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Health and Safety

TID-8206-R

A Compendium of Information for Use in CONTROLLING RADIATION EMERGENCIES

Including Lecture Notes from a Training Session at Idaho Falls, Idaho, February 12-14, 1958

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USAEC Office of Technical Information Extension
Oak Ridge, Tennessee

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ALLEN BRODSKY
G. VICTOR BEARD
Compilers and Editors

Issuance date: September 1960

Office of Health and Safety
U. S. ATOMIC ENERGY COMMISSION

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FUEL ELEMENT BURN TEST

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INTRODUCTION

For evaluating reactor hazards, the per cent of various fission products that will escape from a damaged or melted fuel element must be known. Before 1957, very little experimental information was available on which to base estimates of fission product escape. In the author's opinion, this resulted in occasional hazard estimates that assumed catastrophies beyond physicochemical possibility.

To demonstrate the behavior of a fuel element engrossed in a large fire and to provide some initial data on the percentage release of fission products to the environment, the Idaho Operations Office decided to run field tests to measure the radioactive nuclides released from fuel elements destroyed by fire. Two field tests were run at the National Reactor Testing Station:

Phase A

A 90 per cent enriched fuel element clad in stainless steel was supported in an airframe and surrounded by other reactor materials to simulate conditions of a nuclear airplane crash. The fuel element contained about 5000 curies of fission products. A pool of jet fuel underneath the airframe was ignited and the fire burned for about 2 hr. After the fire died, no activity was measurable by portable survey equipment except inside a 24-sq ft area around Ground Zero. Levels averaged 200 mr/hr at 3 ft above ground within this area. Low-activity levels were detected with air samplers and fall-out plates downwind to 5000 ft, indicating that only an extremely small fraction of the fission products had been released in this experiment. The fuel element was still intact after the fire except for one small puncture, although it had reached a temperature of about 2250°F.

Phase B

A fuel element was heated to about 5000°F by an oxygen-fed fire of thermite, steel wool, and iron filings. The fuel element containing 10,000 curies of fission products was supported upright in a cylindrical furnace and surrounded by the combustible materials. Oxygen was fed into the bottom of the furnace through a side tube near the lower part of the element. An arrangement of feeders around the fuel element dispersed the oxygen throughout the furnace at a steady rate during the burning period. The burning continued for about four minutes. Most of the fuel element was melted and dispersed within 90 seconds. Some of the molten uranium and fission products spurted out the top of the furnace in Roman candle fashion, but most of the molten element ran out the side tube to the ground.

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After the fire was out, analysis of filter samples and fall-out plates showed that ruthenium-103 and -106, cesium-137, and halogens (mostly iodine-131) were the principal activities released. These nuclides contributed greater than 50 per cent, sometimes 80 per cent, of sample activities. Only a minor amount of the activity released (less than 2 per cent) was strontium-90. Assuming that 100 per cent of the cesium, ruthenium, and iodine content of the fuel element had been released in the fire, it was estimated that not more than 10 per cent of the fission product activity had been released.

Measurements of gamma radiation from the fuel element, before and after burning, indicated that the per cent of fission products released was probably much less than 10 per cent. Even though the molten element was spread on the ground after the fire, measurements at several places in the field indicated almost the same radiation levels that were obtained when the element was intact. Reductions at other points could be attributed to absorption by the terrain. Fission product samplers indicated that practically all of the fission products had deposited within a distance of 2000 ft, and a great majority of the material had deposited within 300 ft. These results were obtained with 15-mile-per-hour winds varying in direction to within about 45 degrees. An inversion condition up to several hundred feet and the shifting winds caused the loss of much of the data that instruments had been set up to obtain. However, the main objectives of the experiment were accomplished.

Further details and discussion are given in the sections below.

PROCEDURE

Phase A — Airframe Crash Mock-up

Five trials were run without the element or airframe in place to determine optimum conditions for heating the fuel element. The experiment was then set up as follows: A 90 per cent enriched fuel element containing approximately 5000 curies of 70-day-old fission products was supported by a four-legged stand. The stand was designed to keep the element in fixed position thoughout the experiment. This would have allowed immediate estimates of fission product release to be made from gamma dose-rate measurements. (Unfortunately, in the final assembly a brass nut was mistakenly substituted for a damaged steel one and the support collapsed. This prevented an early estimate of results by gamma measurements.)

The fuel element was surrounded by other reactor materials and a section of a real airplane fuselage to simulate conditions of an airplane crash. The skin of the airframe was made of magnesium, and the supporting members were aluminum. Holes were put in the fuselage to enhance burning. The entire assembly was placed above a teardrop-shaped pool of jet fuel. The teardrop shape had been suggested by trials to keep the fuel element in the hottest part of the flame under expected wind conditions. Trials had shown also that thermite ignition of the jet fuel was required. All experimental conditions were checked before the fire was begun but the brass nut was overlooked.

The fuel was ignited at 1419 on March 20, 1957, and the fire burned until 1615. Automobile tires placed above the fuel element provided a dense black smoke trajectory that could be located visually. Within six minutes, the brass nut on the fuel-element support melted, and the element was dropped onto a platform slightly above the burning jet fuel. However, it was later found that the element had remained in the hottest part of the flame and had reached a temperature of 2250°F, about 100 degrees higher than any temperature obtained in the dry runs.

The field instruments for measuring fission product release consisted of portable survey instruments for walk-in measurements, high-volume air sampler with MS-2133 filter paper, fall-out papers (1 sq ft of surface area) on stands 18 in. above ground level, and electrostatic precipitators and millipore filters for collecting particles for particle-size measurements. Blimps tied to trucks contained some of the air sampling equipment for portability.

Meteorological data were obtained from a network of stations. Winds up to 6000 ft, as well as surface winds, were obtained using balloon ascents and tower instruments. The vertical rise and spread of the plume from Phase A were measured by pairs of theodolites on each side of the plume. Two sky scanners (collimated scintillation detectors) were operated 2000 ft downwind to detect radioactive material passing overhead.

