loadings and gas volumes

set forth under Section I. A and C.

c. Mineral type fiber filter unit for (a) final cleaning of effluent, and (b) emergency protection against electrical power failure.

1.1 Cyclone Design

The cyclone shall be designed to handle gas volumes in the range of 150 to 200 cu. ft. per min. (STP) with an inlet velocity of 3500 ft. per min. at operating temperature. Dilution (cooling) air volumes in excess of 80 cu. ft. per min. STP, shall be admitted to the system downstream of the cyclone. Cyclone collection efficiency shall be at least 100 per cent for particles having diameters greater than 20 microns and a specific gravity of 2.0.

The cyclone shall be constructed from materials resistant to high gas temperature, $>$ 1000°F, and not readily corroded by flue gases.

A ceramic lining (preformed firebrick, castable cement, or ceramic spray treatment) in conjunction with a mild steel shell may be used to minimize temperature and corrosion problems.

Cyclone resistance shall not exceed 3 inches of water.

1.2 Electrostatic Precipitator Design

The electrostatic precipitator shall be either of the rod and cylinder or rod and plate type with ionizing electrode voltages in the range of 15 to 25 KV, D.C.

Collection efficiency shall be at least 99 per cent by weight under average combustion conditions and no lower than 97 per cent during combustion of high volatile wastes.

Based upon theoretical considerations and laboratory studies, an efficiency of 99 per cent should be attainable with a rod and plate type unit (rods and plates aligned parallel to flow) having a plate depth of 3.3 feet, an inlet gas temperature of 750°F, and an average gas velocity of 120 ft. per minute. Provision shall be made to clean the electrostatic precipitator manually only when the incinerator is not in use and collect the dust in a storage hopper located below and tightly sealed to the unit so that no dust escapes to the working area. Storage hopper capacity shall be sufficient for at least 120 hours of continuous burning - approximately 30 lbs. of dust for fifteen 8 hour days assuming an inlet dust concentration of 0.25 grains per cu. ft.

The precipitator shall be designed to operate at gas temperatures in the range of 500 to 800°F or 100 to 200°F. Materials of construction shall

be heat resistant and not subject to corrosion by flue gases. Thermal warping of collector surfaces should be minimized.

1.3 Fiber Filtration Unit

The fiber filtration unit shall be designed to operate at gas temperatures up to but not greater than 500°F depending upon the selected cooling air volume.

Collection efficiency for the effluent leaving the electrostatic precipitator under normal operation should be at least 75 per cent.

Collection efficiency for the incinerator effluent (in the event of electrical power failure) should be at least 90 per cent.

Filter resistance should not exceed 1 inch of water when clean and 3 inches of water at the end of its service life.

Provision should be made to measure filter resistance by means of a standard manometer.

The operating life of the fiber filter unit should be at least 30 days under normal operating conditions. The period of continued operation of the fiber filter unit, should the electrostatic precipitator fail, should be at least 30 minutes so that the residual charge in the incinerator may be completely burned at adequate gas flow rates.

With provision to cool the incinerator effluent to less than 200°F, commercially available filters (high efficiency precleaning types such as those manufactured by Mine Safety Appliances Co., Farr Co., Flanders Filters, Inc., and Cambridge Filter Corp.) may provide the desired cleaning.

Special filter compositions prepared from high temperature resin or ceramic bonded glass or mineral fibers, and designed with leakproof edge seals will be required for filtration temperatures $\geq$ 200°F. Metal fibers might also be used provided that they can withstand thermal and corrosive action of the gas stream.

Since the ACL II incinerator is designed to operate without auxiliary gas firing, gas temperatures within the combustion chamber are closely related to charging rate. In laboratory testing, a fresh waste package was not added until the previous charge was nearly consumed. However, the personnel protection afforded by a double-door loading hopper should permit increased charging rate and hence more uniform combustion temperatures.

If animal carcasses and other high moisture material constitute a large fraction of the waste, auxiliary gas firing equipment, at least on an intermittent basis, should be an integral part of the unit.

ACL-50 Incinerator Design

At the present time this laboratory is preparing design specifications for a 50-lb. per hour incineration-gas cleaning system which, when fabricated, will be installed in the U. S. Army Chemical Center, Nuclear Defense Laboratory at Edgewood, Maryland. This project is sponsored jointly by the U. S. Atomic Energy Commission and the U. S. Army Chemical Corps. Testing and evaluation will be conducted by the NDL group with the assistance of the Air Cleaning Laboratory.

