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BEHAVIOR OF INSTITUTIONAL INCINERATORS
WHEN USED TO BURN RADIOACTIVE WASTES

Final Project Report for August 1, 1950 -
November 1, 1952

By

C. W. Krusé

P. V. Freese

A. Machis

V. C. Behn

November 1, 1952

The Johns Hopkins University

Technical Information Service, Oak Ridge, Tennessee

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Hugh Kirsner
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August 1, 1950 - November 1, 1952

By

C. W. Kruse, P. V. Freese, A. Machis and V. C. Behn

ABSTRACT

This report deals with the development of methods and techniques for measuring the amounts of radioisotope on the stack wall, in ash, stack gas and atmosphere during and after incineration in the conventional refuse-type destructor. Controlled experiments were conducted with P-32, I-131, and Sr-89. It was found that with P-32 and Sr-89 about 90% of the isotope remains in the ash where it may produce a hazard during ash removal and disposal. With I-131 about 80% of the isotope charged is in the stack discharge; however, it is shown that to reach undesirable atmospheric concentrations, the I-131 loading would greatly exceed amounts permitted for safety in ash handling.

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INTRODUCTION

The number of isotope shipments has increased from about 200 in 1946 to almost 8,000 in 1951. The bulk of these shipments were made to institutions studying medical therapy and animal physiology, with shipments of I-131 and P-32 far exceeding all others. The problem of disposal of radioactive waste materials by these off-commission users is therefore becoming widespread.

Incineration is an attractive disposal method that is usually available at institutions engaged in research. Whether intentional or not, portions of the activity finds its way into the refuse to be burned. Examples of such waste are experimental animals, cage cleanings, egg embryos, paper for cleaning up spills and used planchets. A monitoring survey of several institutional incinerators confirms the fact that activity considerably higher than background does occur. The following measurements were made in the incinerator with a 30 milligram per square centimeter glass Geiger Tube:

<u>Incinerator Location</u>	<u>Activity Net Counts/Minute</u>
Johns Hopkins Hospital	200 - 300
Sinai Hospital	80 - 150
New Hunterian Building	200 - 300
Hampton House	90 - 125
School of Hygiene	200 - 11,000
Background	40 - 50

Although incineration reduces the volume of waste and renders inoffensive the organic materials, the radioactive contaminants are not altered. They will pass up the stack as a gas or as particulate matter, will be removed with the ash, or will remain on the interior of the incinerator or its stack wall. The stack gas concentrations of activity may create an atmospheric hazard in the vicinity of the incinerator. Ashes and dust become a hazard to the operator, the collector, and to the public when ultimate disposal is on an open dump. Materials on the walls of the incinerator may present a radiation hazard to those working in the vicinity of the incinerator and stack.

The study herewith reported was undertaken to investigate the behavior of the typical institutional incinerator, without gas filter or dust control, when used to burn radioactive wastes.

The program had for its basic objectives the following items:

- a. The development of test methods for determining the distribution of a radioactive material charged to an incinerator. These techniques were so designed that occupational hygiene organizations could conduct similar examinations as routine health department activities.
- b. The formulation of operational standards for the safe incineration of P-32 and I-131 based on experimental data.

LITERATURE SURVEY

The AEC has had considerable experience with incinerators designed especially to burn radioactive materials in quantities far in excess of those anticipated by off-commission users. The design of these processes has been based on various methods of gas cleaning and special handling of ash residue.

The Mounds Laboratory ^{1/} has reported on a pilot plant incinerator employing flue gas cleaning by stream injection followed by a scrubbing tower. The data on the distribution of radioactivity were as follows:

	<u>Activity Millicuries</u>	<u>Percent</u>
Steam nozzle condensate	2.550	20.3
Spray tower water	0.730	5.7
Stack gas effluent	0.043	0.3
Assumed in ash and furnace	<u>9.227</u>	<u>73.7</u>
Total activity charged to incinerator	12.550	100.0

The Naval Radiological Defense Laboratories ^{2/} issued a report describing investigations on burning of contaminated wood in a hood with a filter system. In these tests, 2.5 microcuries of mixed Ce^{144} , Ce^{141} , Ru^{106} , Cs^{137} , and Sr^{89} , were spread on the wood prior to burning. The radioactivity of both the stack gas filters and the ash residue was determined. The percentage of the original contamination remaining in the ash was between 51 and 87, and the

^{1/} Haring, M. M. and P. S. Schauer, Pilot Plant Work on Solid Burnable Waste Disposal for Mound Laboratory. Mound Laboratory MLM-232, Nov. 1, 1948.

^{2/} Worsham, M. L. W. G. Neall, and A. F. Owings, Possible Health Hazard from the Burning of Combustibles Contaminated with Radioactivity. Naval Radiological Defense Laboratory, AD-134 (14), June 17, 1949.

percentage removed by the filters was between 3 and 21. The total activity accounted for was between 67 and 93 percent.

The Arthur D. Little Company^{3/} has prepared for the Argonne National Laboratory plans for an incineration system. This system includes incineration, collection of ash under water, and wet scrubbing and filtration of the effluent gases. Sources of information considered in formulating these plans, primarily AEC activities, are given in this report.

The Air Reduction Company^{4/} has undertaken pilot plant tests on a destructor using oxygen to minimize the products of combustion.

The U. S. Bureau of Mines^{5/} has developed a method of incineration whereby the ash is fluxed in a molten compound for convenient handling. Sodium hydroxide has been found a suitable flux which may permit reclamation of certain radioisotopes.

Generally, it may be stated that information on the distribution of combustion products resulting from the incineration of radioactive wastes is limited. A great aid in forecasting the behavior of certain isotopes such as P-32 and I-131 may be had in studying literature on the characteristics of these elements under varying conditions of temperature and chemical form.

3/ Arthur D. Little, Inc., Report on Design for Volume Reduction of Combustible Radioactive Wastes by Incineration to Argonne National Laboratory. C-57867, 160 pages plus plans, June 30, 1950.

4/ Grego, F. T., W. B. Moen, C. J. Sullivan and A. Muller, The Development of a Destructor for Processing Solid Combustible Radioactively Contaminated Waste, Air Reduction Company, Inc., ARSC 31, April, 1950.

5/ Corey, R. C., Perry, Harry and Schwartz, C. H., Off-Site Disposal of Radioactive Incinerator Residue. Report 4223, U. S. Bureau of Mines, Pittsburgh, Pa.

