DP-1355

662939

CONFINEMENT OF AIRBORNE RADIOACTIVITY PROGRESS REPORT: JULY - DECEMBER 1973

A. G. EVANS
L. R. JONES

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, S. C. 29801

PREPARED FOR THE U. S. ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(07-2)-1

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy $4.00; Microfiche $1.45

DP-1355

UC-80

CONFINEMENT OF AIRBORNE RADIOACTIVITY PROGRESS REPORT: JULY - DECEMBER 1973

by

A. G. Evans
L. R. Jones

Approved by

J. M. Boswell, Research Manager
Reactor Engineering Division

Publication Date: June 1974

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, S. C. 29801

PREPARED FOR THE U. S. ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(07-2)-1

ABSTRACT

Analyses of the potassium and iodine contents of KI_3-impregnated carbons show a positive correlation between the ratio of iodine to potassium (I/K) and the radioiodine penetration measured by the high-temperature desorption test. When the atom ratio of I/K exceeds approximately 0.30, there is a logarithmic increase in iodine penetration with a linear increase in the I/K ratio. The high-temperature desorption test, therefore, provides a valuable standard quality control test for commercial KI_3 carbons.

Deterioration of water repellency and tensile strength of high-efficiency particulate air (HEPA) filter media during normal service was found to affect simulated accident performance of filters more significantly than similar deterioration resulting from radiation exposure. However, neither radiation exposure nor measured service degradation of particulate filters would be expected to seriously impair overall performance of the Savannah River confinement system if an adequate number of confinement compartments receive approximately equal loading of activity following a postulated reactor accident.

662939

CONTENTS

LIST OF TABLES AND FIGURES

INTRODUCTION

The airborne activity confinement system for each Savannah River production reactor is designed to collect halogens and particulates that might be released in the unlikely event of a reactor accident.[1] A continuing program is in progress at the Savannah River Laboratory to evaluate the performance of the confinement system for removing airborne radioactivity under adverse operating conditions and to develop techniques to enhance the reliability and efficiency of the system.

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 carbon beds, the moisture content of the air passing through the beds, the length of time the carbon has been in service, and the radiation exposure to which the beds are subjected after iodine loading.[2-12]

Impregnated carbons are more effective in retaining iodine in a radiation environment than the unimpregnated carbon currently used in Savannah River confinement systems. Carbons impregnated with triethylenediamine (TEDA) or coimpregnated with TEDA-KI were shown in previous studies to be the most effective adsorbers for the radiolytically formed iodine species.[12] Carbons containing 2 to 5% TEDA were found, however, to have reduced ignition temperatures because of the low flash point and relatively high heat of combustion of the TEDA.[12]

With the selection of a suitable replacement carbon for the confinement system (a 1% TEDA-2% KI carbon having satisfactory iodine retention properties and an acceptable ignition temperature),[13] the anomalous behavior of some of the KI_3-impregnated carbons noted in earlier screening tests[9,10] was investigated.

In these earlier tests, similar carbons (nominally 5% KI_3 on 1500-m^2/g coconut-shell carbons) showed highly variable iodine penetration values when subjected to the high-temperature screening test (4 hours desorption at 180°C). Current work shows that there is a strong correlation between iodine penetration and the atom ratio of iodine to potassium (I/K) in the impregnated carbon. High I/K ratios (approaching or exceeding 1.0) result in higher iodine penetration values, suggesting that excess alkalinity (excess K) is required to retain iodine. Measurements of the pH of water extracts of both new and used carbons tend to verify this conclusion because carbons with a high pH (>7) generally retain iodine better than carbons with lower pH.

High-temperature performance criteria are of potential significance both to the Savannah River confinement system and to systems for other types of reactors because service degradation of high-efficiency particulate air (HEPA) filter media could cause moisture pluggage of HEPA filters. The subsequent reduction in air flow through the carbon beds could result in carbon bed heating.

Previous studies have shown that HEPA filter media deteriorates when exposed to high-intensity radiation or normal service in the confinement system.[11] Preliminary tests measured the relative decrease in two media properties, water repellency and tensile strength, as functions of radiation exposure time and service age. Loss of water repellency and tensile strength in irradiated media is caused by radiolytic decomposition of binder and waterproofing agents. Loss of water repellency in media exposed to normal service is caused by accumulation of hygroscopic atmospheric pollutants (soot and dust) on the media. Irradiated test filters and filters constructed from media with confinement system service are being tested under simulated accident conditions to determine the potential effects of HEPA filter degradation on overall confinement system performance following a reactor accident.

SUMMARY

Confinement system studies to determine basic gas-phase reaction mechanisms of iodine with activated carbon indicate that potassium plays a significant role in high-temperature iodine retention. Low-potassium charcoals (such as coal and petroleum-base carbons) retain iodine less effectively than coconut-shell charcoal, which has a high natural K^+ content. Iodized (KI, I_2, or KI-I_2 impregnated) coconut-shell carbons tend to perform more poorly when the atom ratio of iodine to potassium (I/K) exceeds a value of approximately 0.4. High-temperature (180°C) iodine penetration of some commercial iodized charcoals exceeds 1% when the I/K ratio exceeds 1.0. Carbons of high pH also tend to retain iodine better than low pH carbons; thus, the basic reaction mechanism in iodine retention is probably the conversion of I_2 to an I^- complex.

The high-temperature desorption test (I_2 loading followed by 4 hours desorption at 180°C) can be used as a quality control performance test for commercial iodized carbons.

Small HEPA filters, designed for 10 to 15 cfm air flow, were irradiated by an ~3 x 10^7-rad/hr ^{60}Co source before their performance characteristics were measured in a new test facility containing a "Teflon"*-stainless steel moisture separator upstream of the test filter. Accident conditions were simulated by brief exposure of the filter to mixtures of steam and air at several times filter design flow capacity followed by ~5-hour exposure to steam and air at decaying temperatures; flow was limited by pressure drop across the test filter. Similar test filters, fabricated from filter media with 7 to 48 months service in the confinement system, were exposed to the same test conditions. Although measured pluggage with moisture of test filters made from service-aged media was more severe than pluggage of irradiated filters, potential reduction of confinement system air flow from filter pluggage during an accident would not prevent adequate removal of radioiodine decay heat from carbon adsorbers in the system if at least 3 to 5 filter compartments were on line and radioiodine adsorption was distributed evenly among the on-line compartments. More severe test conditions were required to rupture a test filter than could be postulated during any Savannah River reactor accident.

* Registered tradename of E. I. du Pont de Nemours and Company.

DISCUSSION

CARBON TESTING

High-Temperature Desorption Tests

The high-temperature desorption test was initially designed as a screening test to aid in selecting potential carbon types suitable for use in the confinement system.[9] The test conditions (10-minute loading of elemental iodine at ambient temperature and humidity followed by 4 hours desorption at 180°C) were selected to prevent damage to the "Teflon"-coated test apparatus and "Neoprene"* "O"- rings used as seals in the apparatus. The 180°C temperature is also the upper limit of usefulness for TEDA-impregnated carbons because TEDA boils at 174°C and flashes at ~190°C.[12]

In the original test series,[10] 13 of the 21 candidate adsorbers were subjected to the high-temperature test and had penetration values ranging from 0.003% to 18.08% (Table I). The values fall into three broad penetration catagories: (1) very low (<0.010%), which were coconut charcoals either unimpregnated or impregnated with TEDA or TEDA + KI; (2) intermediate (<0.10%), which were coconut carbons impregnated with I_2, KI_3 or PbI_2; and (3) very high (>1.0%), which were some coconut carbons impregnated with KI_3 and petroleum-base carbons with KI_3 or TEDA impregnation. The anomaly in the data is that four of the 1500-m^2/g coconut-shell carbons impregnated with KI_3 use the same source of base carbon, yet the penetration values range from 0.023% to 18.08% (the extremes are two different lots from the same vendor).