The NDL site is currently acting as a collection and holding depot for various types of liquid and solid wastes from Edgewood and outside facilities. A large part of this material is in the combustible, low-level activity category and includes animal carcasses. Therefore, in preliminary design conferences, it was decided that provision for continuous gas firing would be mandatory. Otherwise, basic dimensions of the ACL-50 unit would follow those of the smaller 25-lb. per hour incinerator. However, it was emphasized that a simple geometrical scale-up would not necessarily guarantee performance comparable to the smaller device.

In our preliminary design drawings, the grate area for the ACL-50 model is twice that of the ACL II. Length to diameter ratios for main and afterburner sections are the same for ACL-50 and ACL II units.

Since previous studies indicate that incinerator performance is a function of both supply air rate and inlet velocity, interchangeable inlet sections will be provided with the field model. Allowance has also been made to vary the number (one or two), inlet diameter, and direction (horizontal or 30° downward) of supply air inlets to the main burning chamber.

It is expected that use of continuous gas firing will not only stabilize combustion temperatures but also permit higher average temperatures, 2000-2500°F. Ordinarily, many commercial type incinerators operate at the 1500-1600°F level which does not appear sufficiently high to eliminate tar and soot formation. Although it is recognized that increased combustion temperatures produce high oxides of nitrogen concentrations in power boilers,

their formation in small volume incineration systems is not considered an environmental pollution problem.

Choice of insulating refractories is under careful study since it is desired to use mild steel construction whenever possible. Laboratory tests have shown that utilizing tangential air at the inlet reduces inside refractory temperature as a result of surface scouring. At the same time supply air is preheated prior to entering the combustion zone.

Since the incinerator effluent gas is expected to depart at high temperatures, ceramic ducting or water-cooled stainless pipe will be installed up to the junction with the dilution (cooling air) duct. The basic gas cleaning system will be essentially the same as that described in the ACL II specifications. Qualitatively, inclusion of auxiliary gas burners should produce a cleaner effluent. However, it is proposed that the gas cleaning system be scaled in direct proportion to burning capacity in the NDL installation pending results of field evaluation. Decontamination levels for low-level particulate activity ($<$ 200uc per lb.) are expected to reduce final stack concentrations to near permissible values. However, it is again emphasized that carbon, sulfur, iodine and phosphorus isotopes are subject to partial removal only with the proposed cleaning system. Should these materials constitute the major activity loading, the hazard associated with their release to atmosphere should be assessed prior to adopting the ACL II or NDL gas cleaning system. Although gas scrubbing or adsorption devices could be added to the cleaning system, attendant disposal costs might be increased to impractical levels.

## REFERENCES


1. McEwen, M., Schauer, P. J., and Aponyi, T.: Development of the Flow Sheet for Incinerating Contaminated Combustible Waste. USAEC Rpt. No. MLM-567, Mound Laboratory, Miamisburg, Ohio (May 15, 1951).

2. Rossano, A. T., Jr., Silverman, L., and First, M. W.: A Preliminary Field Survey of Air Cleaning Activities at Atomic Energy Commission Facilities. USAEC Rpt. No. NYO-1580, Harvard University (February 1, 1951).

3. Schulte, H. F.: The Los Alamos Incinerator. Third AEC Air Cleaning Conference, Los Alamos Scientific Laboratory, Sept. 21-23, 1953. WASH-170, p. 11-12, Washington, D. C. (November, 1954).

4. Industrial Hygiene Group: Preliminary Report on the Los Alamos Incinerator Effluent Collector Performance. Air Cleaning Seminar, Ames Laboratory, Sept. 15-17, 1952. WASH-149, p. 185-6, Ames Laboratory (March, 1954).

5. Rodger, W. A.: The Argonne Incinerator Program. Air Cleaning Seminar, Ames Laboratory, Sept. 15-17, 1952. WASH-149, p. 170-184, Ames Laboratory (March, 1954).

6. Rodger, W. A. and Hampson, D. C.: Operating Characteristics and Economics of a 100 $ft^3$/Day Incinerator for Radioactive Wastes. JAPCA 6:41 (May, 1956).