EQUIPMENT

The incinerator at The Johns Hopkins University School of Hygiene and Public Health was chosen as being typical of equipment and operation found at hospitals and research institutions. It is a slightly modified Model 2G Morse Boulger Destructor employing natural gas as auxiliary fuel. On Figure 1 is shown a cross section of the incinerator used in this study. On Table 1 is given the engineering data collected on the design and operation of the installation. When the incinerator is operated in the usual manner, ashes are removed in the morning and the gas fire started. Janitors and animal room men dispose of combustible materials into the charging chute whenever convenient. There is no supervision of the operation. This is believed to be reflected in the poor quality of ash which has 5 - 15% volatile solids as compared with the 2 - 5% considered to be a satisfactory operation. The ashes are placed in 50-gallon containers, collected two times per week and hauled to the city land fill.

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FIG. 1

INCINERATOR
THE JOHNS HOPKINS UNIVERSITY
SCHOOL OF HYGIENE AND PUBLIC HEALTH
MORSE BOULGER DESTRUCTOR
MODEL 26

Table 1

ENGINEERING DATA

Incinerator Type - Hand Stoked - Dual Chamber with Hearth	
Make - Morse Boulger Destructor 2G	
Rated Capacity in Pounds Refuse Per Hour	200
Actual Loading Pounds/Hour	150-200
Pounds Refuse/Sq.Ft. Grate/Hour:	
At Rated Capacity	37
At Actual Loading	28-37
Auxiliary Fuel	Natural Gas
Fuel Consumption cu.Ft./Hour	400
Volume of Combustion Products:	
Cu.Ft./pound of refuse at 1200°F.	690
Temperature of Combustion Chamber	1000°-1400°F.
Height of Stack	143 Ft.
Construction - 128 Ft. masonry - 10" thick	
15 Ft. x 11.625" diameter steel	
Stack Emission Cu.Ft./Min. at 70°F. and 29.9" Hg	770-1400
Particulate Emission/Cu.Ft. of Stack Gas	
(Median Size 2.5 Microns)	2 million
Stack Gas Temperature:	
At exit	215°-400°F.
Dew Point	105°F.
Refuse Charged (Average):	
Moisture	70%
Combustibles	20%
Ash	10%
Volatile Solids in Ash	5-15%

SAMPLING TECHNIQUES

Stack Gas Concentrations of Radioisotope

The selection of equipment and techniques for determining the stack gas concentration of radioisotope is governed by the physical form anticipated upon incineration. If the isotope is discharged as a gas, a scrubbing train with a suitable adsorber is indicated. Some materials are discharged as particulates and must be captured on filters; others may require both gas scrubbing and filtration. In all cases an effort must be made to obtain an isokinetic sample through the proper selection of sampling nozzle area and pump rate.

Thus where particulate discharge was anticipated, as in the case of P-32, two different sampling techniques were used to filter the particles from the stack gases. Since the hot stack gases were saturated with water vapor at sampling temperatures, it was necessary either to provide a condenser or to keep the entire sampling train above the dew point of the stack gas.

When a condenser was used to trap the moisture prior to filtration, the gas sample was passed through a 4-inch diameter filter of AEC No. 1 ^{6/} paper at a rate of one cubic foot per minute. The filter unit was supported on a cross wire frame within a machined double-funnel type holder. One inch discs were cut from the filter for counting to determine the activity recovered during the sampling period. To this activity was added the activity brought down in the condenser unit. This was done by taking aliquots of the condenser liquor, evaporating and counting in planchets.

^{6/} Stafford, Earl and Smith, Walter J., Dry Fibrous Air Filter Media, Ind. and Engr. Chem., 43 (8): 1346-1351, 1951.

A second type of filter offered several advantages over the type described above. It consisted of a filter thimble with an integral Geiger Tube inserted. The whole was well insulated and provided with a heating element to prevent the condensation of moisture. The arrangement permitted a continuous record of activity level in the stack gas. The Geiger Tube was calibrated for different isotopes and activity concentrations. Removing one inch discs from the filter permitted an additional check on activity recovered by the normal counting procedure. On Figure 2 is shown the detailed construction of the filter thimble. The normal rate of filtration in this unit was 0.75 cubic feet per minute.

With both filtration methods described the small size of sampling nozzle precluded the capture of the rather large flyash particles discharged during the loading of refuse into the incinerator. In order to evaluate the role of the larger particles a settling chamber was provided. The size of the stack gas sample was increased to about 30 cubic feet per minute with a proportionate increase in the diameter of the isokinetic sampling nozzle and pipe. The velocity through the settling compartment was about 27 feet per minute. The entire system was insulated against heat loss and, in addition, two heat lamps were installed within the settling box. The stack gas was first passed through the settling chamber to remove the large flyash particles and a second isokinetic sample of the box discharge was secured for the filter thimble unit. A flow diagram of the complete sampling train is shown on Figure 3. The activity in the flyash collected during the sampling period was determined by taking 10 milligrams finely ground samples and counting in planchets in the normal manner.

FIGURE 2

DETAIL OF FILTER THIMBLE ASSEMBLY FOR MEASURING STACK GAS RADIOACTIVITY

FIGURE 3

APPARATUS FOR MEASURING RADIOACTIVITY ON FLYASH AND STACK GAS PARTICULATE

When dealing with an isotope, such as the alkaline iodides, which volatilize at high temperatures, recovery must be made of the gas rather than the particulate. The sampling apparatus used consisted of two dust collecting type impinger cylinders in series following the filter thimble. One hundred and seventy-five (175) milliliters of adsorber solution was used in each impinger and the filter effluent passed through the solution at 1 cubic foot per minute. In most cases the second impinger contained less than one-tenth as much activity as the first and it was believed unnecessary to add the third impinger to the train. Figure 4 shows the typical flow line of the equipment employed for true gas sampling. The adsorber employed must be determined for each isotope. The total activity in the gas was estimated from the sum of the activity counted on the filter and in samples of the adsorber solution.

The attempt was made to measure activity in the stack gas by inserting a Geiger Tube directly into the gas stream. Since manufacturers were unable to supply any information on tube performance at elevated temperatures, a control temperature box was constructed and D50 tubes tested and calibrated. Some of these tubes gave very consistent counts up to about 200°C., at which temperature breakdown occurred and counts climbed precipitously; however, on return to lower temperature, performance again became normal unless the tube had suffered physical damage. Stack counting at high temperatures was abandoned when it was discovered that the count obtained was due almost entirely to radiation from the stack walls rather than from the gas stream.

In order to properly estimate the recovery of isotope in the stack gas, it was necessary to determine the stack gas discharge

FIGURE 4

APPARATUS FOR MEASURING STACK GAS CONCENTRATION OF RADIOACTIVITY

during the period that the samples were taken. A standard pitot tube was placed in the center of the stack and calculations made using the Bulletin of the Western Precipitation Corporation.^{7/}

All volumes were reduced to 70°F. and 29.9 inches of Hg. A typical flue gas velocity traverse is given in Table 2 from which average velocities could be obtained.