Preliminary investigation of the cause of differences in the performance of the KI_3 carbons indicated that different methods of impregnation were used by the three vendors;[10] however, confirmation of the techniques used could not be obtained because of the proprietary nature of the processes. Variation in the iodine content of the different carbons is also a possible cause (particularly because the greatest performance variation was observed between different lots from a single vendor). The sodium, potassium, and iodine content of each sample was determined by neutron activation analysis. The results of these analyses indicated a

* Registered tradename of E. I. du Pont de Nemours and Company.

TABLE I

High-Temperature Test Data[a]

Mfg	*Base Carbon*	*Surface Area, m^2/g*	*Impregnant*	*Iodine Penetration,[b] %*
A	Coconut	1100	None	0.004
A	Coconut	1500	KI_3	0.052
B[c]	Coconut	1100	None	0.004
B	Coconut	1500	KI_3	0.028
B	Coconut	1100	KI_3	0.056
B	Coconut	1100	I_2	0.070
B	Coconut	1500	PbI_2	0.084
B[c]	Coal	1300	PbI_2	0.420
B	Coconut	1100	KI + TEDA	0.006
B[c]	Coconut	1100	KI + TEDA	0.006
B	Coconut	1100	TEDA	0.003
C	Coconut	1500	KI_3	18.08
C[c]	Coconut	1500	KI_3	0.023
D	Coconut	1500	KI_3	2.412
E	Petroleum	1500	KI_3	6.484
E	Petroleum	1100	TEDA	12.03
E	Petroleum	1500	TEDA	4.560

a. Source of data is Reference 10, except where noted.

b. See text for test conditions.

c. New data.

strong correlation between the atom ratio of iodine to potassium and iodine penetration during the high-temperature test. The sodium content of the impregnated carbons was consistently <0.2 wt % and was not related to penetration.

Chemical Analysis of Carbons

Results of the neutron activation analyses of several of the KI and KI_3 carbons are shown in Table II. Iodine and potassium contents are compared with the iodine penetration values from Table I and with pH values for water extracts of each carbon (5 g carbon extracted with 20 ml distilled water; pH measured after 10 minute contact time). The comparison between I/K ratios and iodine penetration is shown graphically in Figure 1.

TABLE II

Comparison of Chemical Analysis with pH and Iodine Penetration

Carbon	*Iodine,*[a] *wt%*	*Potassium,*[a] *wt%*	*Atom Ratio I/K*	*pH*[b]	*Iodine Penetration,*[c] *%*
A[d]	3.78	1.75	0.665	9.36	0.052
B-1[e]	3.02	1.55	0.601	9.62	0.028
B-2[f]	1.31	1.04	0.386	9.86	0.006
B-3[g]	<0.01	2.09	$<1.5 \times 10^{-3}$	9.98	0.003
C-1[h]	4.01	0.96	1.26	7.05	18.08
C-2[i]	4.23	2.23	0.586	9.02	0.023
D[j]	4.42	1.14	1.19	9.56	2.412
E[k]	3.12	0.96	1.00	8.78	6.48

a. Activation analysis of undried sample.

b. See text for method.

c. High-temperature test.

d. KI_3 on 1500-m^2/g coconut carbon, manufacturer A.

e. KI_3 on 1500-m^2/g coconut carbon, manufacturer B.

f. KI + TEDA on 1100-m^2/g coconut carbon, manufacturer B.

g. Unimpregnated 1500-m^2/g base carbon of the same type used to prepare samples B-1, C-1, C-2, and D.

h. KI_3 on 1500-m^2/g coconut carbon, manufacturer C - first lot tested.

i. KI_3 on 1500-m^2/g coconut carbon, manufacturer C - second lot tested.

j. KI_3 on 1500-m^2/g coconut carbon, manufacturer D.

k. KI_3 on 1500-m^2/g petroleum carbon, manufacturer E.

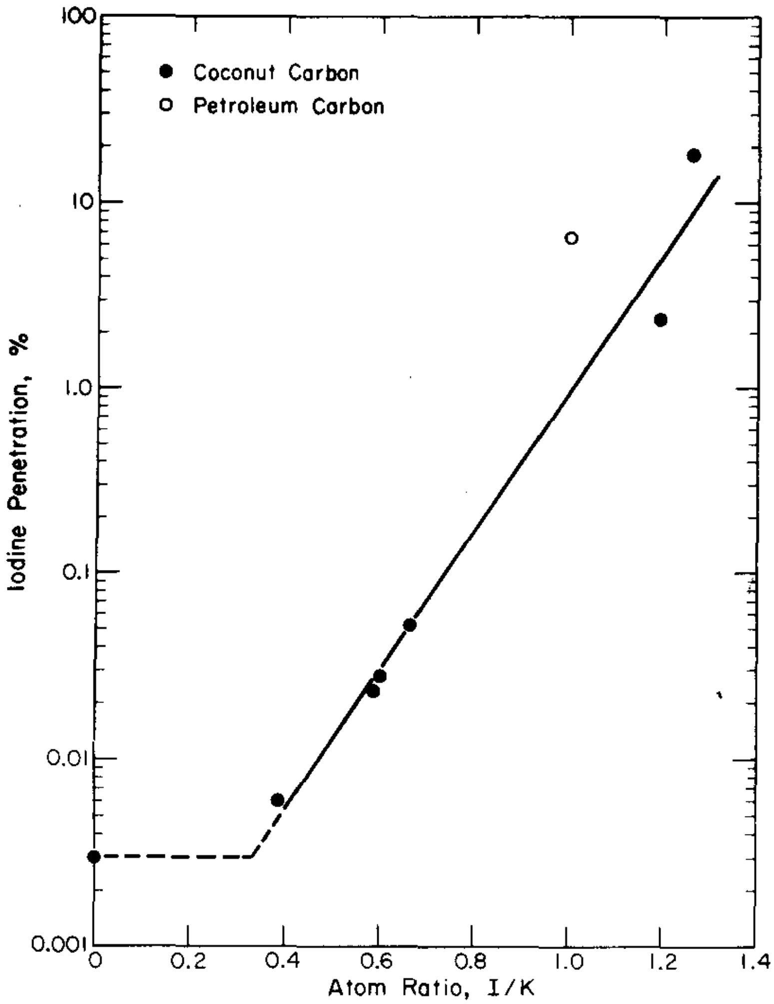

FIGURE 1. Effect of I/K Ratio on High-Temperature Iodine Penetration

Figure 1 indicates a logarithmic increase in high-temperature iodine penetration with a linear increase in the I/K ratio (above a threshold of ~0.35) and suggests that potassium plays a significant role in iodine retention mechanisms. This probably explains why coconut-shell charcoals (which are rich in K^+) are more effective for iodine removal than coal or petroleum-base charcoals. Because variability in performance between different manufacturing lots of KI_3-impregnated carbons could be caused by variations in K^+ content of base carbons as well as differences in impregnation technique, samples of base carbons from 10 different manufacturing lots from the same vendor (covering a 5 year period) were analyzed for potassium content (again by neutron activation analysis). Results are summarized in Table III.