7. Ekman, F. O. and Johnstone, H. F.: Collection of Aerosols in a Venturi Scrubber. Ind. Eng. Chem. 43:1358 (June, 1951).

8. Corey, R. C.: Process Variables Study of Incineration Using Tangential Overfire Air. Air Cleaning Seminar, Ames Laboratory, Sept. 15-17, 1952. WASH-149, p. 154-169, Ames Laboratory (March, 1954).

9. Corey, R. C., Spano, L. A., Schwartz, C. H., and Perry, H.: Experimental Study of Effects of Tangential Overfire Air on the Incineration of Combustible Wastes. Air Repair (JAPCA) 3:1-8 (1953).

10. Dennis, R., Billings, C. E., Samples, W. R., and Silverman, L.: Gas Cleaning Studies of U. S. Bureau of Mines Incinerators, Stack Effluent Tests on BOMAEC-30 and BOMAEC-100 Incinerators. Fourth AEC Air Cleaning Conference, Argonne National Laboratory, November 1955. TID-7513 (Pt. 1) p. 219-245, Washington, D. C. (June 1956).

11. Dennis, R., Muller, F. L., Kristal, E. and Silverman, L.: Special Incineration Studies - Institutional Design. Sixth AEC Air Cleaning Conference, Idaho Falls, July 7-9, 1959. TID-7593, p. 344-364, Washington, D. C. (October, 1960).

12. Thorburn, R. C. and Chandler, R. J.: An Incinerator for Uranium Contaminated Wastes. Ind. Water and Wastes, March, April, p. 46 (1961).

## DISCUSSION

LOYSEN: A cursory survey we made of the major New York Operations Office contractors who might use incineration for disposal of contaminated combustible waste showed that only about one-third of those contractors who might use incineration actually did.

I do not know what proportion of other AEC contractors use incinerators, but I suspect it is probably similar. We believe that incineration, as a means for reducing the volume of contaminated combustible waste has not yet been fully exploited. Therefore, we have begun to assemble some information about factors such as costs, air pollution, volume reduction and other items for the existing commercial incinerators now being used by AEC contractors.

The remarks I have concern our preliminary investigation of three incinerator operations, all of which were for the burning of so-called low level uranium contaminated waste consisting of papers, rags, gloves, towels, boxes, etc. The fourth incineration operation, which Mr. Dennis mentioned, from GE-APED, and was reported in Nucleonics in May of this year. I have included this operation for comparison. There is also another one about which I have some data. This is an incinerator at the National Lead Company in Albany which consists of an open pen.

The first operation is that of United Nuclear Corporation, at Montville, Connecticut. Their incinerator is a Morse-Bogler, 210-pound per hour capacity unit with an auxiliary fly ash settling chamber followed by a short stack. No air cleaning equipment is provided. The approximate installed cost - this is my approximation and not theirs - is about $3,000. Air monitoring consists of a stack sampler, plus four samplers placed at intercardinal points three feet above and eight feet away from the stack. All of these use millipore filters for sample collection.

The results of the extensive air sampling are as follows: In the stack, 194 samples averaged 2.3 $D/M/M^3$ and the other samples, which were about eight feet away, averaged about .7 $D/M/M^3$. United Nuclear determined the median of all the samples -- of 1,019 samples as being 1.0 $D/M/M^3$.

The second operation is at Metals & Controls in Massachusetts. Their incinerator is a Godter, 200-pound plus per hour capacity unit, followed by a 1,000 CFM centrifugal collector and an empty filter box which originally contained absolute filters in this installation. The effluent is discharged from a 20-foot high stack. The cost of this installation was about $3500. Air sampling is achieved by placing a high volume sampler, using Whatman #41 filter paper, in the discharge stream a few feet from the stack.

The average of twenty-one samples collected during about an eight-month period was 8.9 $D/M/M^3$.