Atmospheric Concentrations of Radioisotope

For taking atmospheric samples, a filter unit capable of sampling 20 to 30 cubic feet of air per minute was acquired on loan from the New York Office of the AEC. The air was passed through a 3-1/2 inch diameter filter pad. In this work, Mine Safety Appliance Comfo Respirator Filter Pads (BM2130) were used. The high volume AEC sampler was most useful for all around work. In dusty atmospheres, such as the incinerator room during ash removal, the electrostatic precipitator was also employed. This sampler operates at a rate of three cubic feet of air per minute and was not too useful in sampling atmospheres on the roof or vicinity of the stack. The activity on 1" diameter discs cut from the filter pad was determined in the normal manner. Activity determinations on the solids collected on the aluminum liners of the electrostatic sampler were determined in a different manner. A special fitting was provided so that Nuclear D50 GM Tube could be inserted into the cylinder without disturbing the aluminum liner or sample. In this manner the previously calibrated tube could directly determine the activity collected by the electrostatic precipitator.

^{7/} Western Precipitation Corporation, New York, Bulletin WP-50.

TABLE 2
Velocity Profile in Stack

Stack Diam. = 11.625" Area = 106.2 sq. in.
 $A = 106.2 \div 3 = 35.4 \text{ sq. in.}$

$$R_1 = \sqrt{\frac{A/2}{3.1417}} = \sqrt{\frac{17.7}{3.1417}} = 2.375"$$

$$R_2 = \sqrt{\frac{A + A/2}{3.1417}} = \sqrt{\frac{53.1}{3.1417}} = 4.11"$$

$$R_3 = \sqrt{\frac{2A + A/2}{3.1417}} = \sqrt{\frac{88.5}{3.1417}} = 5.31"$$

Position No.	Gage Inches Oil	Square Root Gauge	Temp. °C	Pitot Dist. Inches
1	0.230		130	21 ⁵ / ₈
2	0.245	0.495	130	19 ¹ / ₄
3	0.205	0.453	130	24
4	0.225	0.474	130	17 ¹ / ₂
5	0.165	0.406	130	25 ³ / ₄
6	0.045	0.021	130	16 ⁵ / ₁₆
7	0.105	0.324	130	26 ¹⁵ / ₁₆
Average	0.131	0.362	130	

Ratio: Av. to Center = $\frac{0.131}{0.230} = 0.57$

Av. vel. to Center vel. = $\sqrt{0.57} = 0.755$

Stack Wall Activity

Four methods were used for estimating the amount of activity remaining in 143-foot stack after the incineration of an isotope.

One method was direct counting in the stack by insertion of the D50 Tube through a hole bored through the metal portion at 5 feet above the roof. This was done only when the incinerator was not in operation. The geometry for this method was determined by building a simulated stack one foot in diameter by 3 feet tall and integrating the count received from a measured amount of radio-isotope placed on a 1 centimeter band which was counted and moved to consecutive positions down the model.

Another method of obtaining stack wall activity was by counting a 6-inch diameter metal disc which was removed from the stack wall. The holder and GM Tube arrangement used in the laboratory were calibrated over aluminum sheets on which had been distributed known amounts of activity. It was impossible to break into the masonry portion of the stack so five 6-inch diameter metal discs were suspended at 30-foot intervals on a weighted wire rope. After each test, the discs were removed and counted in the manner described above. An estimate of the vertical distribution of stack wall activity was provided by this method.

In some cases soot was scraped from the upper stack wall or from the metal discs. A few milligrams of soot were spread as evenly as possible on the bottom of a standard planchet and counted.

Each of the counting methods used gave a value in microcuries per square centimeter of stack. The total activity on the interior surface of the stack was obtained by multiplying the unit area values by the estimated total surface area. Results obtained by the four methods of test were, in one case, as follows:

COMPARISON OF COUNTING METHODS FOR
SURFACE ACTIVITY IN INCINERATOR FLUE

<u>Method</u>	<u>Activity Microcuries</u>	<u>Recovery Percent</u>
GM Tube in Stack	97	6.1
Disc Removers from Stack	82	5.6
Flue Scrapings	53	3.3
Scrapings from Sample Disc	14	1.0

Activity Estimation in the Ash

The entire ash content of the incinerator was removed to a drum and weighed. The ash was then blended in a Maclellan batch mixer for several minutes. The thoroughly mixed ash was divided into eight portions. About 3 samples from each part were finely ground and about 10 milligrams weighed up in planchets for counting in the laboratory setup. The difficulty in mixing due to the range in particle size and activity and the limitation on the size of sample actually counted, imparted a wide variability to the results. Below is tabulated a typical ash analysis showing the wide range in results:

ACTIVITY DETERMINATION IN INCINERATOR ASH BY DRY METHOD

<u>Sample No.</u>	<u>Microcuries/gram of ash</u>	<u>Sample No.</u>	<u>Microcuries/gram of ash</u>
1	.095	11	1.030
2	.102	12	1.060
3	.155	13	1.120
4	.475	14	1.150
5	.640	15	1.430
6	.740	16	1.500
7	.835	17	1.510
8	.920	18	1.540
9	.925	19	1.760
10	1.000	20	1.910

Mean = 0.995 Microcuries/gram

Standard deviation from mean = 0.513 Microcuries/gram

It is obvious that no more than a crude guess of activity in the ash could be obtained with the dry method of sampling. In an effort to obtain a better estimate of ash activity, about 70 - 100 gram samples of the mixed and quartered ash were placed in beakers and digested with a suitable liquid. After a preliminary search it appeared that the best digesting solution for P-32 was 1:3 sulfuric acid, for I-131, 0.02 molar sodium hydroxide and for Sr-89, 1:4 hydrochloric acid. Quantitatively, it was shown that most of the radioactivity leaves the solid phase with 24 hours of digestion. The counts of the supernatant liquor of each beaker were quite variable but by pooling a few milliliters of each beaker and making 20 separate counts of the liquid, the following variation was obtained when the wet method was applied, using the same ash that was analyzed by the dry method:

ACTIVITY DETERMINATION IN INCINERATOR ASH BY WET METHOD

<u>Sample No.</u>	<u>Microcuries/gram of ash</u>	<u>Sample No.</u>	<u>Microcuries/gram of ash</u>
1	0.724	11	0.752
2	0.884	12	0.811
3	0.735	13	0.706
4	0.826	14	0.752
5	0.784	15	0.827
6	0.770	16	0.837
7	0.716	17	0.830
8	0.735	18	0.963
9	0.676	19	0.768
10	0.772	20	0.615

Mean = 0.796 Microcuries/gram

Standard deviation from mean = 0.0776 Microcuries/gram

The wet analysis of the ash gives a lower average activity in microcuries/gram of ash. The variation is not high. The greatest difficulty still remains in selecting from the 35 to 50 pounds of mixed ash representative samples of the whole. It was felt that generally the techniques for determining stack discharge were much

more accurate than ash determination. Therefore, ash activity could be assumed to be the balance of the charge not accounted in the stack or stack discharge.

