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AEC RESEARCH AND DEVELOPMENT REPORT

CONFINEMENT OF AIRBORNE RADIOACTIVITY

PROGRESS REPORT

JANUARY - JUNE 1971

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L. R. JONES

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Savannah River Laboratory

Aiken, South Carolina

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CONFINEMENT OF AIRBORNE RADIOACTIVITY

PROGRESS REPORT: JANUARY-JUNE 1971

by

A. G. Evans
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October 1971

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ABSTRACT

Penetrating iodine compounds can be formed in carbon beds as the result of the radiation background produced by the adsorbed radioiodine. The rate of formation and desorption of these iodine compounds is a function of the radiation field strength, duration of exposure, type and service history of the carbon, and moisture content of the purge gas stream.

On November 9, 1970, about 160,000 curies of particulate activity was released into the K reactor room from an irradiated antimony-beryllium source rod which melted while suspended in air. Approximately 1370 curies reached the confinement filters; only 3 millicuries escaped to the environs.

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INTRODUCTION

The activity confinement system for each Savannah River production reactor is designed to collect halogens and particles that might be released in the unlikely event of a reactor accident. A continuing program is in progress at the Savannah River Laboratory to evaluate the performance of the confinement system for removal of airborne radioactivity under adverse operating conditions and to develop techniques to enhance its reliability and efficiency.

Previous reports* summarize the progress from September 1961 to December 1970.[1-8] This report summarizes studies at the Savannah River Laboratory from January to June 1971.

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* Previous progress reports in this series were entitled *Iodine Retention Studies, Iodine and Noble Gas Retention Studies, High Temperature Adsorbents for Iodine, and Performance of Activated Carbon Beds in SRP Reactor Confinement Facilities.*

SUMMARY

Iodine compounds that will penetrate iodine adsorber beds are formed when elemental iodine, carbon, and moisture are exposed to an intense gamma radiation field. The degree of formation and penetration of these compounds is a function of the intensity of the gamma field, the length of exposure period, the type and service history of iodine adsorber, the moisture content of the purge gas stream, and possibly the temperature. The reaction was observed in tests up to 100 hr in a ^{60}Co gamma field of 1.5×10^7 rads/hr* when I_2 was loaded on activated carbon, and the system purged with ambient air. The reaction ceases when the system is removed from the gamma field. Increasing the relative humidity of the purge gas stream increases the rate of desorption of the penetrating compounds. The total iodine penetration of impregnated carbon beds (KI_3, triethylenediamine, or lead salts) and inorganic adsorbers (silver impregnated or exchanged) is less than that of unimpregnated carbons. The iodine compounds CH_3I, CH_2I_2, C_2H_5I, and C_2H_3I have been recovered and identified as desorption products. A new test facility is being built to permit increased flexibility in testing carbon and other components of the confinement system in an intense gamma radiation field.

On November 9, 1970, antimony in an irradiated antimony-beryllium source rod melted while suspended in air in the K reactor room at the Savannah River Plant. About 160,000 curies of particulate activity was released to the reactor room with about 1370 curies reaching the confinement filters. Only 3 millicuries escaped to the environs; no cleanup outside the reactor building was required.

* Absorbed dose rate in the carbon.

DISCUSSION

FORMATION OF PENETRATING FORMS OF IODINE IN A RADIATION FIELD

Previous confinement system studies at Savannah River have shown that elemental iodine retention on activated carbon is most strongly influenced by the operating temperature of the filter beds, the moisture content of the air passing through the beds, and the length of time the carbon has been in service in the system.[1-7] Companion studies on the radiolytic decomposition of methyl iodide on carbon showed that the presence of an intense gamma radiation field does not significantly increase the effectiveness of carbon for methyl iodide absorption.[3-7]

Extensions of the radiation effects studies to include irradiation of elemental iodine on carbon beds show that penetrating organic iodides (and possibly unidentified penetrating inorganic iodides) are formed when a system composed of elemental iodine, carbon, and moist air is exposed to an intense gamma radiation field. The extent to which the iodides are formed and released from test carbon beds is a function of radiation intensity, duration of irradiation, carbon type, moisture content of the purge gas stream, carbon service history, and possibly the temperature.

Radiation tests were performed in the ^{60}Co irradiation facility with the test apparatus described in previous reports.[6-7] For the current series of tests no methane or methyl iodide were added to the test gas stream. Elemental iodine was volatilized into a humid air stream, passed through a test bed containing carbon or other iodine adsorbers, and then passed through a series of backup carbon beds before release to the atmosphere.

Required Reaction Components

Tests were first conducted to demonstrate that the simultaneous presence of carbon, iodine, moisture, and radiation are required for the formation of the penetrating iodides. The test carbon was an unimpregnated coconut carbon currently used in the Savannah River confinement system. Test results are summarized in Table I. Test conclusions are summarized below.