TABLE III

Chemical Content of Coconut-Shell Base Carbons

Approximate Surface Area, m^2/g	*pH^a*	*K^+, wt %*	*Na^+, wt %*
1100	10.0	0.99	0.13
1100	9.9	1.18	0.51
1100	9.9	0.86	0.06
1100	10.1	0.79	0.18
1100	10.1	0.99	0.07
1500	9.9	1.18	0.11
1500	10.0	1.17	0.07
1500	9.9	1.19	0.08
1500	9.9	1.30	0.09
1500	10.3	1.27	0.06

a. See text for description of method.

The data in Table III indicate that there is little variability in the base carbon, particularly the 1500-m^2/g carbon from which the commerical KI_3 carbons are manufactured. Thus, the variability in performance (and the I/K ratio) is probably a function of impregnation technique. The best carbons are those with a pH greater than 9 and which have I/K ratios less than 0.7.

To validate these conclusions, a series of four iodine solutions were prepared with reagent grade I_2, KOH, and KI. Three solutions were prepared with a constant I_2 content (6.2 grams in 100 ml water) and a varying KOH concentration. The fourth solution was made by dissolving 10.5 g KI in 100 ml water. The first two solutions (4.6 g KOH with I/K = 0.47 and 5.8 g KOH with I/K = 0.60) were predictably clear and colorless (even after standing in fluorescent light for 3 weeks in a sealed polyethylene bottle) because of the absence of the I_3-complex or free I_2 in solution. The pH of both solutions was 12.3. The third solution (2.9 g KOH with I/K = 0.95) was a very dark brown color (characteristic of I_3^- solutions) which stained the plastic bottle on standing and had a pH of 8.9. The fourth solution (KI with I/K = 1.0, pH = 7.3) was initially clear and colorless, but gradually turned a faint brown color on standing in the light.

The solution behavior of the iodine strongly suggests a similar reaction on the carbon surface where some I_2 may be liberated on heating and accounts for poorer performance of the high I/K ratio carbons. The high pH solutions favor formation of I^- complexes which are relatively nonvolatile. High pH carbons (such as coconut carbon) should favor I_2 to I^- conversion, whereas low pH carbons (neutralized coconut or coal and petroleum carbons) should favor the formation of less stable I_3^- complexes, particularly when the I/K ratio exceeds 1.

Several samples of new and service-aged carbons were tested for pH and high-temperature iodine penetration to determine if any correlation existed between residual alkalinity (available excess K^+) and iodine retention. The results are shown in Table IV.

A good correlation between pH and iodine penetration is not shown by the data except for the general trend toward higher penetration with lower pH (Figure 2).

While the I/K ratio in service-aged carbons does not change significantly with time, the pH does change with the accumulation of acidic atmospheric pollulants (such as NO_2 and SO_2). In addition, other atmospheric pollutants (such as hydrocarbons) accumulating on the service-aged carbon are competing with iodine for reactive sorption sites (or compounds in the carbon which will react with I_2). Thus, the rapid decrease in performance (Figure 3) appears independent of carbon type, and an impregnated carbon (G-615, KI + TEDA) deteriorates as rapidly in service as an unimpregnated carbon (416) when evaluated by the high-temperature desorption test.

Use of the High-Temperature Desorption Test

The high-temperature desorption test has been a valuable aid in selecting an impregnated carbon for use in the Savannah River confinement system. The test should prove equally valuable for other investigators interested in screening potential containment system carbons. In addition, the test can be used as a quality control test by carbon manufacturers. Because the I/K ratio correlations are still in the development stage, direct measurement of the carbon performance is the preferred method of evaluation of different lots of carbon. The high-temperature test has been proposed for inclusion in the ASTM and ANSI standard test procedures for nuclear-grade carbons.

TABLE IV

pH and Iodine Retention of Service-Aged Carbon

Carbon Type	*Service Age, months*	*pH*[a]	*Iodine Penetration,*[b] *%*
G-615[c]	0	9.86	0.006
G-615	6	7.41	0.259
G-615	9	7.16	0.474
416[d]	0	9.59	0.004
416	21	4.80	7.22
416	23	4.75	4.24
416	33	4.33	9.47
416	34	3.99	7.22
416	46	3.01	25.70

a. See text for method.

b. See text of description of test.

c. TEDA + KI on coconut carbon, product of North American Carbon Company, Columbus, Ohio.

d. Unimpregnated coconut-shell carbon, product of Barnebey Cheney Company, Columbus, Ohio.

