IRRADIATION STUDIES OF ACTIVATED CARBON

A FINAL REPORT

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INTRODUCTION

Activated Carbon is used in the operation of the Savannah River Plant to trap and retain radioactive iodine in the reactor building effluent air.

Airflow is directed through the carbon bed. Its ability to retain organic iodine degrades over time. Small traces of organic impurities in the air can have important cumulative effects over the service life of carbon.

Tests of the effects of organics on the release of radio iodine from carbon in high radiation field were conducted at the Neely Nuclear Research for Georgia Institute of Technology the Savannah River Laboratory over a period of 18 months. This report documents all results obtained during this period.

1. Experimental Apparatus

The Neely Nuclear Research Center designed and built the apparatus shown in Figure 1. Design features included the ability to do the following.

1. Determine background levels of organic compounds with no charcoal in the System. This simply meant fresh air circulation through the apparatus and collecting organic iodine compounds on different adsorbent columns.

2. Determine background levels of organic compounds in fresh air that has been circulated through activated carbon. This step is essentially a repeat of step 1 but with charcoal (old or new) in system. (Old charcoal refers to charcoal that has been used at SRP in ventilation beds and therefore was exposed to organics in the atmosphere. New charcoal is charcoal that has not been exposed to organic contamination).

3. Determine effects of intense radiation fields on background levels. This meant that the sample holder (shown in Figure 1) containing activated carbon was placed in the irradiation pipe of the Neely Nuclear Research Center. The dose rate in the pipe was approximately 5×10^6 rads/hour.

4. Determine organic iodide levels after about 1 gram of iodine vapor has been added to the system. Collection of iodide compounds on adsorbants starts 30 minutes after the process of iodine addition has stopped.

5. Determine organic iodide levels 3 hours after the process of iodine addition has ceased but sample of activated carbon remained in the intense radiation field.

Measurements with several types of activated carbon were made under dry and also under high humidity conditions.

II Results

Initial background level determinations of organic compounds collected in Tenax, Tenax and charcoal and in Tenax ambersorb and charcoal are listed in Table I. These results indicated that collection rate through the adsorbent should be lowered to 200 c.c. per minute and collection time should not exceed 30 minutes.

Conditions for the next set of measurements were as follows:

1. The first experiment was run to determine background level of organic compounds with no charcoal present in the sample holder. An air flow velocity of 54 feet/minute was maintained in this and subsequent experiments. Samples of the air flowing through the system were obtained by using a small pump to force system air into adsorbent columns containing charcoal, ambersorb and tenax. The flow rate was 200 c.c. per minute. Collection time was 30 minutes for a total volume of air flowing through the column of 6 liters.

2. Experiment (2) was a repeat of Experiment (1) but with activated charcoal GX 176, batch 8, lot 3327 (this charcoal is new), inserted in the sample holder. The amount of this charcoal used was 17.95 grams.

3. Experiment (3) was a repeat of Experiment (2) except in this experiment the apparatus was placed in the irradiation pipe. The field of radiation was 3.62 E6 rads per hour.

4. Experiment (4) was a repeat of Experiment (3) with one exception: iodine was added for two hours and five minutes. The sampling of gas was begun at 1 hour and 29 minutes from the point of iodine introduction into the system. The temperature in the iodine vaporizer was 142°C.

5. Experiment (5) is a repeat of Experiment (4) except that the sampling time was begun one hour and five minutes after iodine flow was valved off.

The results obtained from these experiments are shown in Table II.

The next set of experiments were performed using charcoal Gx176 and charcoal 1502. The run by run descriptions are similar to those described above. The results are given in Tables III and IV.

From here on the Columns used to collect organic iodine compounds were changed from charcoal, Tenax and ambersorb to toluene. The reason for the change was that collection in toluene is about 1000 times more sensitive than of the other mixtures.

The five basic runs to determine background and effects of radiation which were described above were repeated using the following charcoals:

1. Charcoal Batch # NRL 5340
2. Charcoal Batch # NRL 5338
3. Charcoal Batch # P.3 (29 month)
4. Charcoal Batch # K.2 (24 month 1984)
5. Charcoal Batch # 15732 C.6
6. Charcoal Batch # 2V8.2 INEL
7. Charcoal Batch # 15021 (marked radioactive 12/22/86)

The results are summarized in Table V. Note that only methyl iodide was determined in the analysis.

The experiments with the 7 types of charcoal were repeated at a humidity range of 90-100%. This high humidity created a minor problem in the toluene impinger: condensation of water vapor. This necessitated inserting in the line moisture trap prior to the impinger. The material collected in this trap was also analyzed for methyl iodide. The results for this analysis are labeled run #6 (condensate collected) in Table VI.

Finally the same 7 types of charcoal were used to remeasure charcoal adsorptive capacity in the high radiation field in dry atmosphere. For convenience we repeat the conditions for each run.

1. A control sample, comprised of toluene in an impinger, was prepared exactly as other impingers used in this experiment but had no air flow through it. The toluene was analyzed for iodine compounds. This control sample served as a reference for the other 5 samples.

2. The first run was to determine background level of iodide compounds. This was achieved by having fresh outside air flow through the apparatus at 54 ft/min. with no charcoal in it. The air was sampled at a rate of 200 c.c. per minute

for 30 minutes through a toluene impinger. The sample was later analyzed for methyl and other iodides by electron

capture chromatography. The other iodides which were analyzed for but not found were: Ethyl Iodide, Iodopropane, Iodopropene, Iodobutane, Iodopentane, Iodohexane, Iodobenzene, Idotoluene, Iododecane.