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Dutch rabbits were positioned in a network out to one mile from the airframe.

Further details of these measurements are given in References 101 to 103. Also, an unclassified motion picture[104] has been prepared, giving a view of the general procedures and results of these experiments.

Phase B—Oxygen-Furnace Meltdown

In the Phase B burning experiments, a 10,000-curie element was melted in a furnace designed to attain a temperature of 5600°F. The fuel element was loaded in upright position into a cylindrical furnace lined with 3 in. of magnesia. The element was surrounded by $9\frac{3}{4}$ lb of thermite, 2 lb of steel wool, $1\frac{3}{8}$ lb of galvanized iron filings, and 6 squid ignitors. Ten preliminary mock-ups had determined a design that would ensure the melting of the element. Oxygen was fed from a 600-lb gas cylinder through a pipe into the bottom of the furnace and was dispersed throughout the furnace by feeders to assure maximum and uniform heating of the fuel element.

At 1847 on March 20, 1957, the furnace was ignited and it burned for about $1\frac{1}{2}$ min. The entire fuel element was melted, most of the melt running out the bottom of the furnace onto the ground and some of it sputtering out the top of the furnace. Despite careful planning, the first puff of smoke from the furnace went sailing in a more northerly direction than the rest of the smoke. Small amounts of activity were detected from this first puff by air monitors at the Naval Reactor Facility (NRF) 5 miles away. The major part of the fumes, however, were directed within a quadrant of 45°, intersecting some of the sampling stations.

The same detection methods were used in Phase B as in Phase A. A fresh change of filter papers and a new set of rabbits completed preparations for detection in Phase B.

RESULTS

Again, we refer to References 101 to 104 for complete details. This report presents a summary of the essential information.

Phase A—Airframe Crash Mock-up

1. *Original Fission Product Content.* The activities of this element were calculated to be about 5000 curies, assuming an operating time of 120 hr and a cooling time of 70 days (Table 1).

2. *Final Condition of the Element.* Slides are available* showing the final condition of the fuel element.[105] Although temperatures up to about 2250°F were attained, the element was intact after the experiment except for one small triangular puncture of the stainless steel cladding. The element was found to have remained in the area of the jet fuel pond designed for maximum temperature. Flames had surrounded the element for almost 2 hr. After the experiment, the element was pried loose from a mass of resolidified magnesium and aluminum. It appeared that little magnesium or aluminum had actually burned during the experiment.

3. *External Gamma Readings.* Isodose lines were plotted before and after the fire.[106] The large decrease in dose rate at some points of the terrain at first gave the impression that there had been about a 50 per cent release of fission products. However, further measurements gave readings in some areas that were almost as high as the initial readings, and inspection of the debris showed that the element support had collapsed. Thus the lower gamma readings were attributable to shielding by the terrain. The fact that some of the gamma readings were about the same indicates that only a very small fraction of the fission product activity was released. The collapse of the support prevents a more accurate estimate of the fission product release from gamma dose-rate measurements.

4. *Meteorological Conditions.* Since the fuel element did not burn and there was a very small release of radioactivity, the experiments did not determine whether or not most fission products released in such a fire would follow the smoke trail. Detailed measurements of wind

*Not presented with this paper.

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TABLE 1—FISSION PRODUCT COMPOSITION, PHASE A*

Nuclide	Fraction	Curies	Half life
Nb^{95}	0.18	900	35 days
Zr^{95}	0.12	600	65 days
Sr^{89}	0.11	550	53 days
$Sr^{90}-Y^{90}$	0.002	10	19 years
Y^{91}	0.11	550	61 days
Ce^{141}	0.10	500	33 days
$Ce^{144}-Pr^{144}$	0.05	250	280 days
Ru^{103}	0.06	300	40 days
Rh^{103}	0.06	300	54 minutes
Ru^{106}	0.005	25	1 year
Cs^{137}	0.002	10	33 years
$Ba^{140}-La^{140}$	0.06	300	12 days
Pr^{143}	0.03	150	14 days
Nd^{147}	0.006	30	11 days
I^{131}	0.005	25	8 days
Xe^{133}	0.004	20	5 days
Te^{129}	0.006	30	33 days
Miscellaneous plus error	0.09	450	
Total	1.00	5000	

*NOTE: Based on 20 Mw elements at 120 hr operation plus 70 days immediate decay. Assuming a gamma energy of 0.7 Mev and a gamma "curie" content of 2500, the radiation field would be 12,000 r/hr at 1 ft from a point source.

speeds and direction are given in Reference 102. Reference 110 shows the sector of possible contamination and the most probable path of the plume as calculated from mean wind speeds and directions. The times given on the trajectory show when the plume arrived at each perimeter, assuming material was first emitted at 1415 MST. The slide shows that the plume traveled about 25° north of the sampling sector most of the time.

The top of the cloud rose to a measured mean height of 250 ft at 1000 ft downwind, and to 675 ft at 4000 ft downwind. The bottom of the cloud was at mean heights of 65 ft and 160 ft at 1000 ft and 4000 ft, respectively. This shows that the upper winds were more influential than the lower winds in the movement of the cloud. The 15-min average wind directions at 250-ft altitude, at point CF^{110} from 1415 to 1600 MST, ranged from 200 to 218° (coming from the southwest); the average wind velocities were 8 to 12 miles per hour. The 20-ft altitude winds ranged from 200 to 210° at 13 to 14 miles per hour. Thus the cloud moved 20 to 35° to the northwest of the sampling sector most of the time, but short-lived direction changes did bring the cloud directly over the sampling sector at times.

The vertical temperature stratification during the burning period showed temperature decreases of 3 to 4°F from ground to 250 ft, indicating optimum diffusion conditions for this phase. See Table 2 for temperature measurements from 1400 to 2400 MST.

5. *Environmental Measurements.*[101] After the element had been removed, surveys showed that no contamination levels above background could be detected with portable monitoring instruments except within an area of about 24 sq ft at the test location. Here the readings averaged 200 mr/hr at 3 ft above ground.*

High-volume air samples and fall-out plates located downwind produced some low-level activities that were measurable by radioautographic and analytical methods. No sample beyond 5000 ft gave results above background. Reference 109 presents all fall-out data from Phase A.