Activity Determination

The portable equipment employed for counting filter thimble and stack monitoring was a Berkeley Model 1000-B Decimal Scaler with a Nuclear D50 (35 mg/cm²) glass tube. All laboratory determinations were made with a system consisting entirely of Tracerlab* equipment including a 64 autoscaler, a shielded manual sample changer, and a type TGC end window tube (2 mg/cm²).

Isotopes

Radioactive phosphorus, P-32 and iodine, I-131, were chosen for major study because these are the most frequently used radioisotopes. Some preliminary observations were made with strontium-89.

P-32 and Sr-89 emit beta particles with a maximum energy of 1.71 and 1.50 Mev respectively. The half-life of radiophosphorus is 14.3 days and strontium-89, fifty-five days.

Radioiodine, I-131, emits two negative beta particles with a maximum energy of 0.605 (86%) and 0.250 (14%) Mev. I-131 also emits gamma radiations. It has a half-life of 8.0 days.

* Tracerlab Co., Boston 10, Massachusetts

PROCEDURE

Before any isotope was charged to the incinerator, it was necessary to obtain information on the general behavior of the element when subjected to heating. This was accomplished through literature search, supplemented by laboratory studies which involved heating small quantities of various compounds of the element in a muffle furnace. It was possible to withdraw the atmosphere from the muffle furnace through the sampling filter and gas scrubber for recovering the radioactivity lost from the heated planchets. Although the results of these laboratory experiments were not always duplicated in the incinerator, they were useful in forecasting:

1. The probable amounts of isotope expected in the ash and in the stack discharge.
2. The length of time that the stack discharge should be sampled.
3. The effect of chemical form of isotope on behavior when placed in a furnace.

In the series of quantitative runs made in the incinerator, an attempt was made to obtain the maximum of useful information. This called for determining the amount of radioactive material discharged through the stack, dispersed in the atmosphere near the stack, distributed on the stack walls and remaining in the ash. The atmosphere in the incineration room was also sampled during ash removal. Known quantities of radioisotope were charged to the incinerator in amounts ranging from 50 to 2,000 microcuries for each experiment. The charge was added in the form of chick embryos or on cotton and sawdust wetted with the isotope solution. The experiments were spaced so that the background of the stack and incinerator were fairly low before each test run.

EXPERIMENTAL RESULTS WITH RADIOPHOSPHORUS P-32

Preliminary Investigations

Laboratory experiments on P-32 confirmed the fact that phosphoric acid may be vaporized at moderate temperatures. However, since the acid reacts with metallic and glass counting dishes, some of the acid will be converted into a phosphate and will not vaporize. The result of the experiments with phosphoric acid is shown on Table 3.

It can be seen that the greatest loss occurred with the pyrex and stainless steel planchet. The increased loss of activity from the nickel planchet when charge was placed on paper seems to show the possibility of flyash carriage. It appeared that all loss of activity may be expected during the first 15 minutes of heating. The second set of laboratory tests show that very little activity is lost with the alkaline phosphorus compound as compared with the acid compounds. The results of these tests are as follows:

RETENTION OF ACTIVITY IN PERCENT AFTER HEATING AT 600° C.
FOR 20 MINUTES

<u>Planchet Used</u>	<u>pH 0.5</u>	<u>pH 8.0</u>
Pyrex	26	89
Nickel Plated	83	99
Crucible	73	92

These tests indicate that concentrated radioactive phosphoric acid would have to be placed in the incinerator in a glass container in order for as much as three quarters of it to be vaporized as a radioactive fume. Ordinarily, acid isotope placed in an incinerator would react with existing alkali or alkaline earth elements present to form heat stable salts.

The first series of controlled experiments in the incinerator were aimed at determining the amount of P-32 that escaped through the stack. The discharge of activity did not follow a fixed pattern, perhaps

Table 3

PERCENT OF INITIAL ACTIVITY RETAINED AFTER HEATING
VARYING STRENGTHS OF RADIOPHOSPHORIC ACID AT 600°
AND 800° C. FOR VARYING PERIODS OF TIME

<u>Molarity of H₃PO₄</u>	<u>Nickel Plated Planchet</u>			<u>Activity on Paper in Ni</u>			<u>Stainless Steel Planchet</u>			<u>Pyrex Planchet</u>			<u>Temp. °C.</u>	
	<u>Time in Minutes</u>													
	<u>15</u>	<u>30</u>	<u>60</u>	<u>15</u>	<u>30</u>	<u>60</u>	<u>15</u>	<u>30</u>	<u>60</u>	<u>15</u>	<u>30</u>	<u>60</u>		
.25	86	86	86	93	96	99	103	104	103	72	68	67	600	
	100	99	96	69	67	68	88	91	92	-	-	-	800	
.50	103	99	105	86	-	-	99	97	95	89	55	50	600	
	95	93	92	72	70	70	49	49	48	-	-	-	800	
.75	-	95	93	-	91	89	75	65	58	59	45	46	600	
	77	74	74	64	64	63	60	60	60	-	-	-	800	
.97	95	93	94	76	74	75	94	91	86	68	63	58	600	
	91	90	92	70	68	72	59	61	59	-	-	-	800	

because of erratic refuse loading and other variables connected with the type and rate of combustion. The discharge of activity was usually complete within an hour after the incinerator had been charged with radiophosphorus. Figure 5 shows graphically the change in activity within the stack following the addition. These records were obtained with the Geiger Tube in monitoring positions in the stack and subsequent investigations indicated that the activity thus measured resulted from the deposits on the wall of the stack and not from activity suspended in the flue gas.

Activity in the Gas

The radioactivity discharged in the stack gas was determined by settling and filtration of isokinetic samples. A typical activity discharge curve is shown in Figure 6. All of the filterable radioactivity in the stack gas passed out immediately following the addition of the radiophosphorus.

The percentages of the active charge removed from the gas by settling and filtration ranged from 0.4% with a 135 microcurie loading to 1.8% with a 500 microcurie loading. The peak rate of discharge during the latter test was 5×10^{-8} microcuries per cc. of stack gas. The activity recovered appeared on the average to be divided between the flyash and the fume.