- Preirradiation of the carbon in a humid air stream did not cause subsequent substandard performance of the carbon in iodine retention out of the radiation field.
- Preirradiation of the mixture of I_2, H_2O, and air produced no penetrating iodides when the carbon was not irradiated.
- Release of penetrating iodides ceased when the loaded test bed was removed from the radiation field.
- Release of penetrating iodides increased with increasing humidity in the purge gas stream.
- Release of penetrating iodides continued for at least 100 hr (the maximum test duration to date) when the test carbon bed was left in the radiation field.

TABLE I

Effect of Radiation and Moisture on Iodine Penetration[a]

Iodine Penetration, %	Loading Conditions[b]	Desorption Conditions	Remarks
<0.01	80°C 50% relative humidity No radiation	1 hr 30°C 20% relative humidity No radiation	Blank test, no radiation.
<0.01	80°C 50% relative humidity No radiation	1 hr 30°C 20% relative humidity No radiation	Preirradiated carbon at 80°C and 50% relative humidity
<0.01	80°C 50% relative humidity No radiation	1 hr 30°C 20% relative humidity No radiation	I_2, H_2O-air mixture irradiated during loading
0.03	100°C <1% relative humidity 1.5×10^7 rads/hr	1 hr 30°C 20% relative humidity 1.5×10^7 rads/hr	Dry air loading
0.14	80°C 50% relative humidity 1.5×10^7 rads/hr	1 hr 30°C 20% relative humidity 1.5×10^7 rads/hr	Moist air loading
0.15	80°C 50% relative humidity 1.5×10^7 rads/hr	2 hr 30°C 20% relative humidity 1.5×10^7 rads/hr	Removed from radiation field during second hour desorption
0.30	80°C 50% relative humidity 1.5×10^7 rads/hr	4 hr 30°C 20% relative humidity 1.5×10^7 rads/hr	Long ambient air desorption
0.43	80°C 50% relative humidity 1.5×10^7 rads/hr	4 hr 80°C 50% relative humidity 1.5×10^7 rads/hr	Long, hot, moist air desorption

a. Unimpregnated coconut-base carbon.
b. 1-hr loading after 30 min pre-equilibration at proper temperature and humidity.

Tests are planned in an inert atmosphere to evaluate the role of air in the reaction, and with anhydrous air to prove conclusively that moisture is required. The importance of moisture can be inferred, however, from the tests summarized in Table I and from the extended irradiation tests shown in Figure 1. In each of the extended irradiation tests, the desorption rate increased significantly when the humidity was raised from ~20% (ambient) to 90% by the intentional addition of moisture into the inlet air stream. Smaller increases in the desorption rates were also noted with diurnal changes in the relative humidity of the incoming air stream as shown in Figure 2 (the test apparatus is housed in a building which has no temperature or humidity control).