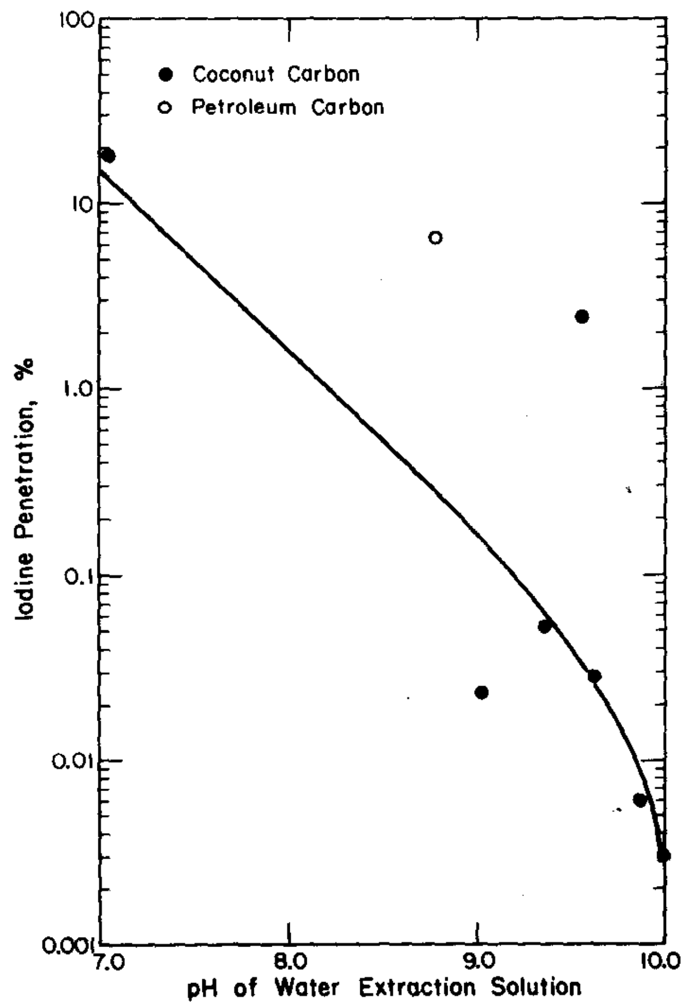

FIGURE 2. Effect of Carbon pH on High-Temperature Iodine Penetration

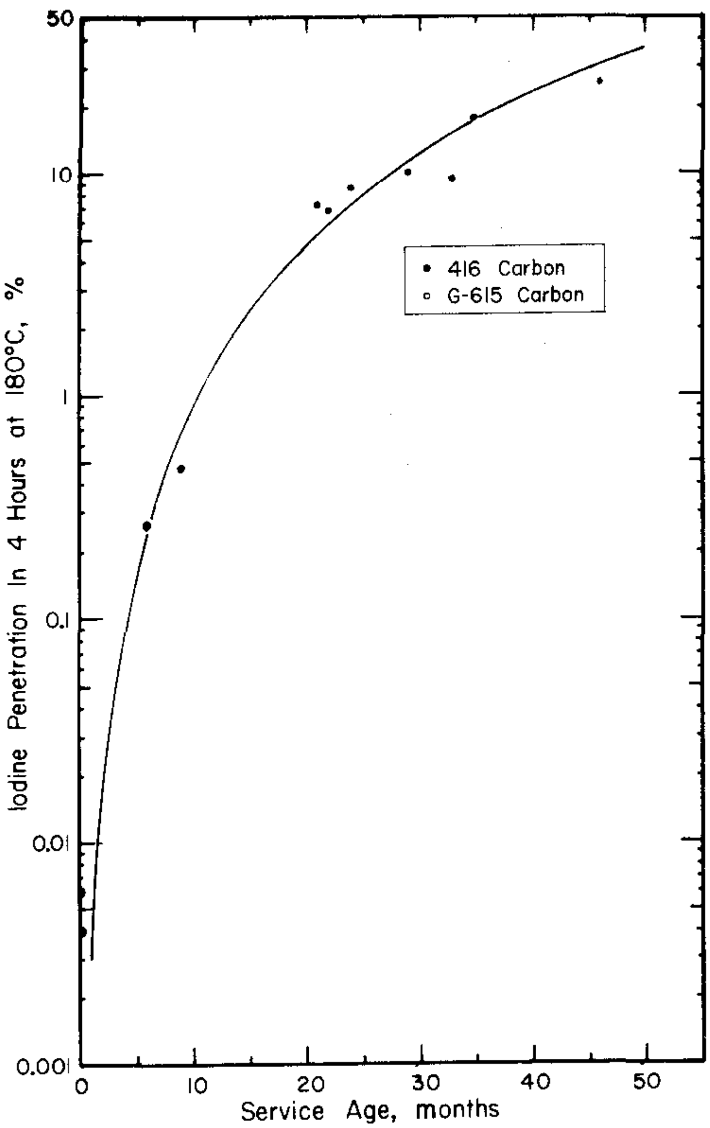

FIGURE 3: Effect of Service on Iodine Penetration at 180°C

Additional Testing

A series of impregnated carbon samples has been prepared by a carbon vendor, and additional samples are being prepared in the laboratory to show the effect of I/K ratios on high-temperature performance. The initial samples were prepared from a single lot of base carbon impregnated with varying amounts of I_2 (vapor phase impregnation). Subsequent samples prepared at Savannah River will duplicate the constant natural potassium samples. In addition, samples will be prepared from leached base carbon (natural potassium removed by repeated water washes) reconstituted with known quantities of K^+ (as KOH) and I_2 in liquid phase impregnation. Initial data from constant K^+ samples (Figure 4) show a similar pattern of increasing pentration with increasing iodine content (increasing I/K ratios). However, the very high penetration

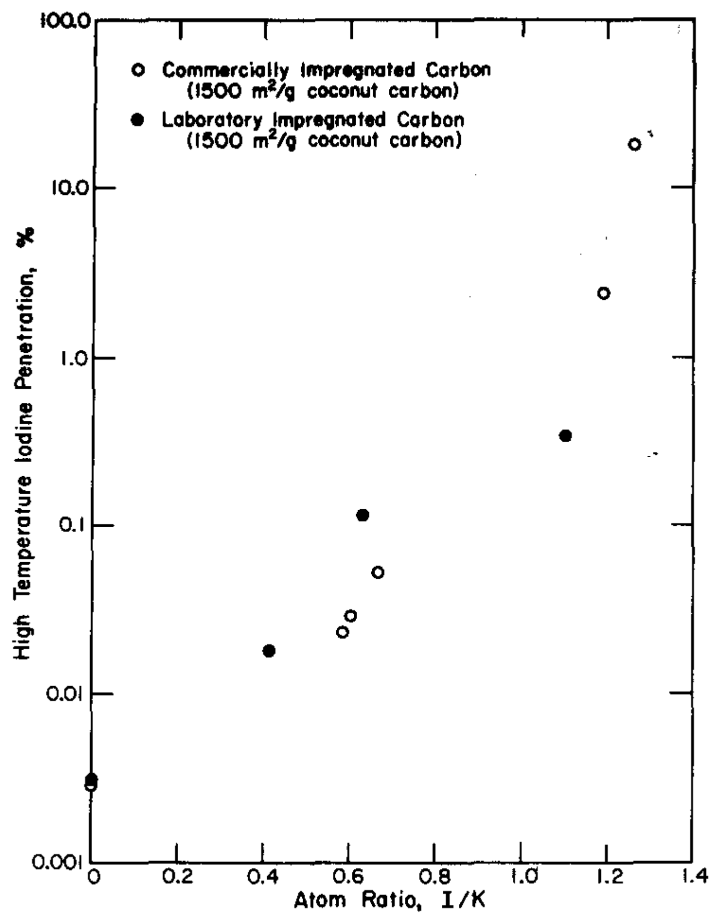

FIGURE 4. Comparison of Commercial and Laboratory KI_3-Impregnated Carbons

(>1%) observed in commercial carbons was not seen in carbons impregnated in the laboratory at high (1.11) I/K ratio. Futher samples are being prepared with I/K ratios of 0.9 to 1.4.

HEPA FILTER TESTING

Test Filters

Small test filters (Figure 5), designed for 10 to 15 cfm air flow, were purchased from the manufacturer of Savannah River reactor confinement filters. The test filters are constructed from confinement filter media and meet all material and construction specifications for Savannah River confinement filters except size and design air flow. Internal spacing of media and aluminum separators is also identical to full-size confinement filters. The performance of these test filters during exposure to simulated accident conditions can be measured in laboratory-scale facilities and is considered to represent confinement filter performance during an accident.

The commercial filter pack was removed from several of the test filter frames (following testing of the original filters) and replaced with a laboratory-fabricated filter pack. The filter pack was constructed from filter media removed from full-size confinement filters with 7 to 48 months service in the confinement system. Performance of "as received" filters, gamma-irradiated filters, and laboratory-fabricated filters has been measured in a new test facility described in the following sections.

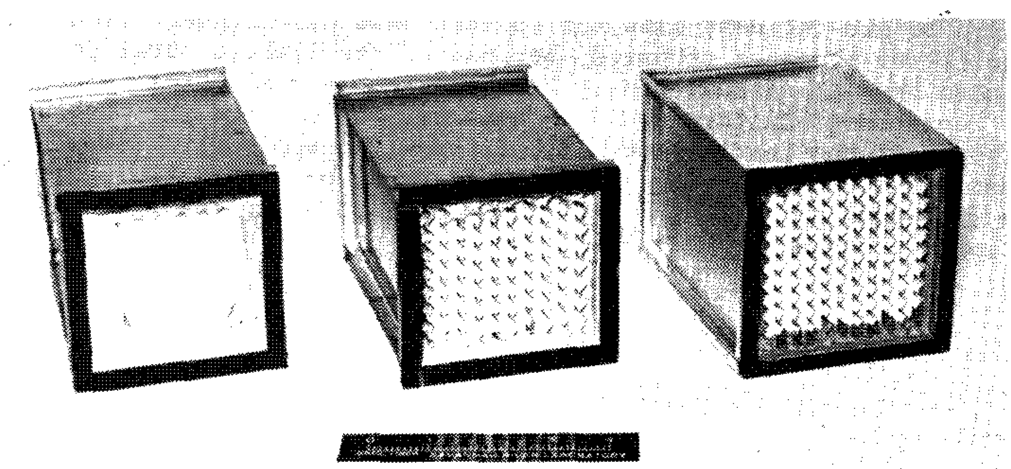

FIGURE 5. Test Filters

Filter Irradiation

Complete test filters were irradiated in an ~3 x 10^7-rad/hr ^{60}Co source described in previous reports.[10,11] Each filter was mounted in a submersible container so that air supplied to and exhausted from the container flowed through the filter to remove heat from gamma absorption and gases from air radiolysis. The container was immersed in water and cooled by natural convection during irradiation. Air temperature inside the container was ~60°C during filter irradiation.

