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THE INHALATION OF RADIOACTIVE MATERIALS AS RELATED TO HAND CONTAMINATION

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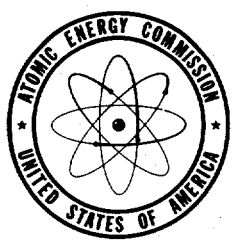

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A B S T R A C T

Tests performed to determine the hazard associated with the inhalation of radioactive materials as the result of smoking with contaminated hands indicate that for dry uranium compounds adhering to the palmar surfaces of the hands, approximately 1.0% of the material may be transferred to a cigarette, and that of this approximately 0.2% may appear in the smoke which is inhaled. Most of the contamination originally placed in a cigarette was found in the ash, and only 11% of the material was not recovered following burning; approximately half of this loss may be attributed to normal losses inherent in the analytical process, the recovery efficiency for which was found by supplementary experiments to be 95%.

THE INHALATION OF RADIOACTIVE MATERIALS AS RELATED TO HAND CONTAMINATION

INTRODUCTION

Experiments have been performed in an attempt to determine the hazard associated with the inhalation of radioactive materials as the result of smoking with contaminated hands. The principal factors calculated were the fraction of material which may be transferred from the hands to cigarettes and the fraction of material on the cigarette which may be inhaled when the cigarette is smoked.

SUMMARY OF RESULTS

The tests indicate that for dry uranium compounds adhering to the palmar surfaces of the hands, approximately 1.0% of the material may be transferred to a cigarette, and that of this approximately 0.2% may appear in the smoke which is inhaled. Most of the contamination originally placed in a cigarette was found in the ash, and only 11% of the material was not recovered following burning; approximately half of this loss may be attributed to normal losses inherent in the analytical process, the recovery efficiency for which was found by supplementary experiments to be 95%.

TRANSFER OF CONTAMINATION FROM HANDS TO CIGARETTES

Contamination Under Field Conditions

In order to simulate those working conditions which, from the standpoint of cigarette contamination, are considered to be the most hazardous that might be anticipated, a work surface highly contaminated with normal uranium tetrafluoride was used as the source of contamination. Transferable contamination on the surface was between 7,000 and 16,000 dis./min./100 $cm.^2$ (1,400 and 3,250 counts/min. at 20% geometry), the average being 11,000 dis./min./100 $cm.^2$. The degree of contamination was determined by the standard method used at K-25, which consists of rubbing approximately 100 $cm.^2$ of the surface vigorously with a test paper backed by 3 fingers, and reading the activity with a Samson alpha survey meter.

The hands were rubbed over the work surface and the contamination was then thoroughly rubbed into the hands so that no very loose material remained on the hands. After repeated contact with this surface, the contamination on the palm attained a value of 83,000 dis./min. (12,500 counts/min. at 15% geometry), the change in contamination level with repeated contact being small toward the end of the test.

The hands were monitored with a Samson alpha survey meter, and each cigarette was handled for a period of about 1 minute. Only 1 hand was used in handling a cigarette, and the hands were recontaminated after each cigarette was handled. The 12 cigarettes so contaminated were counted whole in a laboratory type proportional alpha counter.

The hand and cigarette counts were corrected for counting geometries, and the fraction of the material transferred was determined. The results, shown in table 1, indicate that between 0.7% and 1.6% of the material on the palmar

surface of the hand was transferred to the cigarette; the average value was 1.04% ± 0.09%* and the fraction transferred appeared to be essentially independent of the degree of contamination.

The results of the tests by which the various counting geometries were determined are given in the appendix.