6. *Animal and Vegetation Samples.* Dutch rabbits were exposed to inhalation of material at sampling arcs 100, 300, 500, and 1000 ft from Ground Zero on both sides of the 55° north-

*EDITORS' NOTE: An infinite area source of 1 $\mu c/m^2$ of fission products gives 10.6 $\mu r/hr$ at 3 ft. On this basis an average reading of 200 mr/hr over 24 sq ft would indicate a deposition of about 0.1 curie.

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TABLE 2—VERTICAL TEMPERATURE VARIATION AS A FUNCTION OF TIME

(15-Minute Intervals, March 20, 1957)

Time (MST)	5 ft	100 ft	250 ft
1400	52.4	49.9	49.0
1415	55.4	50.6	49.9
1430	53.5	51.0	50.3
1445	54.4	51.2	50.3
1500	53.0	50.5	49.8
1515	53.5	50.6	50.0
1530	53.9	51.0	50.1
1545	54.9	51.1	51.0
1600	53.4	51.0	50.1
1615	54.9	52.1	51.0
1630	53.2	51.2	50.4
1645	53.8	51.6	50.5
1700	52.6	51.3	50.2
1715	52.1	51.0	50.0
1730	51.9	51.0	50.0
1745	51.5	50.6	50.0
1800	51.0	50.4	49.8
1815	50.5	50.0	49.5
1830	49.3	49.2	49.1
1845	47.6	48.5	48.6
1900	47.0	48.0	48.5
1915	45.0	47.6	47.6
1930	45.0	47.9	48.1
1945	45.0	46.5	46.7
2000	43.7	45.2	46.1
2015	44.1	44.9	45.8
2030	43.8	44.3	46.5
2045	43.2	44.1	47.1
2100	42.0	43.5	46.5
2115	42.2	45.6	45.6
2130	42.4	45.5	45.9
2145	42.9	46.2	46.2
2200	42.5	46.7	46.5
2215	43.1	47.0	46.5
2230	43.7	47.0	47.0
2245	44.2	47.0	46.9
2300	42.6	44.4	46.9
2315	41.5	44.4	46.6
2330	39.4	44.9	47.0
2345	40.6	43.0	46.1
2400	39.0	41.5	45.4

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TABLE 3—FISSION PRODUCT COMPOSITION, PHASE B*

Nuclide	Relative yield (activity)	Half life
Kr^{85}	0.3	10 years
Sr^{89}	4.8	53 days
Sr^{90}	5.9	20 years
Y^{90}	5.9	65 hours
Y^{91}	5.9	61 days
Zr^{95}	6.4	65 days
Nb^{95m}	0.06	90 hours
Nb^{95}	6.4	35 days
Ru^{103}	2.9	40 days
Rh^{103m}	2.9	54 minutes
Ru^{106}	0.4	365 days
Rh^{106}	0.4	30 seconds
Te^{127m}	0.06	90 days
Te^{127}	0.06	9 hours
Te^{129m}	0.34	33 days
Te^{129}	0.34	72 minutes
I^{131}	2.9	8 days
Xe^{133}	6.5	5 days
Cs^{137}	5.9	33 years
Ba^{137m}	5.4	3 minutes
Ba^{140}	6.3	13 days
La^{140}	6.3	40 hours
Ce^{141}	6.0	32 days
Pr^{143}	6.2	14 days
Ce^{144}	6.1	280 days
Pr^{144}	6.1	18 minutes
Nd^{147}	2.6	11 days
Pm^{147}	2.6	2.6 years

*Based on 6.16×10^{21} fissions and immediate 250-day cooling. Calculated from individual nuclide properties.

east sampling line.[110] Three rabbits were on the 100-ft arc, four each on the 300-, 500-, and 1000-ft arcs. Each rabbit was 2½ ft above ground and facing Ground Zero. None of the rabbits exposed on Phase A showed significant activity in the lungs or on the fur of the head.

Radioautographs of sagebrush on the 300-, 500-, and 1000-ft arcs gave no indication of an increase in radioactivity after Phase A.

Phase B—Oxygen-Furnace Meltdown

1. *Original Fission Product Content.* Table 3 presents the calculated fission products content of the Phase B element, totaling about 10,000 equivalent curies of beta and gamma activity. The activities of this element are based on 6.16×10^{21} fissions and immediate 250-day decay.

2. *Final Condition of the Element.* The entire fuel element melted and ran out the bottom of the furnace to the ground. Part of the element sputtered out the top of the furnace to the immediate area, most of the material remaining within 50 ft. The element was melted within 1½ min and the fire was over in about 4 min at 1851 MST. The maximum temperature was estimated to be about 5000°F.

The radiation level from the fuel element dispersed on the ground was 1.25 r/hr at 40 ft, compared to readings before the experiment of 2.1 r/hr at 40 ft from the element in the furnace, and 3.2 r/hr at 80 ft from the unshielded element hanging just above the furnace.

3. *External Gamma Readings.* References 111 and 112 show isodose curves taken before and after the fire and radiation survey levels around the immediate test area. The levels at some distant points in Reference 111 were almost the same after the fire as before the fire.

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This indicates that only a small fraction of the fission product activity was released beyond 50 ft from the furnace.

4. *Meteorological Conditions.* By the time Phase B was ignited (1847 MST), a temperature inversion had set in as shown in Table 2. The wind had shifted from the former 55° angle to an average of about 31°, which caused the trajectory to miss all sampling stations except Numbers 109 and 110 (Ref. 109). The trajectory was calculated from wind observations as described in Ref. 102, and is shown in Ref. 113.

The 20-ft winds at the test site for the first two 15-min periods after 1846 MST averaged 7 miles per hour from 215° and 6 miles per hour from 210°, with a total swing from 195 to 235°. This shows that just downwind of the test site, the cloud moved 20 to 25 degrees to the northwest of the center line of the sampling sector. The vertical temperature variation had changed to an inversion condition, with temperature increases of 1 to 2 degrees Fahrenheit from the ground to the 250-ft level. This inversion prevented the cloud from rising to higher levels and gave poor diffusion conditions.