Simulated Accident Test Conditions

Several test variations were developed to simulate hypothetical Savannah River reactor accidents which would expose confinement HEPA filters to the most severe conditions. More than one accident sequence was simulated because the greatest effects of filter pluggage might not result from the most severe reactor accident conditions.

Test 1

Quenching molten debris in the reactor tank following a specified dry full core meltdown could create a large quantity of steam which would be rapidly vented through the confinement system HEPA filters. Peak filter flow is calculated to last less than 25 seconds and not to exceed ~8.5 times normal operating flow during the transient.

Following the pressure surge, confinement system flow would return to pre-incident flow, or to less than pre-incident flow if some filter pluggage occurred, because of the limited total developed head of exhaust fans. Flow of steam-air mixtures through the confinement filters would be expected to continue for ~5 hours as steam in the reactor room is diluted with supply air flow. Steam-air temperature is calculated to decay exponentially over the five-hour period. The test sequence simulating these conditions is shown in Table V.

Test 2

Less severe reactor steaming conditions would result from quenching molten debris on floor areas beneath the reactor. Steam generated below grade would not produce a pressure surge as severe as steaming in the reactor room because the building volume below grade is approximately twice that of the reactor room. Similarly, calculated steam-air temperatures are also lower during the pressure surge and during the following ~5 hours. The test sequence simulating below-grade steaming is shown in Table VI.

TABLE V

HEPA Filter Standard Test Conditions (Test 1)

Time	*Multiple of Normal Flow Rate*	*Temperature of Steam-Air Mixture, °C*	*HEPA Filter ΔP, in. H_2O*
0 to 25 sec	8.5	92	*a*
25 sec to 4 min	1.0	92	<5
4 min to 14 min	<1.0	80	<5
14 min to 20 min	<1.0	70	<5
20 min to 30 min	<1.0	60	<5
30 min to 40 min	<1.0	50	<5
40 min to 2 hr	<1.0	40	<5
2 hr to 3 hr	<1.0	35	<5
3 hr to 5 hr	<1.0	30	<5

a. No limit, ΔP at specified 8.5 X normal flow depends on condition of filter.

TABLE VI

HEPA Filter Test Conditions (Test 2)

Time	*Multiple of Design Flow Rate*	*Temperature of Steam-Air Mixture, °C*	*HEPA Filter ΔP, in. H_2O*
0 to 20 sec	2.3	70	*a*
20 sec to 15 min	1.0	70	<5
15 min to 25 min	<1.0	60	<5
25 min to 35 min	<1.0	50	<5
35 min to 110 min	<1.0	40	<5
110 min to 170 min	<1.0	35	<5
170 min to 5 hr	<1.0	30	<5

a. No limit, ΔP at specified 2.3 X normal flow depends on condition of filter.

Test 3

Loss of coolant circulation through the reactor and failure of the emergency cooling system could result in boiloff of coolant by overheated fuel assemblies. Steam generation would not be rapid enough to cause a pressure surge in the reactor room, but it could result in flow of steam-air mixtures through confinement filters until the coolant inventory was exhausted. Exposure to normal flow of a steam-air mixture at 40°C for five hours simulates conditions of a loss of reactor circulation accident.

In each test, normal flow was maintained until the test filter plugged to a ΔP of 5 in. H_2O. The ΔP was then held at 5 in. of H_2O by reducing the steam-air flow through the test filter.

Test Criteria

Performance of filters was defined as acceptable if all the following criteria were satisfied during a five-hour test:

- No rupture of the filter media occurred.
- Flow through the filter at a maximum ΔP of 5 inches H_2O did not decrease so much that the equivalent flow through full-size HEPA filters in the confinement system would be less than the flow required to maintain desired subatmospheric pressures in process areas of the reactor building.
- Flow through the filter did not decrease so much that the equivalent reduced flow through carbon adsorbers in the confinement system would result in unacceptable thermal desorption of iodine due to inadequate removal of radioiodine decay heat.

Application of the second and third criteria depends on the assumed number of filter compartments on line and distribution of iodine-laden air flow among those compartments.

New Test Facilities

A schematic diagram of the new HEPA filter test facility is shown in Figure 6. The facility is designed with the following key features:

- Two modules provide steam-air flow to the test HEPA filter. The upper (high flow) module shown in Figure 6 supplies

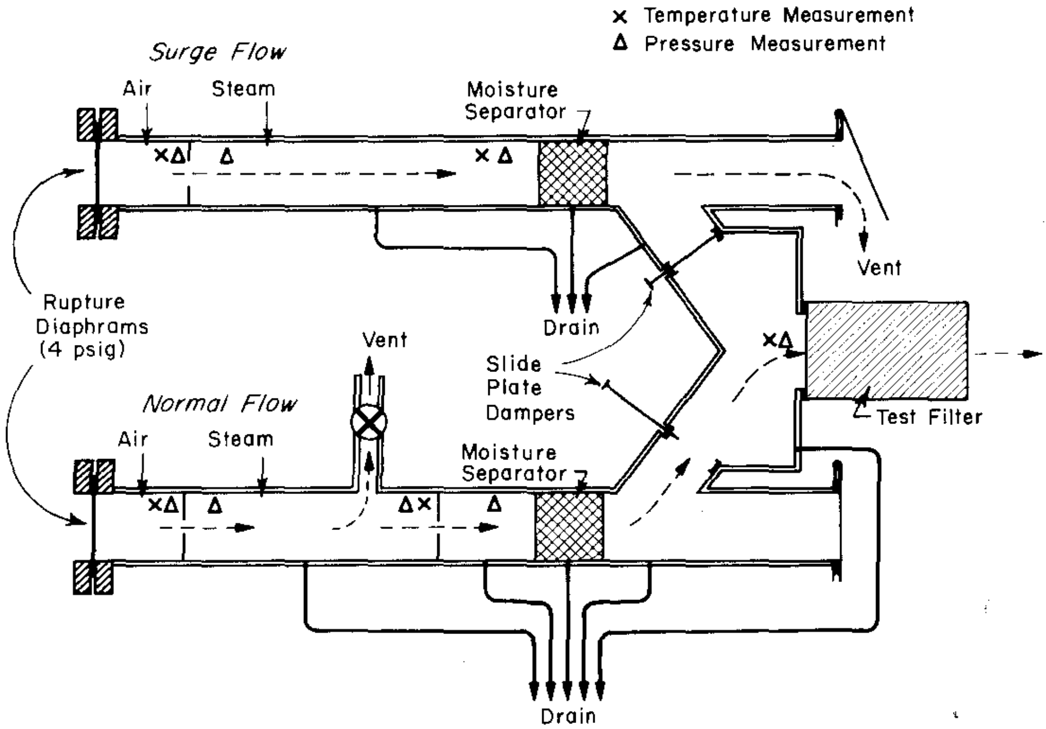

FIGURE 6. Schematic of HEPA Filter Test Facility

steam-air flow at ~85 ft^3/min for the first 25 seconds of the test. The lower (normal flow) module supplies steam-air flow to maintain a constant ΔP across the test filter of 5 inches H_2O for the remaining five hours of the test. Two separate modules are necessary because the flows in the two segments of the test are sufficiently different so that a single orifice will not accurately measure both flows. In addition, changing the flow to the filter from one module at one set of test conditions to the second module at the second set of conditions is much more reproducible than changing test conditions in a single module. Experience in other Savannah River test facilities has shown that after a large decrease in steam-air flow rate, readjustment to the correct steam-air temperature can require as much as 10 minutes. Such a period of nonreproducible conditions is not compatible with the test sequences shown in Tables V and VI. The facility is constructed of "Lexan"* to permit observation inside the modules (Figure 7).