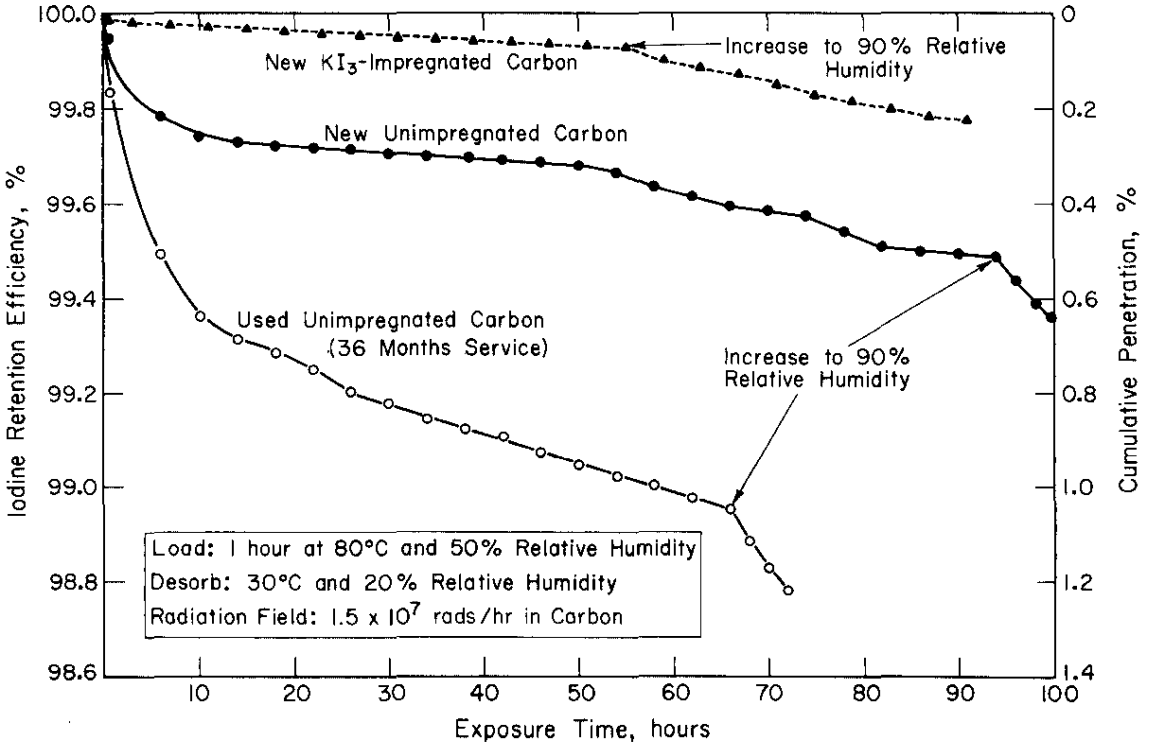

FIGURE 1. Effect of Radiation on Iodine Retention

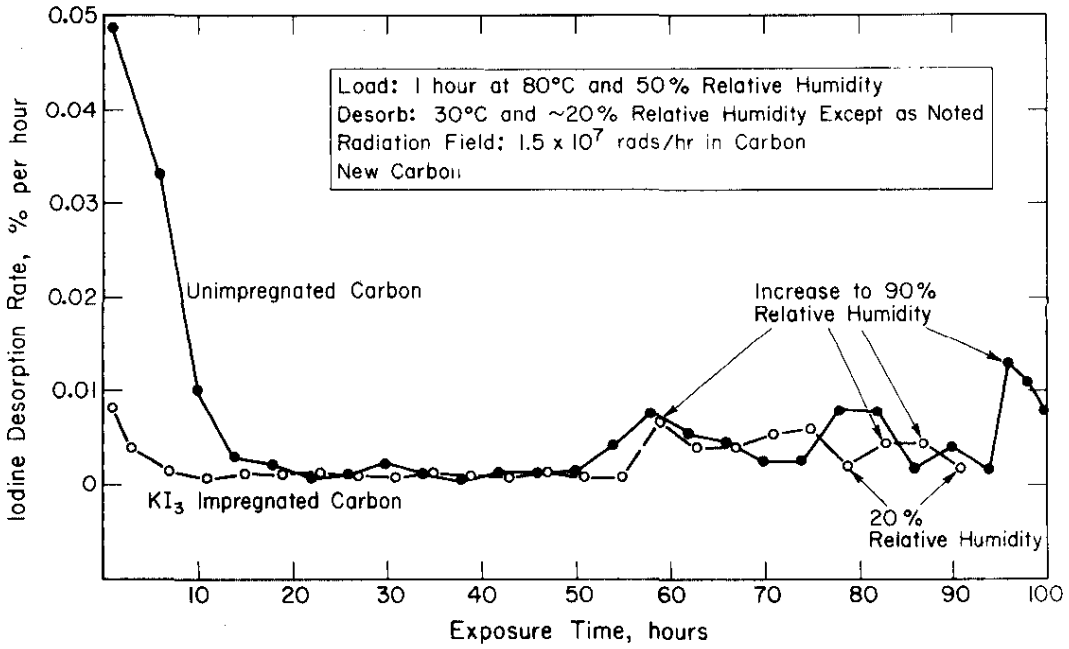

FIGURE 2. Iodine Desorption Rate of New Carbons

The radiation dose rate also determines the rate of iodine desorption. The increase in desorption at the higher dose rate (as shown in Table II) suggests a possible dose rate dependent reaction.

TABLE II

Iodine Penetration as a Function of Dose Rate

Absorber	Cumulative Penetration (in a 50% relative humidity air stream),[a] %		
	1.5×10^7 rads/hr at 80°C	1.5×10^7 rads/hr at 60°C	1.4×10^6 rads/hr at 60°C
Unimpregnated coconut carbon (Mfgr. A)			
1-hr loading	0.0803	0.0414	0.0041
2-hr desorption	0.1271	0.1562	0.0128
4-hr desorption	0.3349	0.2427	-
Unimpregnated coconut carbon (Mfgr. B)			
1-hr loading	0.0669	0.0431	0.0028
2-hr desorption	0.1857	0.1962	0.0103
4-hr desorption	0.2957	0.3181	0.0165
KI_3-impregnated coconut carbon (Mfgr. A)			
1-hr loading	0.0025	0.0027	<0.0001
2-hr desorption	0.0086	0.0063	0.0002
4-hr desorption	0.0154	0.0083	0.0003

a. 5-hr test; iodine loading during first hour.

Design limitations in the present test apparatus limit the range of operating conditions for many of the tests. Thus, the dose rate comparisons were made at 60°C rather than 80°C. At the higher dose rate, gamma absorption heat permits operation at higher temperatures. A new test facility is being constructed to permit greater flexibility in operating conditions; this new facility is discussed in a later section of this report.