Thus the smoke stayed low and remained roughly within a 25° plume along the trajectory, except for the first puff of smoke from the furnace. This initial puff trailed slightly to the west of the later trajectory and carried a small amount of activity to the NRF facility 5 miles north.

The two scintillation-type sky scanners, operated at 2000 ft downwind and 500 ft off the sampling area center line, could not be tilted low enough to detect the unexpected trajectory. To be detected by the western-most scanner, the 211° plume would have had to rise above 1000 ft.

None of the blimps were in a position to get a sample, since the trajectory was too low and out of their paths. This was disappointing, since great pains had been taken to plan the experiment. Meteorological conditions had been studied in advance and ten thousand curies were used based on the experience that under average conditions a release of 1000 curies per mile will yield easily measurable activity out to 10 miles. Nevertheless, some activity did deposit on Stations 109 and 110 of the ground network, allowing an analysis of the type of fission products carried off in the plume.

5. *Environmental Measurements.*[101,103] Reference 112 shows the results of the radiation survey by portable instruments. These measurements, together with Ref. 111, show that most of the fission products remained in the molten material that was spilled on the ground near the furnace.

Field surveys were made with Geiger-Müller survey meters, supplemented by a deep-well counter for measuring vegetation samples. Measurements at Stations 109 and 110 were as follows:

	Distance from furnace, ft	Hi-volume air sampler paper, counts per minute	Fall-out paper, counts per minute
Station 109, 31° east of north	450	1×10^7	-
Station 110, 33° east of north	550	3×10^6	3.5×10^5

Surveys indicated that fall-out had occurred in significant amounts along the 31° trajectory out to 2000 ft. Beyond 2000 ft, ground measurements were not significant. Reference 114 gives intensity readings and vegetation activity readings along the 31° radial. Table 4 shows the Geiger-Müller readings and vegetation activities along perpendiculars to the 31° radial.

The only activity detected beyond 2000 ft that could be attributable to Phase B was that obtained at NRF from the first puff (as mentioned previously); and a small increase in radioactivity on an air monitor at Reno Ranch, about 34 miles from the test site. At 1925 MST, air monitors inside and outside the main NRF building showed a sharp increase in activity by a factor of ten, remaining above background for about 40 minutes. Filter samples removed from air collectors in and out of the main building indicated air concentrations of 16 to 21 disintegrations per minute per liter from 1940 to 1958 MST, and 1.5 disintegrations per minute per liter outside the main building at 2018 MST.

An autoradiograph of the sample tape from the air monitor at Reno Ranch confirmed the collection of small amounts of particulates from about 2115 to 2230 MST.

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TABLE 4—GEIGER-MÜLLER AND VEGETATION READINGS, PHASE B

(A—Geiger-Müller readings mr/hr; B—vegetation c/m/g)

	550 ft		750 ft		1000 ft		2000 ft		3000 ft		5000 ft	
	A	B	A	B	A	B	A	B	A	B	A	B
500											0.025	411
480									0.03	30		
460												
440												
420									0.035	25		
400							0.035	30			0.02	191
380												
360							0.03	30	0.03	35		
340												
320							0.03	40				
300									0.03	110	0.03	200
280							0.045	40				
260												
240							0.03	100	0.03	80		
220												
200					0.04	78	0.02	45			0.03	126
180	0.06				0.04	163			0.03	120		
160	0.04		0.05	145	0.04	90	0.04	40				
140	0.07		0.04	150	0.05	160						
120	0.04		0.06	45	0.04	59	0.035	41	0.035	150		
100	0.04		0.07	30	0.05	128					0.045	81
80	0.08		0.07	130	0.06	488	0.04	110				
60	0.1	345	0.09	520	0.12	1038			0.035	450		
40	0.2	2248	0.16	1500	0.06	2943	0.05	390				
20	0.4	7350	0.6	4380	0.3	3780						
Center	0.6	8608	0.7	4260	0.5	3840	0.07	870	0.04	400	0.05	115
20	0.5	2220	0.6	4260	0.5	580						
40	0.4	531	0.16	440	0.1	426	0.065	470				
60	0.1	458	0.09	220	0.09	301			0.05	300		
80	0.04	74	0.2	70	0.06	129	0.1	430				
100	0.2	152	0.11	15	0.04	75					0.015	117
120	0.04		0.07	40	0.05	14	0.04	220	0.045	740		
140			0.07	100	0.05	158						
160			9.0	110	0.06	31	0.04	100				
180					0.04	71			0.08	220		
200					0.04	73	0.035	60			0.03	77
220												
240							0.04	90	0.04	90		
260												
280							0.035	80				
300									0.035	50	0.025	61
320							0.035	40				
340												
360							0.03	41	0.03	80		
380												
400							0.03	25			0.03	80
420									0.035	35		
440												
460												
480									0.04	80		
500											0.03	65

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Laboratory analyses were done on the air sampler filter papers of Stations 109 and 110. These were the only stations of the sampling network that collected activities sufficient for analysis. The filter papers were 4-in. diameter MSA 2133 type, which had sampled air at about 4 cu ft per minute pulled by Motoair pumps. Station 110 also had a sticky-paper fall-out tray.

Gamma spectra of the filter papers and the fall-out paper are presented in Reference 103. The spectra of the filter papers from Stations 109 and 110 were identical, showing peaks due to I^{131}, Ru^{103}, Ru^{106}, and $Cs^{137}-Ba^{137}$. The fall-out paper showed peaks due to these isotopes, plus peaks at 0.16 Mev and 0.76 Mev. In addition, filter paper samples from the NRF facility showed $Cs^{137}-Ba^{137}$, and Ru^{103}, Ru^{106} as the principal gamma emitters. Thus the time of collection and the spectra indicate that the initial puff from Phase B was detected by the NRF air monitors.