Activity on Stack Wall

Activity determinations made with the Geiger Tube inserted in the stack in the early morning, while the incinerator was not in operation, indicated that the activity in the stack persisted for several months following the addition of radiophosphorus to the incinerator. The activity decreased approximately in accordance with the half-life of P-32 during this period. This is well illustrated by the plot of cold stack monitoring from September 1951 to February 1952 shown on Figure 7.

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ACTIVITY OF STACK GAS FOLLOWING INCINERATION OF P-32

ACTIVITY REMOVED BY FILTER THIMBLE

NOTE: 1 CPM = 8.5×10 MICROCURIES PER CUBIC FOOT OF STACK

FIG. 6

FIG. 7
RADIOACTIVITY OF STACK WALL WITH
INCINERATION OF P-32

The percentage of the active charge deposited on the stack wall increased as the loading increased. The deposit on the lower portions of the stack was somewhat higher than at the top where most measurements were made. On Figure 8 it may be seen that, on an average, the deposit on the wall was 3.5 times the activity at the top of the stack. The percentage of active charge recovered on the walls can be seen in Table 4. One estimate made on the hot stack from a 2 millicurie charge, gave a 32.3% recovery, a value that appears unreasonably high. This reading may have been affected by the high counts encountered due to previous contamination and/or high temperature of the stack gas.

Activity in the Ash

The analysis of activity remaining in the ash by either the dry or the wet technique cannot be considered more than crude estimations of the actual amount present. By monitoring ash spread out in thin layers, it became apparent that the activity is present in small pockets which could not be adequately dispersed by the mixing methods employed. The best technique would probably be to digest in an acid solution all of the ash removed from the incinerator. This would have required a greater expenditure of equipment and materials than was deemed necessary for the study.

The actual proportion of activity accounted for in the ash ranged from 20% to over 100% of the charge.

Dust Hazard

Atmosphere samples were taken at breathing level during ash removal on the morning following the day on which the incinerator was charged with known quantities of radioshosphorus. As shown in Table 5, the activity ordinarily ranged from 4×10^{-10} to 5×10^{-8} microcuries per cc. of air with loadings from 100 to 2000 microcuries. There appeared

32

FIG. 8

VERTICAL DISTRIBUTION OF ACTIVITY
DEPOSITED ON STACK WALL
RADIOPHOSPHORUS P-32

Table 4

P-32 ACTIVITY DEPOSITED ON STACK WALL

<u>Incinerator Charge Microcuries</u>	<u>Activity Deposited on the Stack Wall *</u>	
	<u>Microcuries</u>	<u>Percent of Charge</u>
99	8.7	8.8
135	18.4	13.6
450	9.1	2.0
500	11.2	2.3
1000	15.8	1.6
1000	97.0	9.7
1500	300.0	20.0
2000	645.0	32.0
2000	20.0	1.0
2000	14.0	0.7

* Based on the Average Stack Deposit as Determined from Vertical Distribution within the Stack.

Table 5

ATMOSPHERIC CONCENTRATIONS OF P-32 IN MICROCURIES
PER CUBIC CENTIMETER OF AIR TAKEN IN THE INCINERA-
TOR ROOM DURING ASH REMOVAL THE DAY FOLLOWING
EXPERIMENTAL INCINERATION OF ISOTOPE.

<u>P-32 Incinerated Microcuries</u>	<u>Equipment Used *</u>	<u>Total Volume of Samples Cu.Ft.</u>	<u>Concentration of P-32 Microcuries per cc. of Air</u>
9	H.V.F.	180	0.77×10^{-9}
135	E.S.	9	1.62×10^{-9}
	H.V.F.	90	0.44×10^{-9}
1000	E.S.	9	0.40×10^{-8}
1000	E.S.	15	2.70×10^{-8}
1000	E.S.	6	4.00×10^{-8}
	H.V.F.	90	3.40×10^{-8}
1501	E.S.	12	2.98×10^{-8}
	H.V.F.	100	0.58×10^{-8}
2000	E.S.	9	4.80×10^{-8}
	H.V.F.	105	5.30×10^{-8}

* E.S. = Electrostatic Sampler
H.V.F. = High Volume Filter

to be good agreement between results obtained with the high volume filter and the electrostatic precipitator. To properly assay the dust hazard, the persistence of the P-32 atmospheric concentration during and after ash removal was studied. It was of interest to note that during ash removal examination always showed the presence of activity in the air whether an isotope charge had been placed in the furnace or not. A typical analysis obtained with the high volume filter was as follows:

<u>Time</u>	<u>Volume Sampled Cu.Ft.</u>	<u>Atmospheric Concentration Microcuries/cc. of Air</u>
Day before Test:		
8:15 am	600	1.28×10^{-10}
10:10 am	1200	3.06×10^{-10}
Day of Test:		
8:15 am	600	1.28×10^{-10}
Day after Test:		
8:15 am	625	1.72×10^{-8}
9:20 am	625	3.26×10^{-10}
10:20 am	625	1.43×10^{-10}

These data seem to show that the maximum concentration of P-32 occurs only during the actual ash removal period and that within an hour returns to the natural background. In the above tabulation, all activity was assumed to be P-32; however, a decay study clearly showed that most of the background activity had an exceedingly short half-life. Repeated counts made on background activity in the incinerator room and the outside atmosphere gave the following decay:

<u>DECAY OF NATURAL BACKGROUND ACTIVITY</u>		
<u>Time Minutes</u>	<u>Counts per Minute</u>	
	<u>Incinerator Room</u>	<u>Outside Atmosphere</u>
0	136	224
10	117	192
20	99	135
30	86	108
40	77	102

The presence of the short half-life activity in the atmosphere had been noted in connection with attempts to measure maximum ground concentrations during the discharge of P-32 in stack gas. The low loading used in the experiments coupled with the dispersion obtained from the high stack produced no measurable ground concentrations of P-32. However, atmospheric samples taken on the roof downwind from the stack gave recoveries believed to be P-32 activity in the range of 0.2 to 0.7×10^{-10} microcuries per cc. of air.

Summary of Experimental Results

The study of the behavior of radiophosphorus in wastes burned in the incinerator is summarized on Figure 9. The limitations of sampling techniques probably account for wide scatter of points. Nevertheless, it appears reasonable to assume:

1. That eighty-six percent of the P-32 charged will remain in the ash and constitute a potential hazard on ash removal and disposal.
2. That fourteen percent of the P-32 charged will pass out of the incinerator of which twelve percent will be deposited on the stack walls and two percent in the stack discharge.