TABLE 1

Transfer of Contamination to Cigarettes - Working Conditions

No.	Hand Counts (c/min.) (15% Geometry)	Hand Counts (dis./min.)	Cigarettes (c/min.) (30% Geometry)	Cigarettes (dis./min.)	Transferred %
1	3,250	21,700	73	243	1.12
2	3,500	23,300	62	207	0.89
3	3,500	23,300	88	293	1.26
4	5,000	33,300	73	243	0.73
5	6,250	41,700	128	427	1.02
6	5,000	33,300	120	400	1.20
7	7,250	48,300	109	363	0.75
8	7,500	50,000	158	526	1.05
9	10,250	67,400	219	730	1.08
10	10,500	70,000	166	554	0.79
11	10,000	66,700	217	724	1.08
12	12,500	83,400	390	1300	1.56
Average					1.04 ± 0.09

Maximum Contamination Transfer

In order to determine the maximum amount of uranium which may be transferred to a cigarette, a laboratory test similar to that described above was used. In this case, uranium oxide was transferred from a jar and was spread evenly over the hands but was not rubbed into the hands; the cigarettes were handled as described above. Since there was a considerable amount of loose material on the hands, the fraction transferred to the cigarettes was somewhat greater than that found in the field test, the average being 1.8%. The counts for the cigarettes were determined by splitting them and counting the papers flat; on the basis of the average of several comparisons, this configuration appeared to have essentially the same 30% geometry as when the cigarettes were counted whole. The results of this test are shown in table 2, but since the experimental method did not appear to simulate actual working conditions at K-25, the results were not included in the averages summarized on page 7.

* The limits of error indicated throughout this report are the standard errors of the means.

TABLE 2

Transfer of Contamination to Cigarettes -
Laboratory Test with Hands Dusted

No.	Hand Contamination (c/min.) (15% Geometry)	Hand Contamination (dis./min.)	Cigarette Contamination (c/min. on Paper) (30% Geometry)	Cigarette Contamination (dis./min.)	Transferred %
1	1,250	8,330	33	110	1.3
2	1,500	10,000	87	290	2.9
3	2,750	18,300	102	340	1.9
4	3,500	23,300	177	590	2.5
5*	3,250	21,700	121	403	1.9
6	5,250	35,000	155	516	1.5
7	5,750	38,300	177	590	1.5
8	11,000	73,300	284	946	1.3
9	>12,500	>83,300	291	970	1.2
Average					1.78 ± 0.06
10	>12,500	>83,300	1,140**	3,800	4.6

* No material was added to the hands before handling this cigarette.
** This cigarette was used to wipe material off the hands in order to obtain an estimate of the maximum amount of material which is transferable under the most extreme conditions.

INHALATION OF CONTAMINATION FROM CIGARETTES

In order to determine the maximum fraction of contamination which might be inhaled from a contaminated cigarette during smoking, 0.1 cm.^{3} of uranyl fluoride solution containing approximately 22,200 alpha dis./min., or 11,100 counts/min.*, was injected into each of several cigarettes by means of a hypodermic syringe. The cigarettes were "smoked" approximately 2/3 of their length by pulling air through them with air samplers, the part thus "smoked" including the portion injected with material. The activity in the smoke was collected by using filter papers in the samplers or by using water bubblers in the smoke stream.

Approximately 0.2% of the material was collected from the smoke, while an average of 89% was found in the unsmoked butt and the ash, most of this appearing in the ash. The yield of the analytical method was found by supplementary experiments to be 95%; thus, if the experimental recovery figure is corrected for loss due to the analytical method, the results show that about 94% of the material originally injected in the cigarette remained in the butt and ash. The results of these tests are summarized in table 3; specific results of the individual tests are given in the tables indicated, and details of the tests are given in the following sections of the report. Table 3 also summarizes the results obtained with the cigarettes which were "smoked" after being contaminated by handling as described previously.

* Throughout this report counts were obtained at 50% geometry except where specifically indicated otherwise.