3. The second run was a basic repeat of run (1) but with charcoal in sample holder. The amount of charcoal in each sample is listed in Table VII. The apparatus was not in the irradiation pipe.

4. The third run was a repeat of run (2) except that the apparatus was placed in the irradiation pipe. The field of radiation was 3.80 E6 rads per hour.

5. The fourth run was a repeat of run (3) except in this run iodine was added for about one hour before sampling commenced. Sampling lasted for 30 minutes.

6. The fifth run was as repeat of run (4) except sampling in this case began about one hour after the supply of iodine was exhausted. Again, sampling lasted for 30 minutes.

The results of these measurements are summarized in Table VII.

The surface area and pore size characterizations was performed by Micromeritics Instrument Corporation. Three types of carbon were used: (1) carbon 5340; (2) carbon 15021; and (3) carbon P.3. Three samples of each type of carbon were used under dry and wet conditions. All samples were degassed at 350 C for 16 hours under vacuum.

The surface area and pore size analysis results are summarized Table VIII. The original computer output giving analysis results from Micromeritcs were sent to Dr. Hyder previously.

Table VIII

Summary of surface area and pore size analysis

Carbon sample and history	new	dry	wet	average	
carbon 5340					
BET area(sq m/g)	731	926	783	813	757
Pore volume (cc/g)	0.403	0.513	0.429	0.448	0.419
Pore Diameter (A)	14.3	14.3	14.4	14.4	

carbon 15021					
BET area(sq m/g)	542	266	507	438	424.5
Pore volume (cc/g)	0.298	0.15	0.278	0.242.	0.296
Pore Diameter (A)	14.8	15.1	14.8	14.9	
carbon P 3					
BET area (sq m/g)	429	384	322	378	
Pore volume (cc/g)	0.235	0.214	0.181	0.210	
Pore Diameter (A)	14.8	15	15.1	15.0	

It appears that the two samples designated dry 5340 and dry 15021 may have been misweighed, although Micromeritetics does not think so. The BET surface area and the Pore volume are per gram. If the area and pore volume of these samples are normalized, it appears they would yield essentially the same area and volume as their "new" and "wet" counterparts respectively (see the last column above). The pore size and the pore size distribution are not on a per gram basis and they seem to be unaffected by treatment.

It appears that the history of the sample including irradiation does not effect either the surface area, the pore volume, the average pore radius, or the pore size distribution and hence the ability of the carbon to physically adsorb vapors should be unaffected by the extent of irradiation that these samples have undergone.

Acknowledgement

The Neely Nuclear Research Center, Georgia Institute of Technology expresses its deep appreciation to the Savannah River Laboratory for the opportunity to be of Service to its Safety Programs.