The third operation is that of Pratt & Whitney Aircraft in Middletown, Connecticut. Their Brule incinerator has a rated capacity of about 600 pounds per hour and is connected directly to a 35-foot stack without any interposed air cleaning equipment. This incinerator, I understand, was originally installed to burn classified documents. A cost estimate is not now available, although it should be similar to the others reported here. Air sampling consists of an electrostatic precipitator preceded by a fibreglass prefilter in the stack and high volume air samplers, using Whatman #41 filter paper, for some of the burnings at distances of 150 to 500 feet away from the stack. All of these samplers were on the site. The stack sample results include activity collected on the prefilter as well as in the precipitator itself. The Pratt & Whitney results are divided into two categories because of the distinct levels of waste which were incinerated. For the lower activity type, the stack samples averaged 7.6 $D/M/M^3$ and the distant samples, the ones at 150 to 500 feet, averaged .056 $D/M/M^3$. For the higher activity materials, which I learned were burned in a 55-gallon drum with the effluent piped into the stack, the seven stack samples averaged 530 $D/M/M^3$ and the six distant samples .62 $D/M/M^3$. Volume reduction of 96 to 99 percent were obtained with 99.1 to 99.98 percent of the activity remaining in the ash. Open field burning studies which were conducted by HASL indicated similar activity retention in the ash.

The General Electric APED incinerator is more sophisticated. It has three combustion chambers and is followed by a water spray for gas cooling and two sets of prefilters and absolute filters for dust collection. A sampler in the 25-foot high stack continually monitors for any uranium emission. Obviously there is no significant amount as long as the filters maintain integrity. The cost of this installation, exclusive of testing, is in excess of $10,000. Volume reduction is greater than 99 percent.

The National Lead Company, in Albany, New York, has incinerated some contaminated wastes in a fenced-in area directly on the ground. This is not a commercial incinerator, but since recent data were available they are included in this report. Four samples taken in the smoke near the incinerator ranged from 4.4 to 5.2 $D/M/M^3$. One sample twenty feet downwind was 0.22 $D/M/M^3$. This method does not offer much control over the ash, nor is volume reduction as great as you would get in a commercial incinerator. On the other hand, what could be cheaper. Some data is available from Metals & Controls and Pratt & Whitney, so that the amounts of activity per unit weight of ash can be determined. Giving the Canel lower activity material a relative activity of 1, and the Canel higher activity material therefore would have a value of 100 and the M & C material would have a value of 10.

Remembering that the M & C equipment has a cyclone collector, which is maybe 90 percent efficient, the relation among the air sampling results and activities is quite good.

The reasons for different levels of activity in the waste from the different contractors are not easy to quantitate. The methods used for segregation of contaminated materials, the differences in processes and plant cleanliness are all influencing factors. The most important one that we should consider is the segregation of contaminated materials and there are a few things I know about these that might be of interest.

For instance, at M & C some waste materials in fabrication areas but not contaminated are not included, but all waste known to be contaminated to any extent is included in the material to be incinerated. Thus, by segregating out some of the waste they know or think they know is not contaminated, that may represent the condition for the maximum amount of activity to be found in waste from fuel fabrication operations.

At Pratt & Whitney the lower level waste contained no accountable material, that is, waste used to wipe out pans which had uranium in them or spills or similar types of material. This lower level waste did contain combustibles which were merely in fabrication areas and not necessarily contaminated.

This latter type of waste would be separated out of the material at M & C, for instance. The higher level Pratt & Whitney waste contained mostly the so-called accountable material. Differences in enrichments of uranium used among the different contractors has not been completely evaluated, but all of the contractors handled depleted, natural and various levels of enriched uranium and we would guess they are roughly similar in average enrichment.

Incineration is a useful intermediate method of combustible waste disposal process that reduces expensive handling. Therefore, we should encourage its use where it is found to be economically feasible and safe. Gas or oil-fired commercial incinerators afford a high volume reduction with relatively low installation and operating costs.

As far as safety is concerned, from the data which we have reviewed so far, we have found, no instances where employees exposures have been significant nor where MPC's have been exceeded off site.

The MPC's which are applicable are: 220 $D/M/M^3$ for 40-hour occupation exposure and 7.3 $D/M/M^3$ for 168 hour non-occupational exposure. In fact, all but the Pratt & Whitney lower level activity material case, concentrations in the stacks or in the effluent stream immediately outside are either below or only slightly above the off-site 168-hour per week MPC. Dilution factors depending on the conditions at a particular site and time averaging to take advantage of the periods when the equipment is not operating can permit air concentration at the stack orders of magnitude higher than those noted here.

It appears from our preliminary work that incineration of combustible waste materials used in reactor fuel fabrication is entirely practical: at low cost, with high retention of activity in the ash and insignificant off-site air contamination and high reduction in volume of the wastes. More careful study of the data on hand and the accumulation of additional data is expected to confirm this preliminary conclusion and provide a sound basis for recommending incineration in inexpensive, commercial equipment as a primary method of waste disposal for combustible wastes.