TABLE 3

Summary of Tests

Data in Table No.	No. Cigarettes	Type Collector	Type Contamination	% in Smoke	Total Recovered %
4	4	Filter Paper	UO_2F_2	0.20	86
7	9	Water Bubbler	UO_2F_2	0.03	94
8	4	Water Bubbler	UF_4	0.69	79
Weighted Average				0.23	89

Checks were made on the collection efficiencies of both the water bubblers and the filter papers by using 2 filter papers in series or 2 bubblers in series. No detectable activity was found in the second of 2 bubblers, and only 1.2% of the amount collected from smoke passing through the cigarette was found on the second of 2 filter papers. For the escaping smoke, the corresponding figure is less than 10%. These results indicate that most of the contamination in the smoke, either "inhaled" or escaping, was probably accumulated by the collecting devices.

The results of the individual tests are summarized in the following sections.

Tests Using Filter Papers

The arrangement of the apparatus used to collect activity in the smoke on filter papers is shown in figure 1. The cigarette was held against a funnel attached to a Tornado air sampler for 1 second in a "smoking" position and away from the sampler for 10 seconds so that the escaping smoke was collected by a second Tornado sampler. Two filter papers in series were used in each sampler. The uranium collected was determined by ashing the papers and counting the residue; the uranium remaining in the ash and butt was chemically extracted and alpha counted. About 84% of the original activity was found in the ash, 2% in the butt, 0.20% in the smoke which passes through the cigarette and about twice as much in the escaping smoke, the total recovery thus amounting to 86%. The distribution of the activity is tabulated in table 4, and the comparisons of the amounts of material collected on the front filters and the backing filters are shown in table 5.

TABLE 4

Test Using Filter Papers

No.	Through Cigarette (c/min.)*	%	Escaping Smoke (c/min.)*	%	Ash (c/min.)*	%	Butt (c/min.)*	%	Recovered** %
1	34.1	0.31	59.7	0.54	9,450	85.1	131	1.2	87.2
2	19.5	0.18	29.1	0.26	8,380	75.5	394	3.5	79.4
3	11.7	0.11	38.7	0.35	9,390	84.6	68	0.6	85.7
4	25.0	0.23	43.7	0.39	10,010	90.2	219	2.0	92.8
Average	22.6	0.20	42.8	0.38	9,308	83.9	203	1.8	86.3

* Counting rates on chemically extracted uranium.
** These cigarettes were injected with UO_2F_2 having a counting rate of 11,100 c/min.

TABLE 5

Test for Collection Efficiency of Filter Papers

No.	Activity Through Cigarette* No. 1 Filter (c/min.)	No. 2 Filter (c/min.)	Escaping Smoke No. 1 Filter (c/min.)	No. 2 Filter (c/min.)
1	48	1	101	0
2	16	0	16	6
3	3	0	16	3
4	27	0	11	3
Average	24	0.3	36	3

* Determined by direct alpha counting of filter papers.

In preliminary tests of the type described above, approximately 0.07% of the original activity was found in the smoke, 0.38% in the butt of the cigarette, and 65% in the ash. The total amount recovered in these experiments was considerably less than was recovered from the similar experiments which were performed later and detailed above, the higher recovery being attributed to improved analytical techniques; also, the filter papers were not ashed before counting and the results are probably slightly low due to the absorption of the alpha particles by the paper. Thus, the figures from this test, shown in table 6, were not included in the averages summarized in table 3. It is of interest, however, that these results indicate that a smaller fraction of material collected passed through the cigarette than is the case for the more accurate figures given in table 4.

TABLE 6

Preliminary Test Using Filter Papers

No.	Smoke (c/min.)	Smoke %	Butts (c/min.)	Butts %	Ash (c/min.)	Ash %	Recovered* %
1	11	0.10	27	0.24	5,160	46.53	46.87
2	15	0.14	80	0.72	7,760	69.98	70.84
3	8	0.07	33	0.30	10,260	92.52	92.89
4	0	0.00	39	0.35	7,160	64,57	64.92
5	3	0.03	47	0.42	8,920	80.44	80.89
6	2	0.02	34	0.31	8,640	77.92	78.25
7	5	0.05	38	0.34	5,980	53.93	54.32
8	3	0.03	28	0.25	6,980	62.95	63.23
9	5	0.05	24	0.22	7,900	71.24	71.51
10	21**	0.19**	1120**	10.10**	5,060**	45.63**	55.92
11	8	0.07	76	0.69	5,780	52.12	52.88
Average	6.0	0.06	43	0.38	7,454	65.26	66.59

* These cigarettes were injected with UO_2F_2 having a counting rate of 11,100 c/min.
** These values were not included in the average because the contamination was so placed that all of it was not included in the "smoked" section of the cigarette.