The effect of carbon service is also shown in Figure 1. The initial desorption rate from 36-month carbon is much higher than that of new carbon, but decreases to essentially the same rate after 50-hr desorption (Figure 3).

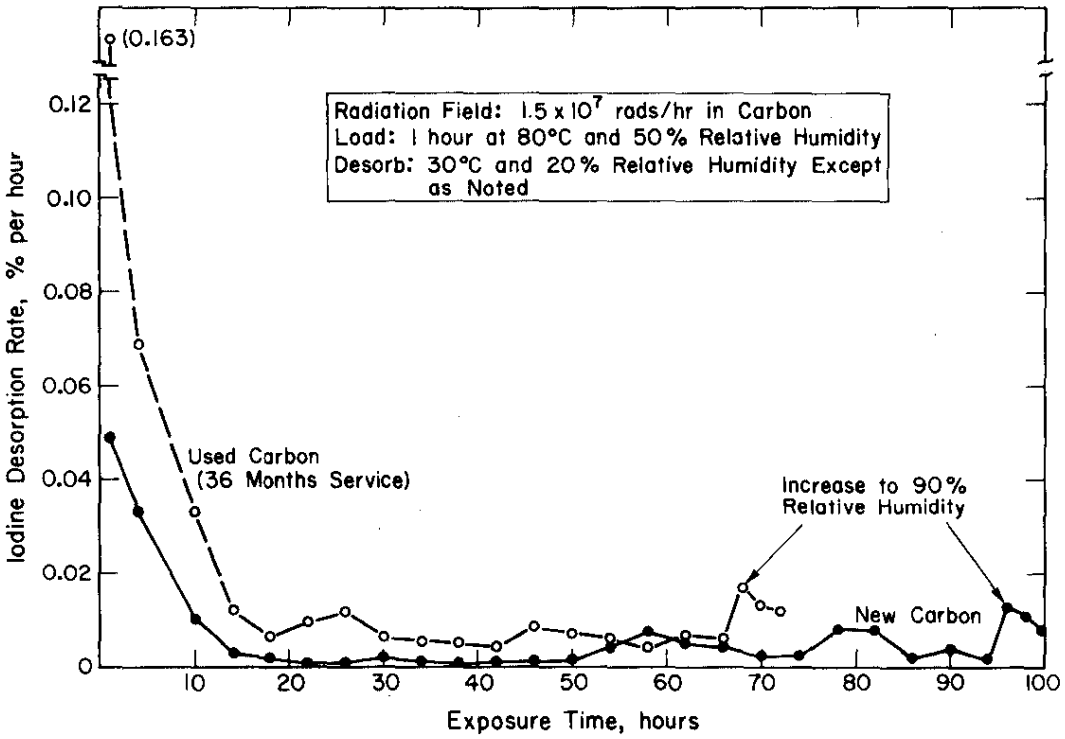

FIGURE 3. Iodine Desorption Rate in a Radiation Field

Reaction Products

Iodine compounds desorbed from the test carbon bed in the radiation field are passed through a series of backup carbon beds, which are located outside the gamma field. The backup beds are maintained at the same temperature or at higher temperatures than the test bed to prevent condensation of moisture in the backup beds and air lines. The first backup bed contains unimpregnated carbon; the next two backup beds contain KI_3-impregnated carbon.

The distribution of activity on the three backup beds varies with the operating temperature of the beds. When the system is maintained at about 80°C (the same temperature as the test carbon bed), the unimpregnated backup bed retains 40-50% of the desorption products, while the first impregnated carbon bed retains ∿99% of the activity passing through the first backup bed. Increasing the temperature of the air stream increases the fraction retained on the unimpregnated carbon. This behavior is consistent with that observed earlier[6] for methyl iodide, because increasing the temperature decreases the relative humidity of the air stream and increases the fraction retained on unimpregnated carbon.

Attempts to recover and analyze the activity trapped on the unimpregnated carbon backup beds have been only partially successful. Both inert gas purging and vacuum heating techniques have been attempted with a net removal of <20% of the activity on the bed. The gases removed from the beds are collected in liquid nitrogen cold traps and analyzed by gas chromatography.

Four organic iodides have been identified in the products collected from the backup beds: methyl iodide (CH_3I), methylene iodide (CH_2I_2), ethyl iodide (C_2H_5I), and vinyl iodide (C_2H_3I). Two noniodinated compounds (methanol and nitromethane) are usually found, and as many as eight other as yet unidentified compounds are present in most samples. Other techniques for collection and identification of the desorption products are being investigated. The small sample size and large dilution factors make direct specific analysis difficult (<40 μg of iodine desorbed into ∿8 m^3 of air containing ∿1.5 kg of H_2O during a typical 4-hr desorption).