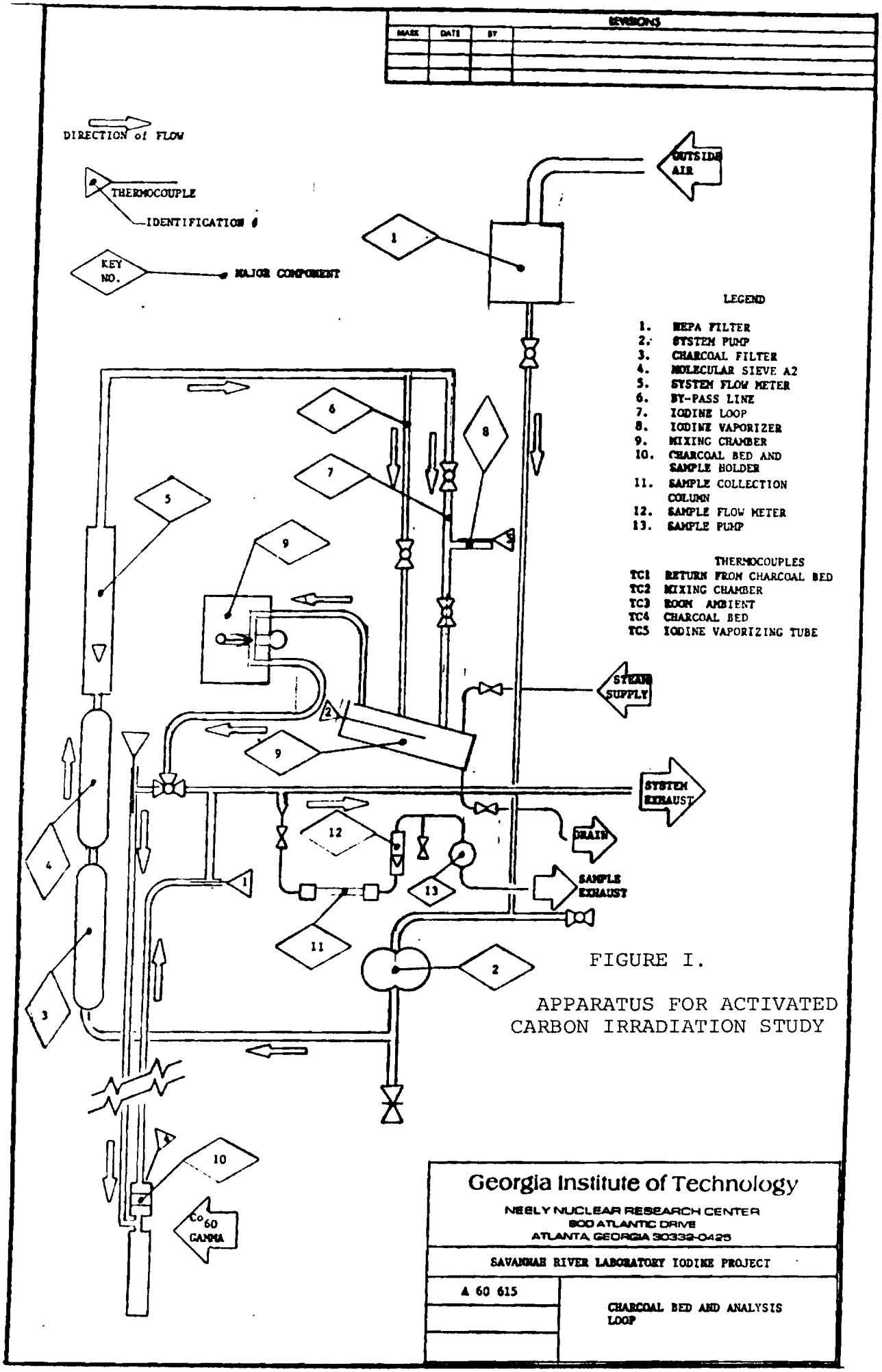

FIGURE I.

APPARATUS FOR ACTIVATED CARBON IRRADIATION STUDY

TABLE I

Collection of Background Levels of Organic Compounds in Tenax, Tenax and Charcoal, and in Tenax, Ambersorb and Charcoal

(All Units are in PPBV)

Organic Compound / Adsorbent	Tenax/Charcoal Lot # 18588	Tenax/Amb./ Charcoal Lot # 18589	Tenax Lot # 18751	Tenax/Amb. Charcoal Lot # 18752
Vol. Collected,L	108	125.2	57.3	75.6
Methoxyethene	1.0			
1,1,2-Trichloro-2,2,1-Trifluoroethane	0.30	0.68	0.1	1.9
Methylene Chloride	0.81			0.14
Hexane	0.15		0.70	5.6
1,1-Trichloroethane	0.17		0.80	6.5
Benzene	0.86		0.40	0.30
Heptane	1.0		0.20	
Trichloroethylene	0.04			
Toluene	0.05	0.65	1.5	0.80
Tetrachloroethylene	0.01			
Ethyl benzene	0.05	0.08	0.1	0.70
O-Xylene	0.14	0.17	0.4	1.0
P-Xylene	0.04			0.10
2-Butoxyethanol	0.07			
1-Methylethylbenzene	0.02			
2-Propanone			4.0	8.1
Trichlorotrifluoromethane				
1,1-Dichloroethene				
2,2-Dimethylhexane				
1,5-Hexadiene				
2,2,4-Trimethylpentane				
2,2'-Dimethylethylene Oxide				
(1-Methylethyl) Cyclopropane				0.60
2-Pentanone				0.50
Oxygenated HC				8.1
Hydrocarbons				2.9

TABLE II

Analysis of Chemicals Collected on Charcoal, Ambersorb and Tenax
(All Units are in PPBV)

Organic Compound	Experiment 1 (Background)	Experiment 2 (Same as Expt. 1 But Sample Holder Contains Carbon GX 176)	Experiment 3 (Same as Expt. 2 But in Radiation Field 3.62 E6 Rads per Hour)	Experiment 4 (Same as Expt. 3 but Iodine Flowing into System)	Experiment 5 (Same as Expt. 4 but no Iodine Flow)
1,1,2-Trichloro-2,2,1-Trifluoroethane				0.16	
Methylene Chloride				1.50	2.0
1,1,1-Trichloroethane	3.00	3.20	4.10	5.40	
Benzene	1.70	2.00	2.60	3.40	
Toluene				.89	3.0
2-Propanone	2.80				
Trichlorotrifluoromethane	0.08	0.64	0.71	1.60	3.2
1,1-Dichloroethene					

TABLE II CONTINUED

Collection of Background Levels of Organic Compounds In Tenax, Tenax and Charcoal, and in Tenax, Ambersorb and Charcoal (All Units are in PPBV)

Organic Compound / Adsorbent / Vol. Collected, L	Tenax Lot # 18834 48 L	Tenax/Amb./ Charcoal Lot # 18835 48 L	Tenax Lot # 18972 15 L	Tenax/Amb./ Charcoal Lot # 18973 15 L
Methoxyethene				
1,1,2-Trichloro-2,2,1-Trifluoroethane			0.27	
Methylene Chloride	33	3.9	14	9.6
Hexane	0.88	0.46	1.1	0.91
1,1,1-Trichloroethane	13	2.7	6.6	7.0
Benzene	17	27	36	34
Heptane				
Trichloroethylene				
Toluene		14		1.8
Tetrachloroethylene				
Ethyl benzene				
O-Xylene				
P-Xylene				
2-Butoxyethanol				
1-Methylethylbenzene				
2-Propanone				5.2
Trichlorotrifluoromethane	1.7	0.19	1.3	0.48
1,1-Dichloroethene	1.4		0.63	
2,2-Dimethylhexane	3.0			
1,5-Hexadiene	0.24			
2,2,4-Trimethylpentane		0.80	1.5	1.1
2,2'-Dimethylethylene Oxide				
(1-Methylethyl) Cyclopropane				
2-Pentanone				
Oxygenated HC				
Hydrocarbons				