Tests Using Water Bubblers

During the tests with water bubblers, smoke was drawn through the cigarettes continuously at a rate which provided even burning of the cigarette with a minimum loss of smoke. Under these conditions, the flow rate could not be adjusted so as to completely eliminate the loss of smoke, since, with higher air flows, the cigarette burned down the outside and left unburned tobacco in the middle.

Two bubblers were operated in series as shown in figure 2, with the smoke entering each bubbler through a fritted disc. On those tests in which the material in the bubblers was analyzed separately, no activity was found in the second one; thus, in most cases, the water from each test was analyzed as a single sample.

On approximately half of the tests, the material which collected in the tubing and on the fritted disc was dissolved in acetone and added to the water, but the results of these tests were not detectably different from those in which only the water was analyzed. The results obtained with cigarettes contaminated by injection are shown in table 7 and those obtained with cigarettes contaminated by handling them with contaminated hands as described previously are shown in table 8.

TABLE 7

Filtration with Water Bubblers

No.	Water (c/min.)	Water %	Ash and Butt (c/min.)	Recovered %
1	1	0.01	11,640	100
2	4	0.04	10,730	97
3	5	0.05	10,480	90
4	1	0.01	9,490	86
5	13	0.12	10,770	97
6*	1	0.01	10,150	92
7*	0	0.00	10,370	94
8*	4	0.04	10,110	91
9*	0	0.00	11,080	100
Average		0.031		94

* These cigarettes were lightly coated with paraffin to reduce possible leakage.

TABLE 8

Cigarettes Contaminated by Transfer* and Smoked with Water Bubblers

No.	Cigarette Contamination (dis./min.)	Water (dis./min.)	Water %	Ash and Butt (dis./min.)	Ash and Butt %	Total Recovered %
1	730	2.6	0.36	534	73.2	73.6
2	555	7.0	1.26	452	81.5	82.8
3	724	4.2	0.58	566	78.2	78.8
4	1300	7.0	0.54	1032	79.4	79.9
Average			0.69		78.1	78.8

* These cigarettes are the same 4 shown in table 1, numbers 9-12.

The analytical procedure was tested by analyzing cigarettes which had been contaminated in the same way as those used in the experiments but which had not been smoked, the results of this test, as shown in table 9, indicating a recovery efficiency of 95%.

TABLE 9

Controls

No.	Recovered (c/min.)	% *
1	10,180	92
2	8,380**	76**
3	10,520	95
4	10,490	95
5***	11,180	101
6***	9,940	90
Average	10,462	95

* Amount of material injected was 11,100 c/min. (22,200 dis./min.).
** With this test, some material was lost as it soaked through the cigarette and deposited on its container during the drying period. The values were thus not included in the averages.
*** These cigarettes were lightly coated with paraffin to reduce possible leakage.

Tests for Leakage from the Cigarette

In order to determine whether some of the material loss might be due to leakage of the solution from the cigarette to the cigarette support during drying, some of the cigarettes were lightly coated with paraffin to prevent such leakage. There was no detectable difference between the results obtained from these cigarettes and the uncoated cigarettes, either on the smoking tests or on the tests to determine the yield of the analytical procedure. It was concluded that in these experiments leakage was not an important factor and the results obtained with the paraffin-coated cigarettes were included with those obtained with uncoated cigarettes.