* Registered tradename of General Electric Company.

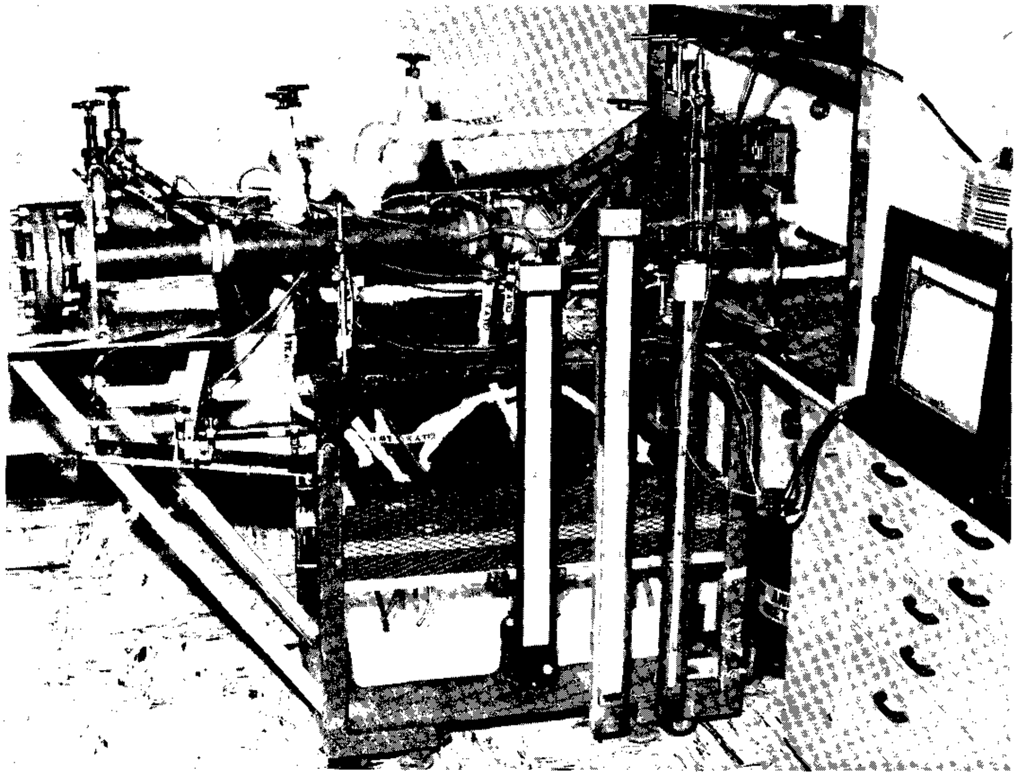

FIGURE 7. HEPA Filter Test Facility

- Both modules are preheated before a filter test by flowing steam and air at the desired test condition through the modules and venting into a laboratory hood through bypass ducts. The test filter is isolated from steam-air flow during preheating by slide plate dampers. At the start of the test, the slide plate damper is opened, and the bypass damper is closed to force full flow through the test filter. Operation in this manner allows reproducible short-duration exposure of the filter and minimizes unwanted steam-air condensation on duct walls.
- Both modules contain two-inch-thick moisture separator units. Because of the relatively small distance between the moisture separator and the test HEPA filter (needed to minimize wall condensation), a vertical offset downstream of the moisture separator is necessary to prevent water droplets (which fly off the downstream side of the moisture separator media) from reaching the face of the test HEPA filter. The relatively larger spacing in the confinement compartments would prevent this occurrence during a reactor accident.[1]

- A fraction of the steam-air flow through the normal flow module can be vented upstream of the moisture separator and test filter during a test. A constant ΔP across the test filter is maintained by varying the fraction of flow vented once the limiting ΔP of 5 inches H_2O is reached with no venting. An additional orifice measures the net stream-air flow through the moisture separator and test filter. This orifice is calibrated over the needed flow range for each steam-air temperature because the steam-air mixture density changes with changing mixture temperature.

- Both modules contain shielded safety rupture diaphragms (set at 4.0 psig) to prevent accidental overpressurization of the facility if dampers are misoperated.

Test Results

Data Analysis

Plugging of a HEPA filter with moisture can be most easily expressed as the measured ΔP across the filter at a selected flow divided by the measured or calculated clean, dry ΔP at that same flow. This plugged ΔP ratio was determined for each test filter at various times throughout a five-hour test; equivalent confinement filter ΔP, ventilation system air flow, and carbon adsorber temperatures were calculated.

Because the exhaust fans in the ventilation system can develop a head of no more than ~5 inches H_2O, rupture of a filter would be expected only during the pressure surge portion of a test. In addition, the test filter would be expected to plug most rapidly during the pressure surge because of the increased steam-air flow.

Filter Rupture

Even though rapid pluggage of filters occurred during the pressure surge portion of Tests 1 and 2, the brief duration of this portion of each test prevented ΔP's from becoming large enough to cause filter rupture. In an effort to determine the pressure surge duration required to rupture a filter, an extended pressure surge test was made on a filter constructed from media with 11 months service. This media was chosen because previous tests had shown its strength to be low. A pressure surge, similar to that previously described for Test 1, lasting for 7 minutes was required to produce gross filter rupture at a ΔP of 15.4 inches H_2O. A pressure surge in the confinement system of this magnitude and duration is not considered credible. Therefore, rupture of HEPA filters would not be expected for any postulated Savannah River reactor accident conditions.

Filter Pluggage and Flow Reduction

Pluggage of filters made from service-exposed media was more severe than pluggage of irradiated filters. Reduced flow caused by filter pluggage at a constant ΔP was determined as a function of time during each test. Figure 8 shows reduced filter flow for Test 1 and media with 7, 11, and 13 months of service. Media with greater service plugged more rapidly during the pressure surge.

Performance deterioration of media with 48 months service was similiar to that of media with 13 months service. The 48-month media accumulated a black soot more slowly during service than other media tested, probably because the other filters were installed in areas where coal-burning powerhouses discharge smoke near the reactor buildings; no powerhouse operates in the area where the 48-month media was installed. Similar soot loading and test performance indicate the 13-month and 48-month medias have equivalent service degradation. Figure 9 shows flow reduction with media with 13 months service and 48 months service during Tests 1, 2, and 3.

Pluggage was retarded by omission of the pressure surge and/or the higher temperatures (Tests 2 and 3). In a variation of Test 1, gamma heating of steam-air flow between the moisture separator and the test filter was simulated with an electrical heater. A ΔT of 4°C was calculated to reduce the relative humidity of the steam-air mixture flow to ~85%. It was assumed that the moisture separator effectively removed entrained moisture droplets and was penetrated only by a saturated steam-air mixture. This reduction from saturated humidity was sufficient to significantly reduce pluggage of the filter media. Although particulate activity or radioiodine collected on HEPA filters could produce some gamma heating, the beneficial effects could not be guaranteed during an accident.