EXPERIMENTAL RESULTS WITH
RADIOIODINE I-131

Preliminary Investigations

Laboratory tests were conducted in the muffle furnace to determine the expected pattern loss of alkaline radioiodides upon heating in various types of planchets. The radioactive material was made alkaline to a pH of 12 with NaOH, and contained traces of sodium bisulphate from the original material. The following results were obtained after heating the planchets at 300° and 600° C. for 15, 30, and 60 minute intervals:

Temperature °C	Retention of Activity on Planchet in Percent								
	Pyrex			Stainless Steel			Nickel Plated		
	Time in Minutes								
	15	30	60	15	30	60	15	30	60
300	98.3	92.6	84.5	95.8	95.0	92.5	98.7	92.3	96.3
600	1.8	1.0	0.9	3.7	2.5	2.2	6.3	4.6	4.5

From these tests it was concluded that at temperatures of 600° or higher 95% of the alkaline iodides are readily volatilized in about 30 minutes.

Several preliminary runs were made in the incinerator to determine which sampling procedure would produce the highest stack gas recovery. The filter thimble used for P-32 analysis was tried with some success. Generally, the recovery was much lower than expected even with sixty minute sampling periods. It was assumed that while some of the activity was being filtered out, most was passing through the filter in gaseous form. Two impingers in series were tested for efficiency in removing I-131 from the stack gas. The adsorbing solution consisted of the following:

0.02M NaOH
0.005M NaHSO₃ (Reducing Agent)
0.0015M KI (Iodine Carrier)

Several experimental loadings of I-131 to the incinerator were made to compare the efficiency of the scrubber with the filter thimble. In these tests the sampling period was limited to 30 minutes based on information derived from the laboratory study. The results of these tests were discouraging, giving a recovery of only about 40% of the charge. The comparison of the two techniques are summarized as follows:

STACK GAS RECOVERY BY FILTER AND IMPINGER TECHNIQUE
WITH 30-MINUTE SAMPLING RUNS AFTER CHARGING I-131

Incinerator Charge Microcuries	Recovery in Stack Gas in Microcuries and % of Charge			
	Filter		Impinger	
	<u>uc</u>	<u>%</u>	<u>uc</u>	<u>%</u>
34	14	41	14	41
34	8	24	6	18
34	12	35	--	--
136	18	13	42	31
176	--	--	44	25
806	--	--	315	39

These findings called for another set of laboratory investigations attempting to duplicate incinerator conditions. A metal crucible was assembled with draw off tube so that the atmosphere heated in the muffle furnace could be sampled through an impinger train.

Known charges of I-131 in planchets were placed in the crucible and heated to 600°C. in the muffle furnace. A summary of these experiments are given below:

LABORATORY EXPERIMENTS WITH I-131 INCINERATION

Length of Sampling Minutes	Sampling Rate C.F.M.	Recovery of Activity in Percent of Charge	
		Stack Gas	Ash
30	0.68	28.3	4.1
30	0.87	28.5	14.6
60	0.64	71.0	17.9
60	0.94	75.0	4.6
60	1.03	84.5	5.4

These data show conclusively that greater than 30 minutes are required for the I-131 to be discharged from the stack. Apparently most of the I-131 leaves the incinerator in about 30 minutes, but is deposited on the stack wall where it is unloaded into the gas stream during the next 30 minutes. It appears that the operation of the filter thimble followed by the gas scrubber is the technique of choice. In all subsequent controlled experiments the sampling interval was increased to one hour or more.

Activity in the Gas

Figure 10 shows the pattern of stack discharge taken with the filter thimble during the incineration of I-131. The curves seem to show that the discharge of filterable radiiodine is complete in about 30 minutes after adding the charge. Many scrubblings of the flue gas were made for only the 30-minute sampling period after the incinerator had been charged with I-131 ranging from 30 to 800 microcuries per test. An average for seven such experiments gave a flue gas recovery of 52% of the charge. The average recovery on the stack wall when measured immediately after these 30-minute runs gave the unusually high recovery of 30% of the charge. This indicated that the loss from the furnace was in the order of 80% of the charge. By increasing the scrubbing period

to 80% of the charge and clearly showed the interrelationship of the I-131 on the stack wall to the concentration in the gas stream. It would appear that initially the I-131 adheres to the incinerator and stack walls but with continued passage of the hot flue gasses is eventually carried away.

Activity on the Stack Walls

As discussed above, the activity on the stack wall is quite variable depending upon the time of measurement after the charge has been placed in the incinerator. At a 30-minute period the recovery on the wall could be as high as 50% of the charge. At the end of 1 hour after charging the I-131, the activity on the stack wall ranged from 5 to 10% of the charge. The loss of activity on the stack wall is very rapid which is partly due to the unloading into the gas stream and partly due to the short half-life of the isotope. For example, 3 millicuries of I-131 were incinerated during the month of July, and on August 1, measurements made on plates that had hung in the stack for the entire period gave the total stack wall activity of less than 30 microcuries.

On Figure 11 is plotted the vertical distribution of activity on the stack wall measured about two hours after the charge had been placed. It may be seen that the deposits decreased with stack length with the average deposit being 1.6 times the activity in the top section.

Activity in the Ash

Both the dry and wet technique were employed in measuring the residual activity in the ash after an experimental charge had been incinerated. A solution of 0.02M sodium hydroxide was used for dissolving the activity in the ash. The results of these experiments were as follows:

FIG. II
VERTICAL DISTRIBUTION OF ACTIVITY
DEPOSITED ON STACK WALL

RADIOIODINE I-131

DETERMINATION OF ACTIVITY IN INCINERATOR ASH

I-131 Charged to Incinerator Microcuries	I-131 Recovered from Ash			
	Dry Method		Wet Method	
	<u>uc</u>	<u>%</u>	<u>uc</u>	<u>%</u>
35.7	0.4	1.2	0.5	1.4
34.8	1.6	4.6	1.0	2.9
34.1	2.9	8.5	0.2	0.6
33.1	6.8	20.6	3.1	9.3
34.5	2.3	6.7	1.0	2.9
34.4	10.4	30.0	2.1	6.1
Average 34.4	4.1	11.9	1.3	3.8

As was the experience with ash analyses, the dry measurements gave a higher recovery than the liquid digestion methods. The variation in recovery obtained from the same charge is typical of the limitations of both techniques. Assuming the analysis of the stack wall deposits and gas scrubbing to be less variable, the amount remaining in the ash would be about 9% of the charge.