DISCUSSION OF RESULTS WITH REGARD TO HEALTH CONSIDERATIONS

Since alpha active materials present a health hazard only if permitted to enter the body, one of the principal factors to be considered in determining the hazard associated with such contamination is the probability that material which is on the hands will be inhaled.

It appears that the principal way by which contamination on the hands may be inhaled is by smoking, and, in view of the experimental results described above, the following assumptions seem to give a very conservative basis for calculating the amount of a uranium compound which may be inhaled by this route.

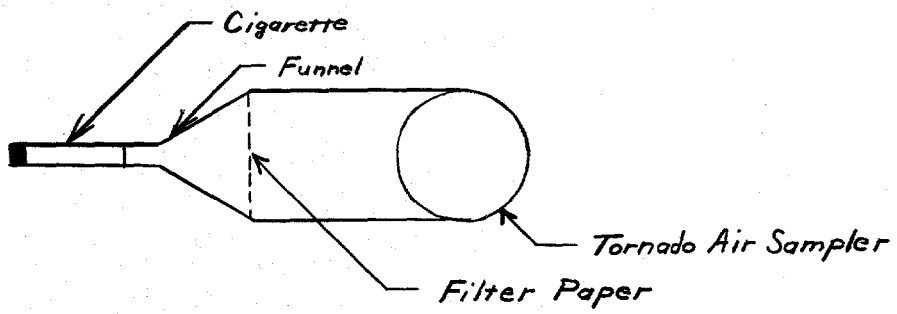
1. No more than 1% of the material on the palmar surfaces of both hands is transferred to a cigarette.

2. No more than 10% of the material on the cigarette is inhaled.

The use of the figure 10% for the fraction of material on a cigarette which is inhaled appears to introduce a safety factor of about 50 as compared with the actual results. This is considered adequate to allow for variations in the characteristics of various uranium compounds which might be encountered, differences in conditions of the hands, and variations in the personal habits of personnel.

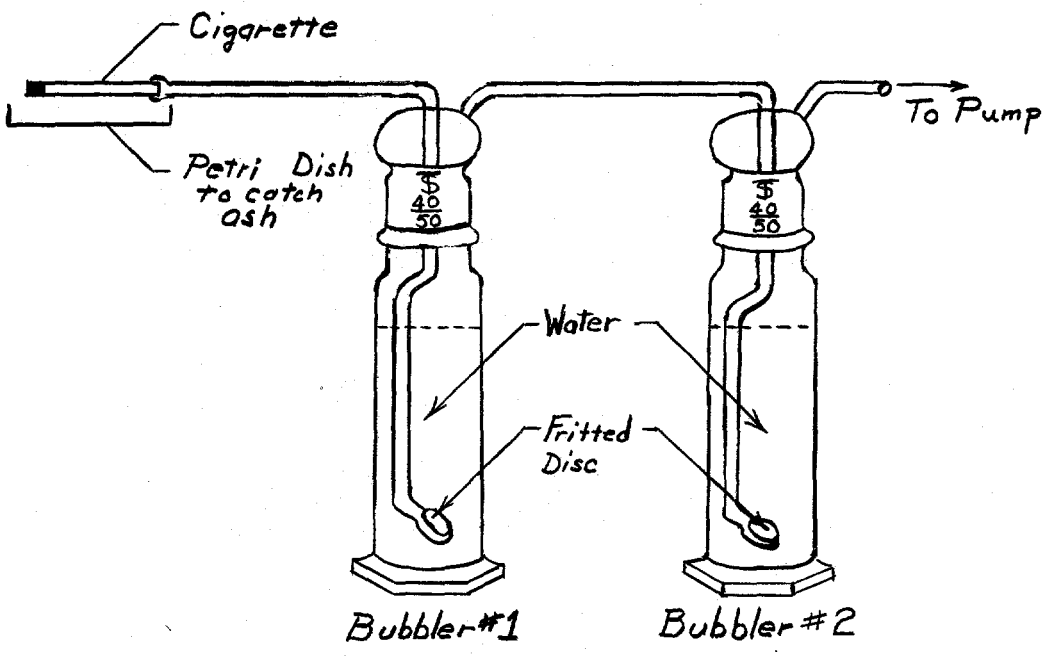
Acknowledgement

The authors wish to express their appreciation to Mr. R. E. Greene of the K-25 Laboratory Division for the preparation of the contaminated cigarettes and for the performance of the chemical analyses involved in this study.