Pluggage of a filter with 13-month media was also significantly reduced when the filter was irradiated to ~2.2×10^8 rads in the ^{60}Co source before Test 1 (Figure 9). Although the moisture repellency of the glass fiber filter media was destroyed by the radiation, the hygroscopicity of the black soot layer on the upstream face of the media was also destroyed. Similar effects with 7-month media were also noted.

Tests with clean unused filters showed that even when the moisture repellency of the filter media was completely destroyed

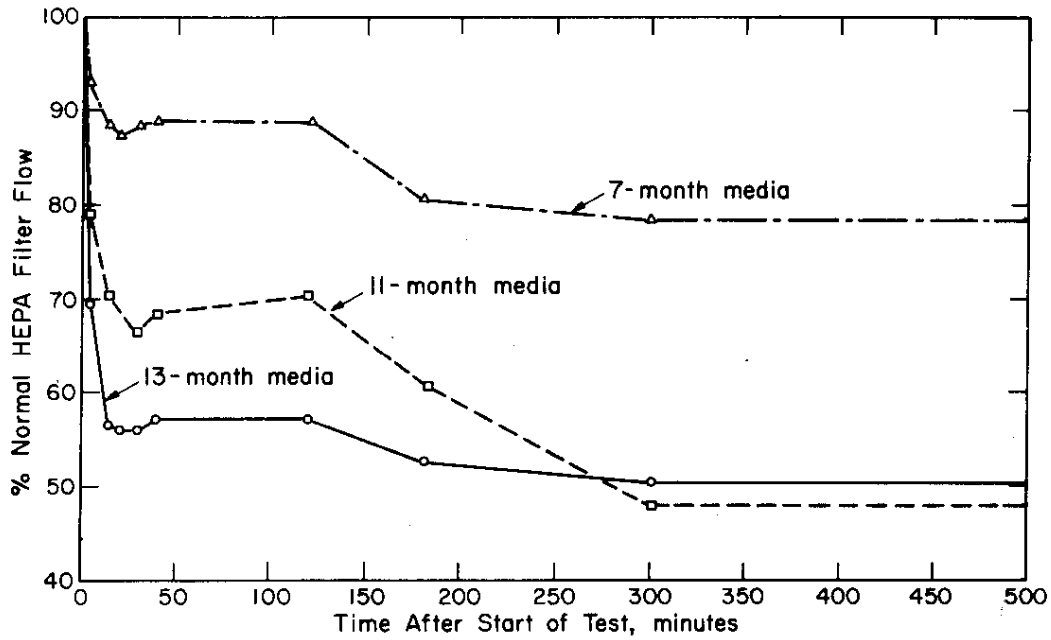

FIGURE 8. Flow Reduction from HEPA Filter Plugging

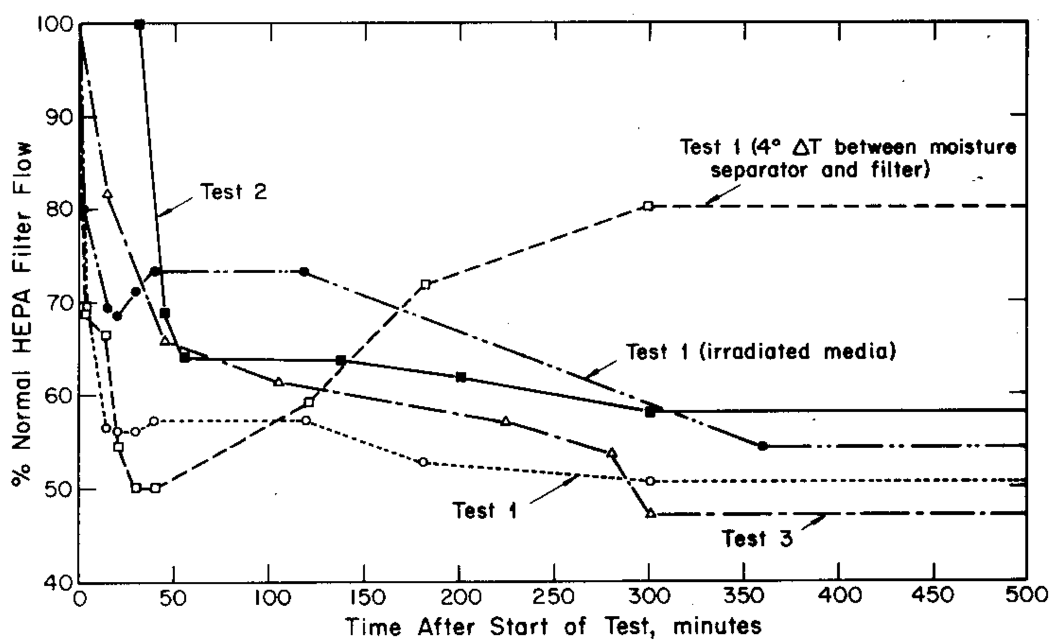

FIGURE 9. Flow Reduction for Test Variations

by exposure to greater than 3 x 10^8 rads in the ^{60}Co source, very little pluggage (less than 10% flow reduction) occurred during a five-hour test because of (a) the removal of entrained moisture by the moisture separator, and (b) the nonhygroscopic nature of clean glass fiber media.

Application of Results

Ventilation and Confinement System Conditions

Confinement HEPA filter pluggage would cause reduction in ventilation system and confinement compartment flows because the total developed head of the building exhaust fans is limited to ~5 inches H_2O. A minimum total exhaust ventilation flow from the process areas is required to maintain these areas at subatmospheric pressures. Minimum compartment flows would be required to adequately cool carbon adsorbers loaded with radioiodine and to limit thermal desorption.

The effect of filter pluggage on system flows following an accident would depend on the number of filter compartments on line and the distribution of steam-air-iodine flow among the compartments. Previous data indicated that with one reactor room exhaust header open, only two compartments received 95% of the reactor room flow.[11] Filter pluggage test data were evaluated assuming different numbers of compartments on line and either equal distribution of steam-air-iodine flow to all compartments or steam-air-iodine flow through only two of the on-line compartments.

Minimum Ventilation System Flow

The reduced total ventilation flow and reactor room flow calculated for measured pluggage of 7-month, 11-month, and 13-month filter media during Test 1 are shown in Table VII for each of five confinement system conditions. A total of ~40,000 cfm is required to maintain desired minimum subatmospheric pressures in the reactor room and below grade. Operation with three or more compartments on line would be adequate to maintain subatmospheric pressures following an accident.