Reaction Mechanisms

The experiments to date have been scoping studies designed to define the nature and magnitude of the phenomenon rather than to establish specific mechanisms or rate constants. The data are sufficient, however, to identify the critical components in the system and, thus, to infer some general reaction mechanisms.

Moisture is apparently one of the critical rate controlling components in the system. Because the principal penetrating products appear to be organic iodides, the moisture content of the purge gas stream probably plays a dual role in iodine desorption:

- Radiolytic decomposition of water furnishes the hydrogen required to form stable alkyl iodides.
- The rate of desorption of organic iodides from the test bed is governed by the relative humidity of the purge gas stream.

In the highly energetic system existing in a radiation field of $\sim 10^7$ rads/hr, the reaction mechanisms are probably all free radical reactions. Of the numerous free radical pathways available to form organic iodides, the simplest (and most probable) is the radiation-induced iodination of organic side chains on the basic carbon structure followed by reaction with hydrogen and hydroxyl free radicals to form organic iodides. Thus for methyl iodide the reactions

$$I_2 + RCH_3 \rightsquigarrow RCH_2I + HI$$

$$H_2O + RCH_2I \rightsquigarrow R\text{-}OH + CH_3I$$

can be postulated. Similar equations can be written for methylene, ethyl, and vinyl iodides.

Sequential hydrogenation of unsubstituted carbon to form methylene free radicals ($\cdot CH_2 \cdot$) or methyl free radicals ($H_3C \cdot$) and subsequent reaction with sorbed or free radical iodine is also possible, but somewhat less probable because of the multiple reactions required.

SCREENING TESTS FOR ALTERNATIVE IODINE ADSORBERS

The scoping studies previously discussed were designed to define the nature and extent of iodine penetration of activated carbon in the presence of an intense gamma radiation field. In the unlikely event of a major reactor accident, the radioiodine loading of the confinement system carbon could create a radiation field of sufficient strength to desorb significant quantities of iodine. Consequently, a series of screening tests was undertaken to find potential alternative iodine adsorbers that are less sensitive to the radiation effects.

Samples of several types of carbon base adsorbers and inorganic base adsorbers were obtained and are being subjected to a series of tests both in and outside the radiation test facility.

Test Conditions

Four tests were used: 1) a control test, 2) a radiation screening test, 3) an NO_2 exposure test, and 4) a high temperature desorption test.

Control and Radiation Tests. Test conditions for the control and radiation screening tests were dictated by equipment limitations in the present ^{60}Co irradiation facility. Elemental iodine is loaded onto the test bed over a 60-min period in an 80°C air stream at 50% relative humidity. Iodine is then desorbed for 4 hr under the same conditions (80°C and 50% relative humidity). In the radiation screening test, both the loading and desorption steps are carried out in a radiation field of 1.5×10^7 rads/hr (absorbed dose rate in the carbon). The control test is performed in the absence of radiation. Iodine is loaded by vaporizing freshly precipitated $^{127}I_2$ tagged with ^{131}I into a prefiltered air stream in the manner described in previous reports.[6,7]

NO_2 Test. Samples of test carbon are artificially aged in an NO_2-air environment in the manner described in the previous report.[7] Total NO_2 exposure is 91.1 mg of NO_2/g of carbon or the equivalent of 36 months of exposure in the confinement system. $^{127}I_2$ tagged with ^{131}I is loaded onto the test carbon over a 10-min period in ambient air (23°C and ∿50% relative humidity) and desorbed for 4 hr with an 80°C air stream saturated with moisture. This test is outside the radiation field.

High Temperature Test. Iodine ($^{127}I_2$ tagged with ^{131}I) is loaded onto the test carbon in 10 min at ambient conditions (23°C and ∿50% relative humidity) and desorbed for 4 hr with hot (180°C) dry air. This test is performed in the absence of a gamma radiation field.

All the tests are made with 1-in.-thick, 2-in.-dia. test beds baffled to minimize wall effects. Air for the tests is prefiltered through a 1-ft-thick carbon bed and a HEPA filter. Air passes through the test bed at a face velocity of 55 ft/min. Iodine loading is approximately 0.7 mg of I_2/g of carbon (∿0.35 mg/g for inorganic adsorbers).

Test Results

The radiation screening tests tend to confirm the earlier evidence that the principal mechanism of iodine penetration is the formation of organic iodides which are poorly adsorbed on unimpregnated carbons. Carbon base adsorbers impregnated with iodine salts and/or triethylenediamine (TEDA) proved consistently better than unimpregnated carbons as did the silver-impregnated and silver-exchanged inorganic base adsorbers.

Artificial aging tests with NO_2 indicate that lead-impregnated carbons may age more rapidly in the confinement system than KI_3- or TEDA-impregnated carbons. NO_2 aging tests have not been performed on inorganic base adsorbers.