Filtering with Filter Papers

Figure 1



Bubbler Filter Arrangement

Figure 2

APPENDIX

Counting Geometries

Geometry for Hand Counts

In determining the hand counting geometry in these experiments, the hands were contaminated from a jar of finely powdered UO_2, the material was thoroughly rubbed into the palms of the hands, and the palm of each hand was monitored with a Samson meter. The hands were then washed twice with the standard K-25 hand decontamination agent*, using a small quantity of water (approximately 400 cm.^{3}) which was carefully retained and analyzed for uranium. Following decontamination, the hands were monitored with a Poppy alpha meter, capable of detecting about 20 counts/min.; in no case did any detectable contamination remain on the hands.

The ratio of the disintegration rate of the recovered material to the sum of the left and right palm counts was found to be 14.4 ± 2.5%, and accordingly 15% was taken to represent the counting geometry for the Samson. The results are tabulated in table 10.

TABLE 10

Hand Counting Geometry

Test	Hand Counts (c/min.) Left	Right	Total	Recovered U. (dis./min.)	Geometry %
1	3,250	3,250	6,500	4.47×10^4	14.5
2	7,500	8,250	15,750	7.96×10^4	19.8
3	3,250	3,500	6,750	3.17×10^4	21.3
4	4,000	4,250	8,250	13.8×10^4	6.0
5	6,000	6,750	12,750	8.04×10^4	15.9
6	4,500	4,250	8,750	9.82×10^4	8.9
Average					14.4 ± 2.5

Geometry for Cigarette Counts

In order to determine the counting geometry for the cigarettes, 12 cigarettes were contaminated by rubbing UO_2 onto the cigarette paper; each cigarette was counted whole in a laboratory type counter and was then chemically analyzed for uranium. The counting geometry as calculated from the counting rate and the known disintegration rate of the recovered material was 31.8 ± 0.8%, or approximately 30%; the results are shown in table 11.

* SBS-310, a hand cleanser manufactured by the Sugar Beet Products Company, Saginaw, Michigan.

TABLE 11

Cigarette Counting Geometry

Test	Count	Dis./Min.	Geometry %
1	59	198	29.8
2	200	624	32.1
3	108	344	31.4
4	166	698	33.3
5	227	670	33.9
6	118	384	30.7
7	599	1,890	31.7
8	887	2,716	32.6
9	889	2,464	36.1
10	1,204	3,696	32.5
11	1,035	3,124	33.1
12	822	3,404	24.1
Average			31.8 ± 0.8

Geometry for Transferable Contamination

The geometry for counting transferable activity was determined by a comparison of the counting rates obtained by means of a Samson alpha survey meter with the results obtained by extracting, plating, and counting the uranium on the samples. The results, tabulated in table 12, indicate an efficiency of 18.5 ± 1.5%, or approximately 20%.

TABLE 12

Counting Geometry for Transferable Activity

Sample	Samson Reading (c/min.)	Analysis (dis./min.)	Counting Efficiency %
1	100	1,286	7.8
2	250	1,504	16.6
3	300	1,781	16.8
4	300	1,741	17.2
5	350	2,315	15.1
6	400	1,460	27.5
7	650	3,938	16.5
8	900	5,561	16.2
9	1,500	9,716	15.4
10	1,600	7,619	21.0
11	1,900	8,034	22.8
12	2,100	7,520	28.0
13	3,000	15,534	19.3
Average			18.5 ± 1.5