TABLE III
Analysis of Chemicals Collected on Charcoal, Ambersorb, and Tenax
(All Units are in PPBV)

Organic Compound	RUN # 1 Background	RUN # 2 (Same as Run 1 But Sample Holder Contains Carbon GX 176, Batch 8, Lot 3327)	RUN # 3 (Same as Run 2 But in Radiation Field 3.62 E6 Rads Per Hour	RUN # 4 (Same as Run 3 But Iodine Flowing Into System	RUN # 5 (Same as Run 4 But No Iodine Flow	RUN # 6 Control (Molecular Sieve Column Never Opened)
Chlorodifluoromethane	5.9	3.5	23.00	7.3	6.3	9.0
Oxiranemethanol	0.77					0.26
Trichlorofluoromethane	0.96	5.7	3.8	1.8	0.71	
2-Propanone	0.88		12.00	9.9	0.69	
1,1,2-Trichloro-2,2,1-trifluoroethane	0.18	0.64	0.89	8.7	0.86	3.0
Methylene Chloride	8.7	17.00	73.00	7.9	7.3	13.00
Hexane	0.89		1.1	1.2	3.6	
Ethyl Acetate	0.86	46.00	1.4	2.5	4.6	
1,1,1-Trichloroethane	9.4	26.00	31.00	8.9	15.00	12.00
Benzene	0.41	23.00	1.4	0.77	0.77	0.82
2,2,4-Trimethyl pentane	0.39			0.44	0.61	1.2
Toluene	8.1	1.6		13.00	13.00	9.5
Propane		0.85	3.5			
1,1-Dichloroethene		1.5				
2-Ethyl-2(hydroxymethyl)-1,3-propanediol		22.00				
Trichloroethene		0.38				
Tetrachloroethene		0.25			0.08	
2,2-Dimethyl Oxetane			1.1			
Ethenyl Acetate			1.6			
3-Methyl Hexane			3.4			
3,4-Dimethyl Heptane			0.92			
3,5-Dimethyl Heptane		6.6				
Methyl Cyclohexane			2.3			
Hydrocarbon			13 ug/cu m			
2,2,3,4-Tetramethyl Pentane			2.0			
2-Methyl Propane				2.7		
Ethanol				7.1		
2-Methyl-2,4-Pentanediol				0.39		
2-Butanone				0.86		
2,3,4-Trimethyl Hexane				0.12		
Acetic Acid Anhydride					0.65	
3 Methyl Pentane					0.31	
3,4-Epoxy-2-Hexanone						0.24

TABLE IV
Analysis of Chemicals Collected on Charcoal, Ambersorb, and Tenax
(All Units are in PPBV)

Organic Compound	RUN # 1 Background	RUN # 2 (Same as Run 1 But Sample Holder Contains Used Carbon 15021	RUN # 3 (Same as Run 2 But in Radiation Field 3.62 E6 Rads Per Hour	RUN # 4 (Same as Run 3 But Iodine Flowing Into System	RUN # 5 (Same as Run 4 But No Iodine Flow	RUN # 6 Control (Molecular Sieve Column Never Opened)
Chlorodifluoromethane	0.73		3.5	2.0		
Oxiranemethanol	0.44	2.9	2.6		0.36	5.0
Trichlorofluoromethane	2.0	23.00	58.00	51.00	9.5	7.3
2-Propanone	5.3	15.00	27.00			0.91
1,1,2-Trichloro-2,2,1-trifluoroethane	2.1		15.00		2.3	45.00
Methylene Chloride	2.1	16.00			1.5	58.00
Hexane	1.0	48.00	93.00	1.2	0.93	9.2
Ethyl Acetate	0.53	6.8	30.00			6.3
1,1,1-Trichloroethane			2.8		6.6	0.88
Benzene	1.3	2.9	21.00	16.00	24.00	26.00
2,2,4-Trimethyl pentane		5.2	11.00			
Toluene		1.6	6.7			
Propane			0.48		0.25	0.28
1,1-Dichloroethene		1.1			14.00	
2-Ethyl-2(hydroxymethyl)-1,3-propanediol			3.4	40.00		
Trichloroethene				15.00		
Tetrachloroethene		1.2	4.3			
2,2-Dimethyl Oxetane						
Ethenyl Acetate						
3-Methyl Hexane						
3,4-Dimethyl Heptane						
3,5-Dimethyl Heptane						
Methyl Cyclohexane		23.00	29.00			6.2
Hydrocarbon						
2,2,3,4-Tetramethyl Pentane						
2-Methyl Propane						
Ethanol						
2-Methyl-2,4-Pentanediol						
2-Butanone						
2,3,4-Trimethyl Hexane				13.00	11.00	
Acetic Acid Anhydride						
3 Methyl Pentane		13.00				1.1
3,4-Epoxy-2-Hexanone						

TABLE IV CONTINUED

Analysis of Chemicals Collected on Charcoal, Ambersorb, and Tenax
(All Units are in PPBV)