Dust and Atmospheric Hazard

The low percentage of I-131 remaining in the ash limits the problem of dust during ash removal. Several examinations of the incinerator room atmosphere during ash removal revealed the following concentrations:

ATMOSPHERIC CONCENTRATIONS OF I-131 IN INCINERATOR ROOM DURING ASH REMOVAL

I-131 Charged to Incinerator	Equipment Used*	Recovery of I-131 Microcuries/cc. of Air
34.1	H.V.F.	0.01 x 10 ⁻¹⁰
	E.S.	3.70 x 10 ⁻¹⁰
34.5	H.V.F.	0.58 x 10 ⁻¹⁰
	E.S.	5.50 x 10 ⁻¹⁰
33.1	H.V.F.	0.30 x 10 ⁻¹⁰
34.5	H.V.F.	0.80 x 10 ⁻¹⁰

* H.V.F. - High Volume Filter

E.S. - Electrostatic Precipitator

It can be seen that the electrostatic sampler obtained much higher concentrations than the high volume filter. Usually the two techniques compare fairly well and since the activity is presumed to be on ash particulate, the wide differences between the sampling methods cannot be explained. While these figures appear to be low it must be cautioned that very small loadings were used to obtain them. The concentrations given are believed to be I-131 free of natural background activity.

The discharge of high concentrations of I-131 in the stack gas offers a potential hazard to the residents in the vicinity of the incinerator. Based on the recovery obtained in the flue gas, one millicurie of I-131 placed in the incinerator would produce a stack gas concentration of about 5.0×10^{-7} c/cc. of gas. This value is about 170 times the maximum permissible atmospheric concentration. Atmospheric samples taken downwind from the stack did not show very high concentrations with the high volume samples; however, very low incinerator loadings of I-131 were employed during these tests.

<u>I-131 Charge</u> <u>Microcuries</u>	<u>Atmospheric Concentrations</u> <u>I-131 Microcuries/cc. Air</u>
34.5	7.9×10^{-12}
34.4	5.6×10^{-11}
697.0	0.11×10^{-9}

Maximum Permissible Concentration 3.00×10^{-9}

These results may be projected to show that during the time of meteorology unfavorable for good dispersion of stack gases, it may be undesirable to charge more than 20 millicuries of I-131 per hour to the experimental incinerator.

Summary of Experimental Results

The over-all behavior of radioiodine in wastes burned in the incinerator is summarized on Figure 12. While fewer experiments were run in the incinerator than with P-32, it is felt that a better accountability was obtained with radioiodine. It appears reasonable to conclude the following:

- (1) Within one hour after charging the incinerator with I-131 eighty percent of the charge will reach the atmosphere, where, depending on the amount charged and the effective stack height, it may produce undesirable atmospheric concentrations of I-131.
- (2) Within the hour after charging, about eleven percent of the charge will remain adsorbed on the stack wall. Apparently wall activity will not reach undesirable levels due to progressive unloading into the gas stream coupled with comparatively rapid decay.
- (3) About nine percent of the activity charged to the incinerator will remain in the ash and depending on loading level could produce undesirable concentrations in the atmosphere during ash removal.

EXPERIMENTAL RESULTS WITH RADIOSTRONTIUM Sr-89

Preliminary Experiments

Several laboratory experiments were conducted to determine the behavior of Sr-89 in acid, alkaline and neutral solutions when heated in the muffle furnace for varying periods of time at 300° and 600° C. The results of these tests are shown in Table 6. These tests show that very little loss on heating occurs at either temperature level with acid or alkaline solutions of Sr-89. This finding was further confirmed by the following laboratory experiments:

ACTIVITY IN COUNTS PER MINUTE AFTER HEATING Sr-89
IN VARIOUS HYDROGEN ION CONCENTRATIONS
AT 600° C. FOR VARYING TIMES
(Average of 2 Replicates)

Time of Heating Minutes	Hydrogen Ion Concentration (pH)				
	1.05	2.2	6.0	8.0	10.4
0	618	672	646	682	688
15	598	667	648	642	687
30	615	642	630	643	656
60	592	648	624	627	649
Total Loss %	4.2	4.4	3.4	8.0	5.4

From these data we can assume 90 - 95% of the Sr-89 charged to the incinerator to remain in the ash residue.

Incinerator Experiments

Only two experiments were conducted in the incinerator. The results of these tests are summarized below:

DISTRIBUTION OF RADIOSTRONTIUM UPON INCINERATION

Charge to Incinerator Microcuries	Recovery in Microcuries and Percent of Charge					
	Stack Gas		Stack Wall		Ash	
	<u>Mc</u>	<u>%</u>	<u>Mc</u>	<u>%</u>	<u>Mc</u>	<u>%</u>
477	1.5	0.3	45.0	9.4	271.6	57
390	1.0	0.2	7.4	1.9	289.5	74

Table 6

ACTIVITY OF Sr-89 IN ACID AND ALKALINE SOLUTION IN COUNTS PER MINUTE *
WHEN HEATED AT 300° AND 600° C. FOR VARYING PERIODS OF TIME

Time of Heating Minutes	Acid Solution				Alkaline Solution			
	300° C.		600° C.		300° C.		600° C.	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
15	465	406	378	390	433	440	396	392
30	377	383	376	378	416	405	364	387
60	353	350	407	402	405	407	380	385

* Average of Three Replicates

When the filter thimble and impinger train was employed in series for measuring the gas concentration of Sr-89, eighty percent of the recovery was made in the impinger which follows the filter unit. The adsorber employed was a 1 to 4 dilution of HCl. The discharge of the Sr-89 was very gradual over a period of one hour.

The stack wall activity was much higher in the first experiment when the charge was added on absorbent paper. In an effort to get better ash recovery, the second charge of Sr-89 was poured into a pan of ash and placed into the incinerator. This resulted in less recovery on wall and gas but a much higher ash recovery since the pan was removed intact.

Acknowledging errors in technique, it may be assumed that a greater percentage of the charge remains in the ash than indicated by experimental examination. It is felt that ninety percent or more of the Sr-89 will be in the ash and would present a serious hazard during ash removal and disposal. The comparatively long half-life of Sr-89 would constitute a hazard if high stack wall activity were permitted to build up. Figure 13 shows the vertical distribution of activity on the stack wall. As was the case with P-32, the concentrations at the lower portions of the stack are considerably higher than the upper levels.

In summary it may be stated that ninety percent of the radio-strontium charged to the incinerator will remain in the incinerator and ash. Of the charge escaping into the stack nine percent will be deposited on the stack wall and one percent discharged with the stack gases.

FIG. 13

VERTICAL DISTRIBUTION OF ACTIVITY
DEPOSITED ON STACK WALL

RECOMMENDATIONS FOR WASTE DISPOSAL BY INCINERATION
OF PHOSPHORUS-32 AND IODINE-131

Toilet disposal of radioisotope waste is preferred over incineration in the ordinary institutional type destructor. However, there are many types of wastes encountered which, due to their bulkiness and character, are not conveniently disposed of in sewer systems without the possibility of stoppages and maintenance difficulties. These wastes, such as experimental animals, cage cleanings and eggs are presently being incinerated without significant health hazards. It is felt that with the experimental data at hand that standards could be suggested to provide for the safe use of institutional incinerators for disposing of moderate levels of radioactivity.