TABLE 5—ANALYSIS OF FILTER PAPERS, PHASE B

Constituents analyzed	Activity on total paper (dis/min)		Per cent of total activity	
	Station 109	Station 110	Station 109	Station 110
I^{131}	-	-	1-3*	1-3*
$Ru^{103,106}$	3.2×10^7	8×10^6	18	17
$Cs-Ba^{137}$	4×10^7	1×10^7	22	21
Sr, Ba fraction	4×10^6	-	2	-
Rare earths	2.5×10^6	-	1-2	-
Alpha activity	$< 8 \times 10^2$	8×10^2	0	-
Unidentified	9.6×10^7	-	53	-
Total activity	1.8×10^8	4.7×10^7	100	100

*Estimated from gamma spectra.

Samples of the filter papers were analyzed by radiochemical procedures, and the fall-out paper was saved for autoradiographs and particle-size studies. After appropriate chemical separations, beta end-window counting, and corrections for counting efficiency and aliquot factor, the analyses were found as given in Table 5. The principal activities were from ruthenium and $Cs^{137}-Ba^{137}$, each on the order of 20 per cent of the beta activity. Small percentages of I^{131}, strontium-barium, and rare earth activity were present, with about 53 per cent of the activity remaining unidentified. The total activities on the filter papers were 4.7×10^7 disintegrations per minute at Station 11 and 1.8×10^8 disintegrations per minute at Station 109.

By referring to Tables 4 and 5, the maximum amount of fission products released is estimated to be about 10 per cent. However, as mentioned above, gamma radiation survey readings indicate that a much smaller fraction than this was released, probably much less than 10 per cent.

The material collected at Stations 109 and 110 was extremely fine—no particles could be detected. On the 300-ft arc, the ecologists found deposits that were either extremely fine particles or gases. At 500 ft, large spots were found indicating that some particulate matter had deposited.

6. *Animal and Vegetation Samples.*[106] Dutch rabbits were located along arcs at 300, 500, 1000, and 2000 ft from Ground Zero. Only the outermost specimens on the northwest edge of the sampling sector showed significant activity. These were the specimens 100 ft northwest of the 55° radial on the 300-ft arc; 175 ft northwest on the 500-ft arc; 330 ft northwest on the 1000-ft arc; and 560 ft northwest on the 2000-ft arc. The count rates as measured in a well-type scintillation counter are given for several total organs of these animals in Table 6.

The samples adjacent to each of the above showed less than 10 per cent of these activities, and were at background along the 2000-ft arc.

Six wild jack rabbits collected about 2000 ft downwind of the test area 36 hr after the burning showed small amounts of contamination. Stomach contents of two were 2000 counts per minute and 7000 counts per minute—compared with a background of about 1600 counts per minute. The fur of one had been increased from a background of about 500 counts per minute

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to 1100 counts per minute; the fur of another contained 14,000 counts per minute after the experiment. The lungs of one had increased from 500 counts per minute background to 1600 counts per minute. In no case did muscle or liver show any increase.

Radioautographs of sagebrush leaves collected after Phase B show traces of radioactivity at the 300- and 500-ft arcs. The activity on the leaves at the 300-ft arc seemed generally diffused over the entire leaf surface, while that at 500 ft occurred as single hot spots.

TABLE 6—ACTIVITY IN RABBITS, PHASE B

	Activity in total counts per minute			
	300-ft arc	500-ft arc	1000-ft arc	2000-ft arc
	100 ft NW of 55°	175 ft NW of 55°	330 ft NW of 55°	560 ft NW of 55°
Fur of scalps and ears	73,000	45,000	26,000	400, slightly above background
Lungs	4,700	4,400	4,600	Background

CONCLUSIONS

The Phase A experiment showed that under conditions approximating the greatest possible heating of a stainless steel clad fuel element in an airplane crash, only a small percentage of the 5000-curie fission products (probably less than a few tenths per cent) was released to the environment. Most of this activity was deposited in a small (24-sq ft) area near the test site. Very little activity was detected outside of this area, and none beyond 5000 ft.

In the Phase B experiment, a 10,000-curie fuel element was completely melted down within $1\frac{1}{2}$ minutes, reaching temperatures around 5000°F. The fractional activity released was estimated from field measurements and filter paper analyses to be a maximum of 10 per cent, probably much less. About 40 per cent of the activity found on air filters was Ru^{103}, Ru^{106}, and $Cs^{137}-Ba^{137}$. About 1 to 3 per cent was I^{131}, and 2 per cent or less was in the Sr–Ba fraction.* Most of the activity deposited was within 300 ft, and practically all was within 2000 ft of the burning site.

Although all of the data hoped for were not obtained, the major objectives of these experiments were accomplished—to demonstrate that fractional release of fission products from fuel elements subjected to fire would probably be much less than some previous hazard estimates had assumed. A convenient summary of other measurements of fission product release from nuclear fuels is given in Ref. 107. Other information is available in unclassified Refs. 115 to 126 and 177.

The results of fission product release experiments to date,† as well as the field tests described here, are instructive. Further full-scale field tests, as well as laboratory experiments, are needed to better define the probabilities and conditions of fission product release from fuel elements subjected to heat and destruction.

*EDITORS'NOTE: A recent report[177] concludes that 30 per cent of the cesium and about 1 per cent of the strontium was released in a meltdown experiment. Iodine was found to be the only aerosol that had more than 5 per cent penetration through pleated filters.

†April 1959.