Organic Compound	RUN # 1 Background	RUN # 2 (Same as Run 1 But Sample Holder Contains Used Carbon 15021	RUN # 3 (Same as Run 2 But in Radiation Field 3.62 E6 Rads Per Hour	RUN # 4 (Same as Run 3 But Iodine Flowing Into System	RUN # 5 (Same as Run 4 But No Iodine Flow	RUN # 6 Control (Molecular Sieve Column Never Opened)
1,2-Dichloroethene						0.35
(1-Methylethyl) cyclopropane	0.83	5.8				6.7
2,2,6-Trimethyl octane					0.59	0.42
2,2,3,4,6,6-Hexamethyl heptane					0.53	0.23
5-Methyl-5-propylnonane						0.22
Chloromethane	0.82					
1-(Ethenyloxy)-2-methylpropane	0.35					
2-Butene		23.00	6.3	6.5	3.3	
2-Methyl butane		28.00	20.00			
2-Methyl butane		16.00				
Diethylmethyleser borinicacid		22.00				
2-Ethyl-4-methyl-1-pentanol		0.64			1.2	
Heptane		0.88				
1,4 Dioxane		0.43	1.2			
2-Methyl-2-propene-1-01 acetate			18.00	6.3		
1,2-Propanediol			24.00			
3,3-Dimethyl pentane			32.00			
3-Methyl pentane			22.00			
Mixture 2,3 Butadione/2-Methyl pentane						
7-Methyl-1-octane			8.5			
5-Methyl-1-heptene			0.47			
4-Methyl nonane			7.2		85.00	
5-Methyl nonane			0.54		26.00	
1,3-Dimethyl cyclohexane			0.77		3.0	
1,2-Dimethyl cyclohexane			0.45			
1-Ethyl-1-methylcyclohexane			0.32			
Butyl cyclohexane			0.52			
2,3-Dimethyl hexane			0.37			
Difluoromethylsilane				7.8	1.7	
Dodecafluoropentane				0.53		
Iodomethane				11.00	6.5	
2-Propanol				5.6		
2-Methyl-2-propanol				5.3		

TABLE IV CONTINUED

Analysis of Chemicals Collected on Charcoal, Ambersorb, and Tenax
(All Units are in PPBV)

Organic Compound	RUN # 1 Background	RUN # 2 (Same as Run 1 But Sample Holder Contains Used Carbon 15021	RUN # 3 (Same as Run 2 But in Radiation Field 3.62 E6 Rads Per Hour	RUN # 4 (Same as Run 3 But Iodine Flowing Into System	RUN # 5 (Same as Run 4 But No Iodine Flow	RUN # 6 Control (Molecular Sieve Column Never Opened)
3-(Methylbutyl) cyclopentane					0.54	
4-Methyl octane					1.0	
2-Propenyl cyclohexane					5.4	
1,3,5-Trimethyl cyclohexane					1.1	
Ethyl benzene					2.7	
2,5,6-Trimethyl octane					1.9	
2,2,8-Trimethyl decane					0.59	

TABLE V

*Methyl Iodide Analysis By Electron Capture Chromatography**

EXPERIMENT 1. CHARCOAL BATCH 5340 (18.128 GRAMS USED)

Run #	Time On	Time Off	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity	Methyl Iodide ppbv
Control										ND
1 (Background)	08:47	09:17	66	30	31	31	87	8.00E-10	12.6%	0.19
2 (Charcoal)	09:31	10:01	90	32	30	31	108	8.40E-10	9.6%	0.45
3 (Charcoal in Gamma)	10:29	10:59	98	32	33	35	109	9.21E-10	8.9%	4.80
4 (Iodine Introduced)	11:32									
(9.502 G in container)	12:25	12:55	51	32	32	71	68	2.44E-10	10.8%	13.00
5 (Residual Iodine)	14:00	14:30	94	31	32	70	106	5.26E-10	9.6%	3.20

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the Mixing Chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

ND = not detected

**The following substances were analyzed for but were not detected: Ethyl Iodide, Iodopropane, Iodopropene, Iodobutane, Iodopentane, Iodohexane, Iodobenzene, Iodotoluene, Iododecane*

TABLE V CONTINUED

*Methyl Iodide Analysis by Electron Capture Chromatography**

EXPERIMENT 2. CHARCOAL BATCH 5338 (15.671 GRAMS USED)

Run #	Time On	Time Off	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity	Methyl Iodide ppbv
Control										ND
1 (Background)	11:00	11:30	79	29	29	30	98	5.90E-10	.6%	ND
2 (Charcoal)	11:53	12:23	91	33	32	24	107	6.18E-10	.9%	ND
3 (Charcoal in Gamma)	12:35	13:05	99	31	30	38	115	6.63E-10	1.2%	0.16
4 (Iodine Introduced)	13:10									
(9.075 G in container)	14:12	14:42	51	29	30	50	73	2.21E-10		0.86
5 (Residual Iodine)	15:42	16:13	102	40	33	52	117	5.02E-10	10.8%	0.94

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the Mixing Chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

ND = not detected

* *The following substances were analyzed for but were not detected: Ethyl Iodide, Iodopropane, Iodopropene, Iodobutane, Iodopentane, Iodohexane, Iodobenzene, Iodotoluene, Iododecane*

TABLE V CONTINUED

*Methyl Iodide Analysis By Electron Capture Chromatography**

EXPERIMENT 3. CHARCOAL BATCH P.3 (22.7266 GRAMS USED)

Run #	Time On	Time Off	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity	Methyl Iodide ppbv
Control										ND
1 (Background)	11:10	11:40	106	39	33	31	116	8.13E-10	1.3%	0.70
2 (Charcoal)	11:47	12:18	105	36	31	27	116	8.32E-10	1.2%	0.65
3 (Charcoal in Gamma)	12:35	13:05	108	38	31	38	118	8.32E-10	NO	0.74
4 (Iodine Introduced)	13:25									
(9.625 G in container)	14:32	15:02	71	65	32	37	52	3.40E-10	12.4%	0.95
5 (Residual Iodine)	16:21	16:51	53	38	33	63	83	8.17E-10	11.1%	0.99