The formulation of the standards for the safe incineration of Phosphorus-32 and Iodine-131 is based on the following assumption:

1. That each isotope will act independently.
2. That the greatest hazard will be through the ingestion or breathing of activity rather than external radiation hazard.
3. The maximum permissible 24-hour concentration is 1×10^{-7} microcuries of P-32 per cc. air and 3×10^{-9} microcuries of I-131 per cc. air.
4. The performance of the incinerator used for the experiments is representative of those normally encountered at medical or research institutions.
5. The performance obtained with experimental loadings of isotope can be projected for higher and continuous charging.
6. The incineration of radioisotopes takes place during an 8-hour working day.

The activity deposited on the stack wall is not generally accessible to human contact excepting during periods of equipment maintenance. Even though this contact with the activity may be infrequent, it is thought best not to allow the walls to reach too high a level. With a given loading a known percentage will be deposited on the wall and will reach an equilibrium between amount added daily and natural decay.

The hazard associated with the discharge of isotope in the stack gas is not only dependent upon the concentration in the stack gas but the effectiveness of dispersion of the material in the surrounding atmosphere. The estimates of the maximum possible concentration at ground level are based on Sutton's Tables ^{8/} for large inversion conditions with 1 m./sec wind. The values in Sutton's Tables give the maximum ground concentration in milligrams per cubic meter and the stack emission in grams per second. It can be computed that there are 0.81×10^{-5} grams of I-131 per curie and 3.52×10^{-6} grams of P-32 per curie.* The conversion from microcuries per cc. to mg per cubic meter is as follows:

$$\text{I-131} = \frac{3 \times 10^{-9} \text{uc}}{\text{cc.}} \times \frac{10^6 \text{cc.}}{\text{cu.m.}} \times \frac{\text{curie}}{10^6 \text{uc}} \times \frac{0.81 \times 10^{-2} \text{mg}}{\text{curie}} = 2.43 \times 10^{-11} \text{ mg/cu.m.}$$

$$\text{P-32} = \frac{1 \times 10^{-7} \text{uc}}{\text{cc.}} \times \frac{10^6 \text{cc.}}{\text{cu.m.}} \times \frac{\text{curie}}{10^6 \text{uc}} \times \frac{3.52 \times 10^{-3} \text{mg}}{\text{curie}} = 3.52 \times 10^{-10} \text{ mg/cu.m.}$$

Referring to the values in the table for maximum ground concentration during large inversions, units expressed for a source of 1 microcurie per second are given below:

^{8/} The Theoretical Distribution of Airborne Pollution from Factory Chimneys - O. G. Sutton, Royal Meteorological Society, Quart. J. 73, 426-435, 1947.

* Grams per curie = $7.67 \times 10^{-9} A$ (atomic wt.) $\times T_d$ (half life days)

Height of Stack Meters	Maximum Ground Concentration			
	Milligrams/cu.m.		Microcuries/cc.	
	<u>I-131</u>	<u>P-32</u>	<u>I-131</u>	<u>P-32</u>
10	5.4×10^{-12}	2.4×10^{-12}	6.8×10^{-10}	6.8×10^{-10}
25	1.4×10^{-12}	0.6×10^{-12}	1.7×10^{-10}	1.7×10^{-10}
50	0.4×10^{-12}	0.2×10^{-12}	0.6×10^{-10}	0.6×10^{-10}

It will be noted that the ground concentration of any isotope is the same when the emission is expressed in the curies per second scale. While such concentrations have not been experimentally measured, it may be recalled that an emission of about 0.2 microcuries per second of I-131 give an atmospheric concentration of 1.1×10^{-10} microcuries per cc. of air. The sample was taken about 6 meters below the top of the stack during positive lapse conditions and about 1 m./sec wind velocity.

The hazard presented during ash removal is based on the experimental concentrations obtained with various charges of isotope. The rather high concentrations obtained are offset by the fact that the dust does not remain long in the air after the cleaning has been completed. Nevertheless, consideration should be given that possibly the radioactive dust could be resuspended in the air several times during the working day through ash loading and unloading.

On Figures 14 and 15 are shown in graphical form the allowable limits for safe operation of incinerators disposing of P-32 and I-131 wastes. Loading of the incinerator is expressed microcuries of isotope per pound of refuse per hour.

It can be seen that the limitation of P-32 incinerated is determined by the hazard in ash removal and handling. With due allowance for the short exposure anticipated the safe loading limit is about 4 microcuries per pound of refuse per hour or 800 microcuries per hour in the experimental incineration. The very small

fraction of P-32 escaping up the stack eliminates any cause for concern. Even with the 10 meter stack one could approach a loading of 132 millicuries per pound of refuse per hour without undesirable atmospheric concentrations.

For I-131 the hazard of handling ash becomes the limiting factor as was the case with P-32. In spite of the fact that 80% of the isotope incinerated is discharged to the atmosphere, it can be shown that amounts added must be extremely large to reach undesirable concentrations during adverse weather conditions:

<u>Stack Height m.</u>	<u>Allowable charge in uc/lb. refuse/hour</u>
10	100
25	400
50	1125

These values are considerably higher than the 2 microcuries per pound of refuse per hour limit imposed by hazardous atmospheric concentrations during the removal of ashes.

It is believed that adequate safety factors have been provided through this analysis but much will depend on the systematic charging of activity with the refuse in order to keep within desirable limits.

SUMMARY

1. A description is given of methods and equipment used for determining the distribution of radioisotope in stack gas, stack wall and ash during the incineration of known charges with refuse.

The activity deposited on the stack wall is determined by direct monitoring with the GM Tube inserted into the stack. The average stack deposit is estimated by measuring the vertical distribution of activity on metal discs hung at intervals throughout the length of the stack.

Both dry and wet methods of ash activity recovery do not satisfactorily measure the concentrations of radioisotope remaining in the ash.

The use of the high volume air filter and the electrostatic precipitator are described for determining the activity in the atmosphere.

2. Controlled experiments in the incinerator using radiophosphorus, P-32, radioiodine I-131, and radiostrontium Sr-89 gave the following recovery distribution:

<u>Isotope</u>	<u>Recovery in Percent of Charge Incinerated</u>		
	<u>Stack Gas</u>	<u>Stack Wall</u>	<u>Ash</u>
P-32	2	12	86
I-131	80	11	9
Sr-89	1	9	90

3. The experimental data has been employed to formulate suggested standards for the safe incineration of P-32 and I-131. The maximum desirable charge in microcuries per pound of refuse per hour is 4 for P-32 and 2 for I-131. The maximum charge of both P-32 and I-131 is based on the breathing hazard during ash removal.