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REFERENCES

1. Alvin F. Meyer, Jr., "Handbook of Peacetime Nuclear Accidents," October 1, 1958, Office of the Surgeon, HQ, Strategic Air Command, Offutt Air Force Base, Nebraska.
2. M. E. Cassidy, R. E. Graveson, and H. D. LeVine, "HASL Aerial Survey System," Report NYO-2071, New York Operations Office, July 29, 1957.
3. F. J. Davis and P. W. Reinhardt, "Instrumentation in Aircraft for Radiation Measurements," Nuclear Sci. and Eng. 2: 713-727 (1957).
4. H. Blatz, "Alpha Contamination from Radium (surface, air, and breath)," in Proceedings of the Health Physics Conference, Idaho, 1952.
5. R. K. Dickey, L. B. Silverman, and M. L. Griswold, "Beta Skin-Dose Measurements by Specially Designed Film-Pack Dosimeters," Report WT-1178A, University of California at Los Angeles, May 1957.
6. R. L. Steach, "A Bibliography of Reactor Hazards," Report HW-32630, Hanford Works, Aug. 2, 1954. (Classified).
7. L. M. Beacham, Jr. et al., "Civil Defense Information for Food and Drug Officials," DHEW, Food and Drug Administration, Washington 25, D. C., December 1956.
8. H. F. Henry et al., "Studies in Nuclear Safety," Report K-1380, Oak Ridge Gaseous Diffusion Plant, August 1958.
9. A. D. Callihan et al., "Nuclear Safety Guide," Report TID-7016, Los Alamos Scientific Laboratory, August 1956.
10. "Decontamination," Report TM3-220, Departments of the Army and Air Force, October 1953.
11. H. Nishita and K. H. Larson, "Summary of Certain Trends in Soil-Plant Relationship Studies of the Biological Availability of Fall-out Studies," Report UCLA-401, University of California, Los Angeles, July 28, 1957.
12. J. L. Dick, W. R. Hurdlow, and E. M. Hippeli, "Safe Levels of Contamination from Fission Products," Report AFSWC-TN-56-2, Air Force Special Weapons Center, April 27, 1956.
13. G. M. Dunning, "Criteria for Establishing Short Term Permissible Ingestion of Fallout Material," Am. Ind. Hyg. Assoc. 19: 2 (April 1958).
14. J. J. Fitzgerald and C. G. Detwiler, "Optimum Particle Size for Penetration Through Millipore Filters," A.M.A. Archives of Industrial Health 15: 3-8 (January 1957).
15. "Collection Efficiency of Air Cleaning and Air Sampling Filter Media," Am. Ind. Hyg. Assoc. 16: 2 (June 1955).
16. A. H. Booth, "A Method of Calculating Fission Gas Diffusion from UO_2 Fuel and its Application to the X-2-f Loop Test," Report CRDC-721, Atomic Energy of Canada, Ltd., September 1957.
17. "General Health Physics," Report IGRL-IB/R-21, United Kingdom Atomic Energy Authority, September 1957.
18. R. C. Chadwick and A. C. Chamberlain, "The Maximum Permissible Level of Iodine-131 over Grassland," Report AERE-HP/M-24, Atomic Energy Research Establishment, May 28, 1951.
19. Harry Wexler et al., "Meteorology and Atomic Energy," Report AECU-3066, U. S. Weather Bureau, July 1955.

1187906

20. G. W. C. Tait and W. F. Merritt, "Emergency Radiation Monitoring of Drinking Water," Report CRHP-733, Atomic Energy of Canada, Ltd., October 1957.
21. H. Goldstein and J. E. Wilkins, Jr., "Calculations of the Penetrations of Gamma Rays," Report NYO-3075, Nuclear Development Associates, Inc., June 30, 1954.
22. S. Glasstone (Ed.), "The Effects of Nuclear Weapons," U. S. Department of Defense, 1957.
23. "Maximum Permissible Radiation Exposures to Man," Radiology 68: 260 (1957).
24. C. R. McCullough, "Safety Aspects of Nuclear Reactors," D. Van Nostrand Company, Inc., Princeton, N. J., 1957.
25. F. C. Brooks et al., "Radiological Defense Planning Guide," Report TOI-58-26, Technical Operations, Inc., July 31, 1958.
26. Simon Kinsman (Comp. and Ed.), "Radiological Health Handbook," Environmental Health Handbook, Report PB-121784, Robert A. Taft Sanitary Engineering Center, January 1957.
27. F. P. Cowan and J. B. Kuper, "Exposure Criteria for Evaluating the Public Consequences of Catastrophic Accidents in Large Nuclear Plants," Health Physics 1(1) (June 1958).
28. G. W. C. Tait and W. F. Merritt, "Emergency Radiation Monitoring of Drinking Water," Health Physics 1 (September 1958).
29. C. R. Phillips, H. G. Guyton, and H. M. Decker, "Evaluation of Eight Common Household and Personal Items for Emergency Use as Respiratory Protective Expedients," Physical Defense Division, Fort Detrick, Frederick, Maryland, October 1958.
30. G. M. Dunning and John A. Hilcken (Eds.), "The Shorter-Term Biological Hazards of a Fallout Field," Report M-6637, U. S. Atomic Energy Commission and Armed Forces Special Weapons Project.
31. J. Moteff, "Fission Product Decay Gamma Energy Spectrum," Report APEX-134, General Electric Company.
32. E. P. Cronkite, V. P. Bond, and C. L. Dunham (Eds.), "Some Effects of Ionizing Radiation on Human Beings," Report TID-5358, Naval Medical Research Institute, Naval Radiological Defense Laboratory, and Brookhaven National Laboratory, July 1956.
33. K. Z. Morgan, W. S. Snyder, and M. R. Ford, "Maximum Permissible Concentration of Radioisotopes in Air and Water for Short Period Exposure," in Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Vol. 13, P/79, p. 139, United Nations, New York, 1956.
34. Richard J. Smith (Comp.), "Reactor Safety," Report TID-3073, Technical Information Service Extension, May 1958.
35. C. K. Beck et al., "Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants," Report WASH-740, Division of Civilian Applications, AEC, March 1957.
36. A. G. Hoard, M. Eisenbud, and J. H. Harley, "Annotated Bibliography on Fall-out Resulting from Nuclear Explosions," Report NYO-4753, New York Operations Office, September 1956.
37. "Accidental Radiation Excursion at the Y-12 Plant, June 16, 1958," Report Y-1234, Union Carbide Nuclear Company, July 28, 1958.
38. K. Z. Morgan, "Emergency Permissible Levels," Fourth Annual Meeting on Bioassay and Analytical Chemistry, University of Rochester, November 3–4, 1958.
39. A. P. Talboys and E. C. Spratt, "An Evaluation of Laundering Agents and Techniques Used in the Decontamination of Cotton Clothing," Report NYO-4990, Johns Hopkins University, Mar. 1, 1954.
40. "Maximum Permissible Internal Dose of Radionuclides: Recent Changes in Values," Nuc. Sci. and Eng. 1: 477 (December 1956).
41. W. J. Bair, "Calculations of MPC in Air (MPC_{air}) for Ru^{106} Particles," Report HW-52287, General Electric Company, October 1, 1957.
42. E. C. Albritton (Ed.), "Standard Values in Nutrition and Metabolism," Report WACD 52-301, December 1953.
43. J. W. Healy, "Calculations of Environmental Consequences of Reactor Accidents," Report HW-54128, General Electric Company, December 11, 1957.
44. J. B. Hursh, "Suggested Urinary Tolerance Levels for Enriched Uranium," Report UR-515, University of Rochester, Dec. 26, 1957.