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the Mixing Chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

ND = not detected NO = not observed

*The following substances were analyzed for but were not detected: Ethyl Iodide, Iodopropane, Iodopropene, Iodobutane, Iodopentane, Iodohexane, Iodobenzene, Iodotoluene, Iododecane

TABLE V CONTINUED

*Methyl Iodide Analysis By Electron Capture Chromatography**

EXPERIMENT 4. CHARCOAL BATCH K.2 (23.59745 GRAMS USED)

Run #	Time On	Time Off	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity	Methyl Iodide ppbv
Control										ND
1 (Background)	10:03	10:33	74	32	30	29	91	6.88E-10	0.6%	0.23
2 (Charcoal)	10:43	11:13	96	41	34	23	106	7.35E-10	0.7%	0.29
3 (Charcoal in Gamma)	11:22	11:52	94	35	32	34	109	7.35E-10	1.2%	0.31
4 (Iodine Introduced) (11.03 G in container)	11:54 13:01	13:31	55	41	37	75	74	2.96E-10	1.3%	0.66
5 (Residual Iodine)	14:35	15:05	96	37	31	73	111	7.52E-10	9.8%	0.75

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the Mixing Chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

ND = not detected

* *The following substances were analyzed for but were not detected: Ethyl Iodide, Iodopropane, Iodopropene, Iodobutane, Iodopentane, Iodohexane, Iodobenzene, Iodotoluene, Iododecane*

TABLE V CONTINUED

*Methyl Iodide Analysis By Electron Capture Chromatography**

EXPERIMENT 5. CHARCOAL BATCH 15732 C.6 (22.85725 GRAMS USED)

Run #	Time On	Time Off	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity	Methyl Iodide ppbv
Control										ND
1 (Background)	11:44	12:14	93	31	29	27	108	6.71E-10	11.4%	1.80
2 (Charcoal)	12:29	12:59	99	37	31	27	109	6.75E-10	11.8%	1.80
3 (Charcoal in Gamma)	13:23	13:53	100	32	30	41	113	7.20E-10	10.4%	1.50
4 (Iodine Introduced) (10.03 G in container)	15:01 16:00	16:30	57	41	35	45	75	2.30E-10	8.7%	0.92
5 (Residual Iodine)	17:36	18:06	54	37	32	42	77	7.70E-10	8.7%	0.70

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the Mixing Chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

ND = not detected

**The following substances were analyzed for but were not detected: Ethyl Iodide, Iodopropane, Iodopropene, Iodobutane, Iodopentane, Iodohexane, Iodobenzene, Iodotoluene, Iododecane*

TABLE V CONTINUED

*Methyl Iodide Analysis by Electron Capture Chromatography**

EXPERIMENT 6. CHARCOAL BATCH 208.2 (17.95295 GRAMS USED)

Run #	Time On	Time Off	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity	Methyl Iodide ppbv
Control										ND
1 (Background)	10:43	11:13	28	29	28	28	28	6.70E-10	.1%	3.30
2 (Charcoal)	11:18	11:48	33	29	28	28	44	6.70E-10	.1%	2.40
3 (Charcoal in Gamma)	12:00	12:30	57	31	30	38	72	6.93E-10	.1%	1.80
4 (Iodine Introduced) (10.04 G in container)	12:32 13:35	14:05	70	68	30	36	53	3.37E-10	.4%	2.50
5 (Residual Iodine)	15:05	15:35	56	39	31	69	80	6.62E-10	1.8%	1.80

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the Mixing Chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

ND = not detected

The following substances were analyzed for but were not detected: Ethyl Iodide, Iodopropane, Iodopropene, Iodobutane, Iodopentane, Iodohexane, Iodobenzene, Iodotoluene, Iododecane

TABLE V CONTINUED

*Methyl Iodide Analysis By Electron Capture Chromatography**

EXPERIMENT 7. CHARCOAL BATCH 15021 (20.8699 GRAMS USED)

Run #	Time On	Time Off	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity	Methyl Iodide ppbv
Control										ND
1 (Background)	11:24	11:54	90	35	29	28	100	7.47E-10	.4%	8.00
2 (Charcoal)	12:05	12:35	56	34	30	24	52	7.47E-10	.4%	2.50
3 (Charcoal in Gamma)	13:01	13:31	36	31	30	32	38	7.20E-10	1.0%	1.80
4 (Iodine Introduced) (9.238 G in container)	13:35 14:30	15:00	42	34	31	71	44	2.57E-10	1.0%	1.60
5 (Residual Iodine)	16:04	16:34	37	31	30	77	49	6.12E-10	12%	4.60

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the Mixing Chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

ND = not detected

*The following substances were analyzed for but were not detected: Ethyl Iodide, Iodopropane, Iodopropene, Iodobutane, Iodopentane, Iodohexane, Iodobenzene, Iodotoluene, Iododecane

TABLE VI

Methyl Iodide Analysis By Electron
Capture Chromatography
(High Humidity Conditions)