Most of the KI_3-impregnated carbons are more sensitive to high temperatures than unimpregnated carbon. TEDA apparently lessens the sensitivity of KI_3-impregnated carbon to high temperatures. Test data on individual adsorbers are summarized in Table III.

TABLE III

Screening Test Results

			Measured Iodine Penetration, %			
Mfgr.	Base	Impregnant	Control[a]	Radiation Screening[a]	NO_2[a]	High Temp[a]
A	Carbon[c]	None	0.004	0.335	0.061[b]	0.004
B	Carbon[c]	None	0.003	0.299	-	-
C	Carbon[d]	KI_3	0.011	0.059[b]	1.675	6.317
A	Carbon[c]	KI_3	0.001	0.027	0.228[b]	0.052
A	Carbon[e]	KI_3	0.002	0.127[b]	-	-
B	Carbon[c]	KI + TEDA	0.001	0.025[b]	0.049	0.007
B	Carbon[e]	KI_3	0.001	0.013[b]	0.028	0.043
B	Carbon[c]	TEDA	-	0.003	0.024	-
A	Carbon[c]	Pb Salts	-	0.046	-	-
B	Carbon[f]	Pb Salts	0.003	0.015	1.877	-
B	Carbon[c]	Pb Salts	0.001	0.136[b]	0.433	-
B	Inorganic[g]	Ag Salts	-	0.168	-	-
B	Inorganic[g]	Ag Salts	0.008	0.195	-	-
D	Inorganic[h]	Ag Salts	0.001	0.011	-	-

a. Test conditions are described in the text.
b. Average of 2 or more runs.
c. Coconut shell carbon, 950-1100 m^2/g surface area.
d. Petroleum base carbon.
e. Coconut shell carbon, 1400-1600 m^2/g surface area.
f. Coal base carbon, 1200-1300 m^2/g surface area.
g. Aluminum silicate base adsorber, 400-450 m^2/g surface area.
h. Silver-exchanged zeolite.

Further testing of the more promising adsorbers will be scheduled in the new irradiation test facility. As described in a later section of the report, the new test facility will permit more precise control of test variables, such as temperature and humidity.

OFF-SITE DOSE IMPLICATIONS

Previous estimates of off-site thyroid doses that could be received in the unlikely event of a major reactor accident were based on the assumption that iodine penetration of the confinement system would be essentially instantaneous.

The current studies indicate that radiation may cause a larger release of iodine than previously assumed, but that the release would be protracted rather than instantaneous. Data from the present studies (used carbon desorption rates shown in Figure 3) were combined with observed SRP meteorological data[9] to appraise the impact of the larger releases on potential off-site doses.

The combination of protracted releases and more realistic meteorological assumptions results in lower off-site dose estimates than postulated in the previous analysis. Relative thyroid dose comparisons are shown in Figure 4. The percentile figures shown represent the probability that each specific dose value will not be exceeded.

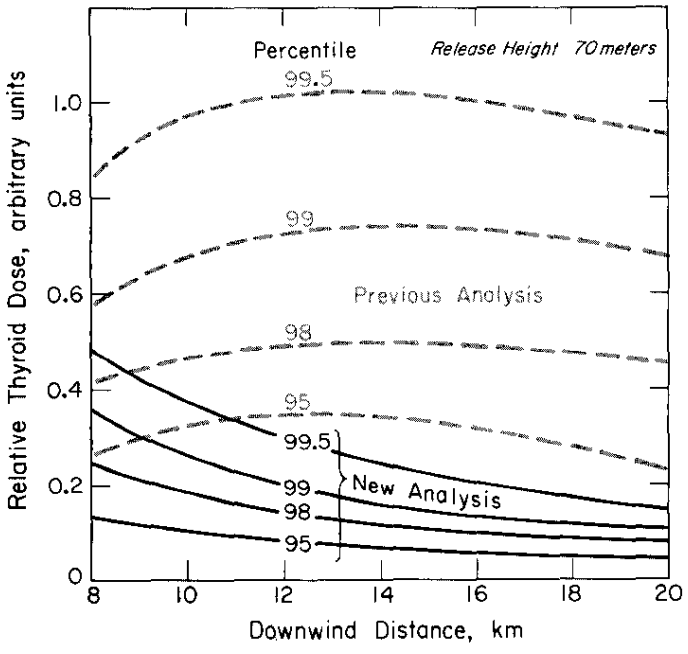

FIGURE 4. Effect of Protracted Releases on Off-Site Dose Estimates

NEW FACILITIES FOR IODINE AND METHYL IODIDE RADIOLYSIS TESTS

Increased emphasis on testing of carbon in a radiation field and radiation degradation of other confinement system components has resulted in the need for expanded component performance testing capabilities in an intense gamma radiation field. A new test filter assembly is being built which will permit testing of all confinement system components (carbon bed, HEPA filter media, moisture separator media, gaskets, adhesives, etc.) simultaneously in an intense gamma radiation field and under postulated accident conditions. Flow areas of components are scaled to obtain face velocities equivalent to full size components in the confinement system. The test assembly can be positioned in the gamma field so that any single component is in the highest flux zone, while other components receive a lesser exposure.