1187907

45. F. E. Frost, "Radioactive Waste Processing and Disposal Bibliography," Report UCRL-4891, University of California Radiation Laboratory, May 6, 1957.
46. "Reactor Safety Conference Held at New York City, Oct. 31, 1957," Report TID-7549 (Pt. II), American Nuclear Society, Atomic Industrial Forum, Inc., and U. S. Atomic Energy Commission.
47. "Environmental Contamination from Weapon Tests," Report HASL-42, New York Operations Office, October 1958.
48. D. F. Hayes, "A Summary of Incidents Involving Radioactive Material in Atomic Energy Activities, June 1945 through December 1955," Report TID-5360, U. S. Atomic Energy Commission, August 1956.
49. "Reactor Safety Bibliography," Report AECU-3589, Division of Reactor Development, U. S. Atomic Energy Commission, May 1957.
50. Alfred W. Klement, Jr., "A Selected List of References on Plutonium Hazards," WASH-1002, Division of Biology and Medicine, U. S. Atomic Energy Commission, Washington, D. C., 1958.
51. "Recommendations of the International Commission on Radiological Protection," Supplement No. 6, Revised Dec. 1, 1954, Brit. J. Radiol. (London) (1955); (superseded by Reference 93).
52. "Emergency Exposures to Nuclear Radiation," Federal Civil Defense Administration Technical Bulletin, TB-11-1, August 1956.
53. J. J. Fitzgerald, "Reactor Safeguards," Section 8, p. 185, Dangerous Properties of Industrial Materials, Edited by N. Irving Sax, Reinhold Publishing Corporation, New York, N. Y., 1957.
54. J. B. Hursh, S. Zizzo, and A. H. Dahl, "Use of Commercially Available Portable Survey Meters for Emergency Fission Product Monitoring of Water Supplies," Report UR-180, University of Rochester, Aug. 3, 1951; see also Nucleonics (November 1951).
55. W. E. Rothe and L. W. Tuttle, "Irradiation of the Gastrointestinal Tract of the Rat by Insoluble Beta Emitters," Report UR-529, University of Rochester, June 1957.
56. "Permissible Emergency Levels of Radiation in Water and Food," FCDA Technical Bulletin TB 11-8, December 1952; Reprinted June 1959 by Office of Civil and Defense Mobilization.
57. "Emergency Measurements of Radioactivity in Food and Water, FCDA Technical Bulletin TB 11-9, December 1952.
58. "Emergency Exposures to Nuclear Radiation," FCDA Technical Bulletin TB 11-1, July 1957.
59. "Technical Data for Civil Defense," Nucleonics (November 1951).
60. "Emergency Action to Save Lives," Catalog No. FCD I.Z:EM3, U. S. Government Printing Office, Washington, D. C., 1954, 5 cents.
61. J. O. Blomeke et al., "Uranium-235 Fission-Product Production as a Function of Thermal Neutron Flux, Irradiation Time, and Decay Time," Report ORNL-2127, Parts I and II, Oak Ridge National Laboratory, November 1958.
62. L. H. Jones, "Source Strength Information for Shielding and Stack Effluent Calculations," Report IDO-16453, Phillips Petroleum Company, October 3, 1958.
63. C. R. Schwob, "Radiological Safety in Special Weapons Accidents," Report USNRDL-TR-273, National Radiological Defense Laboratory, October 22, 1958.
64. M. E. Smith and I. A. Singer, "Diffusion and Deposition in Relation to Reactor Safety Problems," Am. Ind. Hyg. Assoc. Quarterly 18(4): 319-330 (December 1957).
65. E. Glueckauf, P. Cosslett, and R. Watts, "Removal of Radio-active Iodine from Milk," Report AERE-C/M-371, Atomic Energy Research Establishment, January 1959.
66. M. K. White (Comp.), "Hazards and Safety Measures Related to Nuclear-Powered Merchant Ships: An Annotated Bibliography of Classified Literature," Report ALI-50, Arthur D. Little, Inc., Aug. 30, 1958. (Classified).
67. H. C. Paxton et al., "Nuclear-Critical Accident at the Los Alamos Scientific Laboratory on December 30, 1958," Report LAMS-2293, Los Alamos Scientific Laboratory, February 1959.
68. H. Hurwitz, Jr., "Safeguard Considerations for Nuclear Power Plants," Nucleonics 12(3) (March 1954).