EXPERIMENT 1. CHARCOAL BATCH 5340 (17.4622 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
0 (Control)										nd
1 (Background)	10:43	30 MIN	55	28	29	25	45	1.53E-08	100	0.2408
2 (Charcoal)	11:39		61	31	30	32	49	1.49E-08	91	5.934
3 (Charcoal in Gamma)	12:21		74	33	30	45	53	1.46E-08	91	12.642
4 (Iodine Introduced)	13:16									
1.0015 G in container	14:16		73	39	30	78	53	1.24E-08	92	52.7524
5 (Residual Iodine)	15:38		71	40	31	83	53	1.23E-08	93	155.0236
6 (condensate collected)	10:43	(cumulative)								7.224

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VI CONT'D

Methyl Iodide Analysis By Electron
Capture Chromatography
(High Humidity Conditions)

EXPERIMENT 2. CHARCOAL BATCH 5338 (16.2249 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	10:18	30 MIN	73	34	29	31	78	1.33E-08	100	1.8232
2 (Charcoal)	11:07		72	31	29	37	84	1.23E-08	100	0.4472
3 (Charcoal in Gamma)	11:46		71	37	29	52	83	1.24E-08	98	0.4472
4 (Iodine Introduced)	12:16									
1.001 G in container	13:16		70	39	30	66	78	1.29E-08	96	3.1476
5 (Residual Iodine)	14:48		71	39	30	67	79	1.29E-08	96	4.2656
6 (condensate collected)	10:18	(cumulative)								nd

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VI CONT'D

Methyl Iodide Analysis By Electron
Capture Chromatography
(High Humidity Conditions)

EXPERIMENT 3. CHARCOAL BATCH P.3 (23.8185 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	10:33	30 MIN	72	33	30	32	84	1.31E-08	93	0.1032
2 (Charcoal)	11:14		70	34	30	40	84	1.35E-08	92	nd
3 (Charcoal in Gamma)	12:06		71	33	31	35	89	1.36E-08	95	1.2212
4 (IodinIodine introduced	12:41									
1.0000 G in container	13:42		72	33	31	58	80	1.29E-08	96	2.5112
5 (Residual Iodine)	15:12		72	34	33	61	81	1.35E-08	93	2.494
6 (condensate collected)	10:33	(cumulative)								nd

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VI CONT'D

Methyl Iodide Analysis By Electron
Capture Chromatography
(High Humidity Conditions)

EXPERIMENT 4. CHARCOAL BATCH K.2 (22.5374 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	09:38	30 MIN	73	31	31	37	86	1.28E-08	96	nd
2 (Charcoal)	10:28		73	31	30	33	86	1.39E-08	93	nd
3 (Charcoal in Gamma)	11:23		71	31	30	43	87	1.38E-08	91	1.0148
4 (Iodine Introduced)	12:24									
1.001 G in container	13:24		74	32	31	68	86	1.32E-08	92	2.6144
5 (Residual Iodine)	14:54		73	32	31	63	89	1.20E-08	94	2.7692
6 (condensate collected)	09:38	(cumulative)								3.8184

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VI CONT'D

Methyl Iodide Analysis By Electron
Capture Chromatography
(High Humidity Conditions)

EXPERIMENT 5. CHARCOAL BATCH 15732 C.6 (24.8596 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	09:59	30 MIN	72	31	31	44	84	1.12E-08	97	nd
2 (Charcoal)	10:57		72	31	32	37	85	1.23E-08	97	nd
3 (Charcoal in Gamma)	11:39		71	31	31	44	85	1.22E-08	98	1.2212
4 (Iodine Introduced)	12:10									
1.0012 G in container	13:12		74	31	31	61	85	1.22E-08	98	3.0272
5 (Residual Iodine)	14:42		72	32	32	68	86	1.30E-08	100	1.4964
6 (condensate collected)	09:59	(cumulative)								26.144

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VI CONT'D

Methyl Iodide Analysis By Electron
Capture Chromatography
(High Humidity Conditions)

EXPERIMENT 6. CHARCOAL BATCH 208.2 (20.1721 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	09:12	30 MIN	71	32	32	44	88	1.16E-08	98	nd
2 (Charcoal)	10:01		72	32	32	49	86	1.25E-08	97	nd
3 (Charcoal in Gamma)	10:38		71	32	32	45	86	1.34E-08	97	0.4988
4 (Iodine Introduced)	11:52									
1.001 G in container	12:52		72	33	33	59	80	1.26E-08	97	0.4816
5 (Residual Iodine)	14:26		72	34	33	62	88	1.32E-08	98	0.5504
6 (condensate collected)	09:12	(cumulative)								nd

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VI CONT'D

Methyl Iodide Analysis By Electron
Capture Chromatography
(High Humidity Conditions)

EXPERIMENT 7. CHARCOAL BATCH 15021 (22.5068 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	10:06	30 MIN	74	41	34	42	86	1.39E-08	98	nd
2 (Charcoal)	10:47		75	37	33	48	86	1.35E-08	98	nd
3 (Charcoal in Gamma)	11:19		73	34	35	48	86	1.30E-08	96	0.7568
4 (Iodine Introduced)	12:16									
1.0003 G in container	13:16		76	35	36	65	86	1.29E-08	96	2.9584
5 (Residual Iodine)	14:46		75	35	36	67	86	1.33E-08	96	4.8504
6 (condensate collected)	10:06	(cumulative)								1.7372

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VII
Methyl Iodide Analysis By Electron
Capture Chromatography
(Low Humidity Conditions)