The test filter assembly will contain six independent modules. Each module will be constructed with an outer wall and an inner wall. Cold or heated water will flow through the annular space between the walls to heat or cool each module independently. The annular space will be seal welded from the inside of the module where the process gas stream will flow. The modules will be sealed to each other with "Viton"* O-rings or fiberglass gaskets. This design allows water cooling or heating of the assembly without risking leakage of water through gaskets into the process gas stream.

A chamber is provided in the assembly to trap entrained water which may be removed from the process gas stream by the moisture separator or particulate filter during a steam-air test.

The temperature of the process gas stream will be monitored at four locations in the test assembly. The temperature of the effluent cooling water from each module can also be monitored.

Because test data are obtained by scintillation counting of pieces of the apparatus following the test, each module was also designed to give the best practical geometry for counting.

A new test facility is being built to accommodate the new test filter assembly. The new facility will include:

* Registered trademark of Du Pont.

- A new larger ^{60}Co source consisting of $\sim 1.3 \times 10^6$ curies of ^{60}Co in 28 slugs arranged in a ring around the base of a 10-in.-dia. air-filled aluminum access tube. The ^{60}Co source will be under $\sim$24 ft of water. The access tube will contain an "S" bend similar to the access tube in the present source[6] for attenuation of the gamma beam from the source. The ^{60}Co slugs will be held in a slug holder which can be opened and removed from around the base of the tube to permit removal of the tube. The gamma dose rate in the new source is expected to be $\sim 2 \times 10^7$ rads/hr, or about 30% greater than the present facility.

- A new hood to replace the small glove box used currently. The new hood will contain the elemental iodine and methyl iodide sample apparatus, steam-air-iodine mixing apparatus, and backup carbon beds mounted in a scintillation counter to monitor penetration of the test filter assembly during a test. Sensitivity of the present in-place counter is inadequate for elemental iodine tests because space inside the glove box does not allow optimum counting geometry or adequate background shielding. A water-cooled condenser may also be used to remove water from the steam-air mixture downstream of the test filter assembly. Analysis of this condensate will permit determination of the quantity and composition of penetrating iodine which is scrubbed from the gas stream by the condensate. A schematic diagram of the new test facility is shown in Figure 5.

Component performance can be determined over the following range of conditions:

- The following process gases: air-I_2, air-I_2-CH_3I, steam-air-I_2, steam-air-I_2-CH_3I, steam-air-I_2-CH_4.

- Face velocity through carbon bed from 0 to 65 ft/min (0 to 4.5 ft/min for HEPA filter media, 0 to 400 ft/min for moisture separators).

- Relative humidity from 0% to 100%.

- Air or steam-air mixture temperature from ambient to $\sim$80°C.

- Gamma radiation field from 0 to 2×10^7 rads/hr.

- Elemental iodine or methyl iodide sample loading time from 5 min to 5 hr.

The new test facility and test filter assembly should be completed in 1971.