Although there are some gaps in our information at this time, we expect to be able to fill these and add some information from other contractors during the next few months.

I would like to ask that if anybody here has information which he thinks would be of value to our survey, that he get in touch with me, either here or at the Health & Safety Laboratory in New York. I am particularly interested in obtaining some information on incineration of waste containing materials other than uranium. Lastly, there are some representatives of the contractors who are present and if they have anything to add or correct, I would be happy to have them do so.

Thank you.

GEMMELL: I think that since the Rocky Flats incinerator has been mentioned, that we ought to give them a chance to tell us a little about it.

BALLS: Mr. Dennis, about three weeks ago, came out to visit us. About two years ago we asked Mr. Dennis and Dr. Silverman to assist us in setting up a gas cleaning system for an incinerator and they advised us at that time of the work they had completed with respect to the slag wool filter beds and we had had experience in our own plant using a regular little commercial incinerator which you might find in the home enclosed in a dry box system, utilizing a wet caustic scrubbing system, a series of filters, and so forth, after that and we had had varied experience. We had been able to recover some material, but we had experienced a great deal of maintenance cost with regard to the scrubbing system, due to the atmosphere, mainly, of the combustion air. Our operations there are primarily chemical in nature and, as a result, the waste material that we are interested in incinerating contains a great deal of nitric acid, hydrochloric acid, sulphuric acid, and many other additional chemicals in smaller quantities than the ones I have mentioned.

Certainly you can imagine, as we drive off these chemicals up an exhaust system, on an incinerator, the inside of that incinerator and its exhaust system are going to corrode. If you select a mild steel type of system, that is all right for perhaps sulphuric acid in very small quantities, but certainly the nitric and hydrochloric acids are going to get at it. If you select stainless steel - we are talking about a wet system - then hydrochloric acid is going to go after it, and this was our experience on a wet scrubbing system, using a caustic scrubber.

In the new incinerator we decided that we would try to pursue a completely dry system. We installed in our incinerator the slag wool bed that had been done at Harvard Air Cleaning Laboratory.

In addition to this, we put in a set of absolute filters. Our system contains a series of preheaters of additional (inaudible) -- we preheat this dilution air and cool it down slightly, but not to a point of condensation, heat it back up -- heat the dilution air up and kick it back into the streams to make sure we do not get any water condensation in our exhaust gas streams.

We have experienced success in operating this particular unit for about two months. We, however, did have a great deal of cost from the standpoint of replacement of the absolute filters. The absolute filters we had were of the glass media, the aluminum separators and aluminum frame. We had no experience with rupture or failure of the filters with additional contamination in the off-gas air from the site or plant.

We were burning, as Mr. Dennis indicated, about an average of sixty pounds per hour. Our primary interest is the recovery of radioactive materials from the waste that we have. Our operating costs, and I will just simply close up by going into the operating costs -- these are figures that I have since accumulated, since Mr. Dennis was there - run approximately $11 a cubic foot of combustible waste charged to the incinerator.

Now, comparing this with our normal contaminated wastes, which we are not interested about from the recovery standpoint, costs us about $1.25 a cubic foot to ship this off site for burial.

Certainly we would have to expect a great deal of volume reduction in order to process that type of waste through this incinerator, but our experience in the volume of reduction accomplished with the salvageable or recoverable waste, if you would like to use that term, would make it still economically feasible for us to burn our regular contaminated waste in the incinerator and then take that ash, which did not contain recoverable quantities of material, and ship the ash off site for burial. We could realize a tremendous dollar savings.

This is our definite intention. We have now completed a few modifications on the gas treatment, off-gas treatment, equipment and we have intentions, approximately the 1st of November, to place the unit back in operation, first to reduce our backlog of recoverable materials and then to start incinerating the actual contaminated wastes which will go off site for burial.

Our initial unit is completely enclosed in a stainless steel dry box system with a ventilation such that contamination does not leak into the room where the operating personnel are housed.

We have health physics samples in the off-gas area which have proved that we are not, at least to the best of our measuring abilities, put any contamination into the site air.

I do not know what else I can add at this time. If anybody wants to talk about our facility, we will certainly be glad to try and answer any questions you might have.