EXPERIMENT 1. CHARCOAL BATCH 5340 (15.8585 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	10:45	30 MIN	41	29	28	28	55	9.02E-09	0.7	nd
2 (Charcoal)	11:53		49	31	31	27	60	8.97E-09	0.7	0.40
3 (Charcoal in Gamma)	12:30		48	29	29	39	59	8.52E-09	0.6	3.14
4 (Iodine Introduced)	13:06									
0.5000 G in container	14:06		43	32	29	68	49	8.46E-09	9.7	5.06
5 (Residual Iodine)	15:36		48	33	31	70	58	8.83E-09	17.6	2.44

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VII CONT'D

Methyl Iodide Analysis By Electron
Capture Chromatography
(Low Humidity Conditions)

EXPERIMENT 2. CHARCOAL BATCH 5338 (17.2389 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	10:22	30 MIN	54	29	29	28	69	9.85E-09	0.2	nd
2 (Charcoal)	11:01		49	29	29	28	57	9.85E-09	0.2	nd
3 (Charcoal in Gamma)	11:46		48	30	27	41	57	9.72E-09	0.3	0.17
4 (Iodine Introduced)	12:17									
0.5025 G in container	13:18		43	33	29	68	48	8.36E-09	0.3	nd
5 (Residual Iodine)	12:58		49	34	30	68	60	8.34E-09	1.1	nd

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VII CONT'D
Methyl Iodide Analysis By Electron
Capture Chromatography
(Low Humidity Conditions)

EXPERIMENT 3. CHARCOAL BATCH P.3 (23.3151 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	09:55	30 MIN	47	32	32	30	60	8.75E-09	0.5	nd
2 (Charcoal)	11:03		47	32	30	25	60	8.99E-09	0.5	0.14
3 (Charcoal in Gamma)	11.39		48	33	33	60	60	9.01E-09	0.7	0.07
4 (IodinIodine introduced	12:13									
0.5041 G in container	13:13		44	34	31	64	50	8.28E-09	1.2	0.03
5 (Residual Iodine)	14:43		51	36	34	65	61	9.54E-09	12.0	0.07

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VII CONT'D

Methyl Iodide Analysis By Electron
Capture Chromatography
(Low Humidity Conditions)

EXPERIMENT 4. CHARCOAL BATCH K.2 (21.6936 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	09:32	30 MIN	44	28	27	27	56	9.85E-09	0.1	nd
2 (Charcoal)	10:50		44	29	26	22	55	9.86E-09	0.1	nd
3 (Charcoal in Gamma)	11:34		45	29	27	61	57	9.98E-09	0.1	0.40
4 (Iodine Introduced)	12:23									
0.5032 G in container	13:23		40	31	28	65	46	8.64E-09	1.2	2.10
5 (Residual Iodine)	14:58		46	31	28	65	58	8.61E-09	1.2	2.10

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VII CONT'D
Methyl Iodide Analysis By Electron
Capture Chromatography
(Low Humidity Conditions)

EXPERIMENT 5. CHARCOAL BATCH 15732 C.6 (24.1689 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	10:23	30 MIN	41	25	28	28	52	8.87E-09	0.6	nd
2 (Charcoal)	10:59		43	27	28	25	54	8.87E-09	0.3	nd
3 (Charcoal in Gamma)	12:09		47	31	29	56	58	9.06E-09	0.3	0.31
4 (Iodine Introduced)	12:44									
0.5074 G in container	13:50		45	32	28	63	54	8.12E-09	0.3	0.80
5 (Residual Iodine)	15:25		46	32	26	64	59	8.76E-09	0.3	0.58

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VII CONT'D
Methyl Iodide Analysis By Electron
Capture Chromatography
(Low Humidity Conditions)

EXPERIMENT 6. CHARCOAL BATCH 208.2 (19.4761 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	09:38	30 MIN	46	29	28	28	56	8.62E-09	0.4	nd
2 (Charcoal)	11:40		47	29	28	28	58	8.62E-09	0.4	nd
3 (Charcoal in Gamma)	12:12		48	32	29	53	56	8.54E-09	0.4	nd
4 (Iodine Introduced)	12:44									
0.5146 G in container	13:50		45	32	29	62	48	7.80E-09	0.5	nd
5 (Residual Iodine)	15:22		49	33	30	62	62	8.02E-09	0.6	nd

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected

TABLE VII CONT'D
Methyl Iodide Analysis By Electron
Capture Chromatography
(Low Humidity Conditions)

EXPERIMENT 7. CHARCOAL BATCH 15021 (20.8784 GRAMS USED)

RUN #	START	SAMPLE TIME	TC1	TC 2	TC 3	TC 4	TC 5	Current Amps	Humidity Percent	Methyl Iodide ppbv
(Control)										nd
1 (Background)	09:31	30 MIN	49	33	33	28	60	1.02E-08	0.1	nd
2 (Charcoal)	10:06		50	34	35	22	60	1.02E-08	0.1	nd
3 (Charcoal in Gamma)	10:46		52	36	36	58	61	1.00E-08	0.1	0.45
4 (Iodine Introduced)	11:27									
0.5005 G in container	12:27		43	35	34	60	50	8.44E-09	0.1	0.40
5 (Residual Iodine)	14:01		53	38	35	61	63	8.28E-09	0.1	nd

All temperatures in degrees Celsius

TC 1 (Type K thermocouple located in the internal volume of the mixing chamber)

TC 2 (Type K thermocouple located in the return from the charcoal bed)

TC 3 (Type K thermocouple measuring room temperature)

TC 4 (Type T thermocouple located in the charcoal bed)

TC 5 (Type T thermocouple measuring surface temperature of the mixing chamber)

nd = not detected