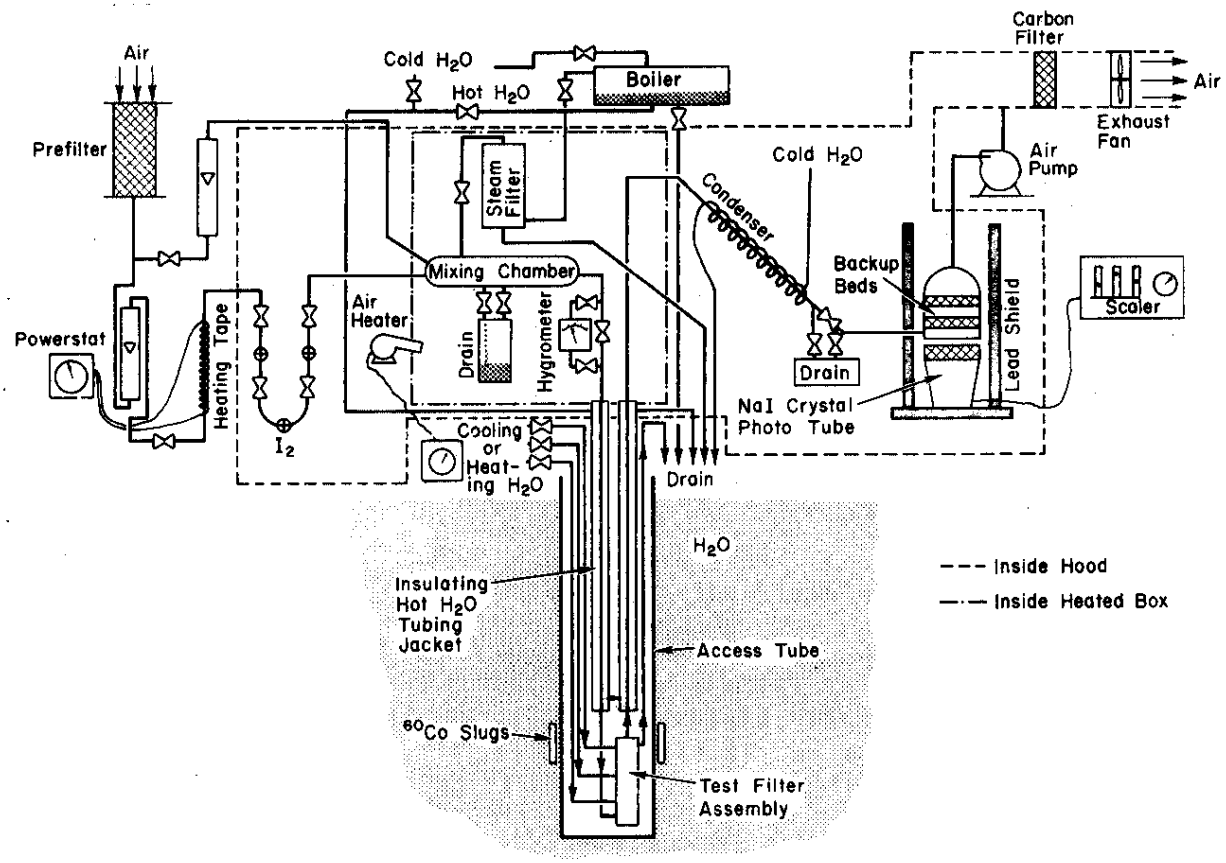

FIGURE 5. Schematic Diagram of New Test Facility

CONFINEMENT OF PARTICULATE ACTIVITY

On November 9, 1970, antimony in an irradiated antimony-beryllium neutron source rod melted while the rod was suspended in air by the reactor component charge machine in the K reactor room at the Savannah River Plant.[10] About 160,000* curies of particulate antimony and tellurium activity was released into the reactor room. Approximately 1370 curies reached the confinement filters. Only 3 millicuries escaped to the environs; no cleanup outside the reactor building was required.

The exhaust system for each reactor building includes five confinement filter compartments to contain released radioactivity in the event of a reactor accident.[7] Exhaust fans maintain a negative pressure in the reactor room, the ducts to the filters, and the filter compartments. Four or five compartments are usually on-line. Each compartment contains moisture separators, particulate filters, and charcoal adsorbers. The unshielded aluminum filter compartments are located on the reactor building roof 55 ft above ground level and are designed for remote removal.[10]

Four compartments were on-line with a total air flow of 86,400 ft^3/min when the accident occurred. The maximum radiation level at the side of the hottest filter compartment was about 70 rads/hr immediately after the accident and 25 rads/hr by the time of replacement.

Radiation surveys were made on each filter compartment after removal from the reactor building roof in February 1971. Data were used to calculate the quantity and distribution of activity in and among the four contaminated filter compartments as shown in Table IV. The activity was unevenly distributed among the compartments because all air exhausted from the reactor room enters one end of the plenum feeding the confinement compartments. Compartments 2 and 3 were nearest the end of the plenum where reactor room air enters. The distribution of activity within each compartment was indicated by radiation measurements taken from the ends of the compartment. Extrapolation of the radiation measurements showed that the activity was concentrated near the upstream end of the compartments as shown in Table IV.

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* Updated value since issue of Reference 10.

TABLE IV

Activity Distribution in K Filter Compartments

Compartment	Activity Curies[a]	Activity %	Distance from Upstream End to Activity Concentration, ft[b]
2	631	46	5.4
3	672	49	5.9
5	64	4.7	3.4
6	4	0.3	4.6
Total	1371	100	

a. ^{124}Sb, ^{122}Sb, ^{125}Sb, ^{123m}Te, and ^{125m}Te, November 9.

b. Upstream face of moisture separator is 4.7 ft from upstream wall of compartment; particulate filter unit is 9.8 ft; carbon bed is 15.0 ft.

Radiation exposure (beta and gamma) to moisture separators in Compartments 2 and 3 is estimated to exceed 10^7 rads before radiation levels will have decayed enough to allow the compartments to be opened for inspection. Some damage to "Teflon"* fibers in the moisture separators is expected. Exposure to particulate filters and carbon beds (gamma) is estimated to be insufficient to cause any measurable damage.

Additional data on the distribution of activity within each compartment and on radiation damage to filter components will be obtained when the filter compartments are opened for examination.

* Registered trademark of Du Pont.

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