Carbon Adsorber Temperatures

Calculated carbon adsorber temperatures following an accident depend on (a) the fraction of the reactor iodine inventory assumed to reach confinement filters after the fuel melts, (b) calculated radioiodine decay during residence time in the reactor room and

TABLE VII

Calculated Flows With Plugged HEPA Filters

Confinement System Conditions			*7-Month Media*		*11-Month Media*		*13-Month Media and 48-Month Media*	
Condition	*Reactor Room Headers*	*Iodine Distribution*	*Process Room Flow*	*Total System Flow*	*Process Room Flow*	*Total System Flow*	*Process Room Flow*	*Total System Flow*
I	2	I_2 on 2 of 2 compartments	19250	59250	8000	26200	9500	29000
II	2	I_2 on 3 of 3 compartments	22250	69200	13250	41000	14700	45300
III	1	I_2 on 2 of 3 compartments	21750	67400	13000	40600	14350	44500
IV	1	I_2 on 2 of 4 compartments	28300	88000	24700	76100	25200	78000
V	1	I_2 on 2 of 5 compartments	32200	99300	29750	91000	30200	92300

ductwork before reaching the carbon adsorbers, (c) the number of compartments in which the iodine is assumed to be adsorbed, and (d) the calculated air flow through the iodine-loaded compartments. HEPA filter pluggage following an accident would reduce compartment air flows causing an increase in carbon adsorber temperatures. If significant pluggage occurred in the first hour after fuel melting and caused reduction in reactor room air flow, the longer iodine residence time in the reactor room would allow greater radioiodine decay before adsorption, and carbon adsorber temperatures would be lower. Thus, the degree of filter pluggage and the service age of the filter media would not affect carbon adsorber temperatures as much as the number of compartments on line and, more importantly, the distribution of steam-air-iodine flow among the compartments.

Table VIII shows calculated maximum carbon adsorber temperatures for 7-, 11-, and 13-month HEPA filter media and five confinement system conditions. Temperatures are not shown for irradiated media but would be lower than for unirradiated media because of the reduced pluggage of irradiated media. Steam-air-iodine flow through only two of three or more on-line compartments would increase carbon adsorber temperatures. Only a fraction of the total system flow would be removing iodine decay heat, while the remainder would flow through uncontaminated compartments. That fraction flowing through the two iodine-loaded compartments would be further reduced because only HEPA filters in these two compartments would plug from exposure to steam-air-flow. Although some redistribution of steam-air-iodine flow to other compartments would be expected as pluggage occurred, no redistribution was assumed as a conservatism. Therefore, the highest adsorber temperatures would result from having the fewest compartments on line if equal distribution of steam-air-iodine flow occurred; highest temperatures would result from having the largest number of compartments on line if unequal distribution occurred.

Although thermal desorption and service characteristics of impregnated carbons chosen to replace currently used unimpregnated carbon have not been fully determined, comparison of preliminary iodine desorption test data with temperatures in Table VIII indicates that iodine loading in only two of four or five compartments containing HEPA filters with greater than 7 months service could result in excessive iodine desorption following an accident.

A postulated reactor accident was assumed to release 50% of the reactor iodine inventory for all carbon adsorber temperature calculations.

Further HEPA Filter Studies

Vendor-fabricated test filters are being exposed to confinement system air flow in a weathering (service aging) test facility described in a previous report.[10] Although this facility is operated primarily to obtain service-aged activated carbon samples, a special module containing 36 test HEPA filters has been added. The test filters receive approximately design flow so that exposure should provide service aging approximately equivalent to that for confinement HEPA filters. Tests of these filters are expected to verify preliminary data obtained with the laboratory-fabricated service-aged filters.

In addition to Savannah River filters, test filters from an alternative vendor and made from different materials are being exposed to service in the facility to determine the extent to which service degradation depends on the type of filter media and filter construction.

A preliminary indication of the effects of Savannah River service on other types of HEPA filter media was obtained by treating samples with an extract made by dissolving soot removed from used confinement filter media in ethyl alcohol. Water repellancy tests described in a previous report[11] were made for samples which had been soaked in the soot extract and then allowed to dry at ambient temperatures. Data are compared in Table IX with water repellancy of used Savannah River confinement filter media reported previously. The loss of water repellancy is a physical effect which is reversible and not media-selective. Loss of tensile strength is a slow reaction which cannot be duplicated by simple methods.

TABLE VIII

Calculated Carbon Adsorber Temperatures With Plugged HEPA Filters

Condition	*Reactor Room Headers*	*Iodine Distribution*	*Temperature, °C* *7-Month Media*	*11-Month Media*	*13-Month Media and 48-Month Media*
I	2	I_2 on 2 of 2 compartments	115	150	138
II	2	I_2 on 3 of 3 compartments	113	117	122
III	1	I_2 on 2 of 3 compartments	131	139	154
IV	1	I_2 on 2 of 4 compartments	147	170	197
V	1	I_2 on 2 of 5 compartments	159	184	217

TABLE IX

Water Repellency of HEPA Filter Media

HEPA Filter Media Treatment	*Savannah River Media*		*Media Type F*[a]		*Media Type B*[a]	
	Time for H_2O to Penetrate Media	*Height of H_2O Column Required to Rupture Media, inches*	*Time for H_2O to Penetrate Media*	*Height of H_2O Column Required to Rupture Media, inches*	*Time for H_2O to Penetrate Media*	*Height of H_2O Column Required to Rupture Media, inches*
NEW (None)	>48 hr	39.5	>48 hr	32.5	>48 hr	39.0
SERVICE						
4 months	>4 hr	32.5				
7 months	>4 hr[b]	28.0[b]				
11 months	209 sec[b]	6.7[b]				
13 months	66 sec[b]	15.0[b]				
48 months	57 sec	10.4				
NEW						
(Treated with soot extract)	39 sec[c] 27 sec[b]	34[c] 31[b]	31 sec[c]	33[c]	11 sec[c]	33[c]
NEW						
(Treated with soot extract; then rinsed with clean solvent)	>4 hr	39				

a. Same Media Designation as in Reference 11.
b. Average of 10 tests.
c. Average of 3 tests.

REFERENCES

1. W. S. Durant, R. C. Milham, D. R. Muhlbaier, and A. H. Peters. *Activity Confinement System of the Savannah River Plant Reactors.* USAEC Report DP-1071, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1966).

2. W. S. Durant. *Performance of Activated Carbon Beds in SRP Reactor Confinement Facilities - Progress Report: September 1961 - September 1965.* USAEC Report DP-1028, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1966)

3. R. C. Milham. *High Temperature Adsorbents for Iodine - Progress Report: January 1965 - September 1966.* USAEC Report DP-1075, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1966)

4. R. C. Milham and L. R. Jones. *Iodine and Noble Gas Retention Studies - Progress Report: October 1966 - December 1968.* USAEC Report DP-1209, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1969).

5. R. C. Milham and L. R. Jones, *Iodine Retention Studies-Progress Report: January 1969 - June 1969.* USAEC Report DP-1213, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1969).

6. R. C. Milham and L. R. Jones. *Iodine Retention Studies - Progress Report: July 1969 - December 1969.* USAEC Report DP-1234, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1970).

7. A. G. Evans and L. R. Jones. *Iodine Retention Studies - Progress Report: January 1970 - June 1970.* USAEC Report DP-1259, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1971).

8. A. G. Evans and L. R. Jones. *Iodine Retention Studies - Progress Report: July 1970 - December 1970.* USAEC Report DP-1271, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1971).

9. A. G. Evans and L. R. Jones. *Confinement of Airborne Radioactivity - Progress Report: January 1971 - June 1971.* USAEC Report DP-1280, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1971).

10. A. G. Evans and L. R. Jones. *Confinement of Airborne Radioactivity - Progress Report: July 1971 - December 1971.* USAEC Report DP-1298, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1972).

11. A. G. Evans and L. R. Jones. *Confinement of Airborne Radioactivity - Progress Report: January 1972 - June 1972.* USAEC Report DP-1316, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1973).

12. A. G. Evans. *Confinement of Airborne Radioactivity - Progress Report July 1972 - December 1972.* USAEC Report DP-1329, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1973).

13. A. G. Evans and L. R. Jones. *Confinement of Airborne Radioactivity - Progress Report: January 1973 - June 1973.* USAEC Report DP-1340, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, S. C. (1973).