## DISCUSSION

PATTON: In the first place, on the burning of high level waste, this was merely a sample burning to determine about what we were going to get. In the second place, the large volume reduction is due, in great part, to the loosely packed material as it comes to the incinerator. It is directly out of the laboratory and is loosely packed in plastic bags, which is the reason we get the very large reduction in volume. These are the two major points that I think might be worth while.

One other thing. The capacity of this particular incinerator, and I am not sure exactly why -- the commercial rules said it should burn at 635 cubic feet per minute, but the State Department of Health lowered this to about 330, as the permissible burning rate.

LOYSEN: You mean pounds per hour?

PATTON: Yes. Evidently they had some standards.

GEMMELL: Any other of you gentlemen care to comment on what was said by Mr. Loysen? Are there other comments on the last two papers?

CHESTER (ORNL): I have a question for Dr. Silverman on these tests he made of the stability of his low density foam. You mentioned figures of 100, 200 and 300 roentgens per hour, and stated there was no effect. I certainly don't question this in the slightest, but I think that your test is perhaps two, three or four orders of magnitude too low in radiation that would be expected in an incident inside a reactor vessel.

I think the use of low density foam to hold down particulates is a fine idea. It would have cut down airborn activity in the SL-1, but I don't think you have presented evidence of the radiation stability of your foam.

SILVERMAN: This is a very preliminary report on foam stability and, aside from proving that a demonstration away from home doesn't work, I did want to state that the density of the foam is so low that you would not expect too much radiation absorption. It may well be, that the specific of some activity particles may give us more trouble than actual ionization. One might expect that with enough ionization, you might get "radiolysis," and worry about water disappearing from the foam. We made a quick test, which is still incomplete. In the SL-1 case it wouldn't be so bad because the radiation level was not more than a 1,000 r per hour.

Again, it is a question of how long you would be exposing the foam to a 1,000 r per hour level. We are not certain we have 72-hour foam stability.

I am agreeing with you, for the moment, that the foam would be destructed. I still feel, however, that we can replace the foam fairly rapidly. If you have a reactor containment vessel of, let us say 100,000 cubic feet, just for the sake of discussion, and if you had a generator that produced 25,000 cubic feet a minute, which isn't very big - a truck-mounted unit has a gasoline motor for driving the fan which makes it large (the pressure drop on this unit is less than an inch of water). If an electric motor and fan system were available and turned on and it operated properly, you could expect to make foam all of the time within the containment. What happens, the foam you produce is that you recirculate it back through the fan and this would destroy and reform it faster than the radiation.

I can agree with you and say we still have a counter-measure. The things I don't know the answer to and I can only go on the basis of experience with other irradiated foams at much higher density where radiolysis has been the problem.

I agree with you that these radiation doses are hardly any more than a first try at exposure. I want to mention one thing, while I still have the floor. In passing, I did not mention my Table 5. This was an attempt to study foam cleanup dynamically. You will note fairly good results for performance in a dynamic system. This was an attempt to inject an aerosol into a foam stream in a duct. We were passing foam down a pipe at 39 feet a minute and injected the aerosol after the foam generator surface because the spray generator does act as an inefficient filter. We injected gentian violet aerosol into the foam and then sampled the duct at 40 inches and at 80 inches. We had a removal of about 80 per cent for these two aerosols. That, too, is preliminary data, but it indicates you can obtain collection in a moving duct system that is supplied with foam.

I would appreciate any comments any of you have on the diffusion board approach, too, because we feel this has some potential for reactor applictions.

BELTER: Mr. Dennis, in your discussions with the GE people on the incinerator, did they mention anything at all as to how they arrived at this $100,000 for off-site disposal?

DENNIS: First, it took into account concrete encasement in drums. They furnished a cost figure of $6.25 to $6.50 per cu. ft. which seemed high, but that was the number quoted. Upon that basis they arrived at this $100,000 figure. This information is reported in reasonable detail in Industrial Water and Wastes March-April, 1961, page 46. Aside from the fact that they are satisfied with performance, they are only operating one day a week. I think some of the data are very qualitative, that considerable data are missing and that guesswork is required to estimate gas flow and operating temperatures.

LOYSEN: If you are interested in that information, I have the copy of Nucleonics which has this breakdown of how they figured out their costs.