1187908

69. J. J. Fitzgerald, H. Hurwitz, Jr., and L. Tonks, "Method for Evaluating Radiation Hazards from a Nuclear Incident," Report KAPL-1045, Knolls Atomic Power Laboratory, March 26, 1954.
70. J. J. Fitzgerald, D. G. Chappell, "Graphic Aids to Estimate Nuclear Radiations Hazards," Report KAPL-1178, Knolls Atomic Power Laboratory, August 30, 1954.
71. R. E. Albert and L. C. Arnett, "Clearance of Radioactive Dust from Human Lung," A.M.A. Arch. Ind. Health 12: 99-106 (July 1955).
72. R. A. Conard and C. I. Tessmer, "Beta Radiation Lesion of the Skin," A.M.A. Arch. Dermatol. 74(6): 663-6 (December 1956).
73. E. P. Cronkite, "Treatment of Radiation Injuries," Military Med. 118(4): 328-34 (April 1956).
74. H. O. Davidson, "Biological Effects of Whole-Body Gamma Radiation on Human Beings," Report ORO-T-357, Johns Hopkins University, December 1956.
75. J. J. Fitzgerald and J. L. Flynn, "Health Problems Associated with the Civilian Reactor Problem," Report KAPL-1804, pp. 1-35, Knolls Atomic Power Laboratory, April 30, 1957.
76. W. J. Friedman, "Decontamination of Synthetic Radioactive Fallout from the Intact Human Skin," Am. Ind. Hyg. Assoc. 19(1): 15-19 (February 1958).
77. L. H. Hempelmann and J. G. Hoffman, "Practical Aspects of Radiation Injury," Ann. Rev. Nuclear Sci. 3: 369-392 (1953).
78. B. A. Stoll, "New Drugs for Irradiation Sickness," Radiology 68(3): 380-385 (March 1957).
79. "Transfusion Treatment of Radiation Disease," Brit. J. Med. 5105: 1151 (November 8, 1958).
80. "Report of The United Nations Scientific Committee on The Effects of Atomic Radiation," General Assembly, United Nations, Thirteenth Session Supplement No. 17(A/3838), New York, 1958; and Supplement, "An Approach to a General Method of Computing Doses and Effects from Fall-out," A/A C.82/INF-3, 23 July 1958. Available from International Documents Service, Columbia University Press, 2960 Broadway, New York 27, N. Y.
81. "Fission Product Formation and Decay Characteristics," Report IGRL-IB/R-29, United Kingdom Atomic Energy Authority, December 1957.
82. R. Cosway, L. A. Huard, and M. R. Zavon (Comps.), "Atomic Energy, Radiation, and the Law, A Bibliography," August 1949–September 1957. Available from Professor Richard Cosway, College of Law, University of Cincinnati, Cincinnati 21, Ohio.
83. C. D. Yaffe, D. H. Byers, and A. D. Hosey (Eds.), "Encyclopedia of Instrumentation for Industrial Hygiene," University of Michigan, Institute of Industrial Health, Ann Arbor, Michigan, 1956.
84. David Revinson, "Selected Bibliography on Analysis of Certain Radioactive Elements in Biological Materials," Report NYO-4702, New York Operations Office, Dec. 7, 1956.
85. John B. Hursh (Ed.), "Chemical Methods for Routine Bioassay," Report AECU-4024, University of Rochester, November 1958.
86. "A Summary of Transportation Incidents in Atomic Energy Activities, 1949–1956," Report AECU-3613, Safety and Fire Protection Branch, AEC, December 1957.
87. D. F. Hayes, "A Summary of Accidents and Incidents Involving Radiation in Atomic Energy Activities, June 1945 through December 1955," Report TID-5360, Safety and Fire Protection Branch, AEC, August 1956.
88. An Atomic Energy Commission Staff Paper, AEC 43/345, February 9, 1951.
89. Merril Eisenbud, "Lessons Learned from a Pyrophoricity Incident," Nucleonics 14(12): (1956).
90. "Proposed Licensing Criteria for Shipping Containers for Irradiated Fuel Elements," U. S. Atomic Energy Commission, unpublished data, 1959.
91. R. V. Batie and D. E. Patterson, "Shipping of Radioactive Materials at the National Reactor Testing Station," Report TID-7569(pp. 68-73), Idaho Operations Office, 1958.
92. "The Biological Effects of Atomic Radiation–A Report to the Public," National Academy of Sciences and National Research Council, Washington, D. C., 1956.
93. K. Z. Morgan, Committee Chairman, "Report of Committee II, International Commission on Permissible Dose for Internal Radiation, 1958 Edition," Oak Ridge National Laboratory, unpublished data. (Supersedes Reference 51.)

1187909

94. P. M. Frazier, C. R. Buchanan, and G. W. Morgan, "Radiation Safety in Industrial Radiography with Radioisotopes," Report AECU-2967, Radiological Safety Branch, AEC, November 1954.
95. G. W. Morgan, "Some Practical Considerations in Radiation Shielding," Report IDB-4, U. S. Atomic Energy Commission, Oak Ridge, Tenn.
96. Hanson Blatz (Ed.), "Radiation Hygiene Handbook," McGraw-Hill Book Company, Inc., New York, New York, 1959.
97. C. B. Braestrup, H. O. Wyckoff, and Charles C. Thomas, "Radiation Protection," 1958.
98. H. H. Rossi et al., "Protection Against Neutron Radiation up to 30 Million Electron Volts," NCRP Report, NBS Handbook 63, Superintendent of Documents, Washington, D. C.
99. D. J. Hughes and R. B. Schwartz, "Neutron Cross Sections," Report BNL-325 (2nd Ed.), Nuclear Cross Sections Advisory Group, AEC, July 1, 1958.
100. P. C. Tompkins, O. M. Bizzell, and C. D. Watson, "Practical Aspects of Surface Decontamination," Nucleonics 7(2): 42 (1950).
101. P. Griffiths et al., "Site Survey Participation in NRTS Burning Experiment," Report ICF-2132, May 1957. (Classified)
102. Harry L. Hamilton, Jr., "Meteorological Report on the Burning Experiment," Report ICF-2144, May 13, 1957. (Classified)
103. Claude W. Sill and Earl R. Ebersole, "Burning Experiment, Phase B, Analysis of Fallout Materials," Report ICF-2081, May 2, 1957. (Classified)
104. Encel Dodge, Technical Advisor, "Fuel Element Burning Experiment," U. S. Department of Agriculture, Motion Picture Service Production No. 1185-46, Rev. December 8, 1958.
105. G. V. Beard, U. S. Atomic Energy Commission, Washington, D. C., slides on the Burning Experiment, 1957. (Classified)
106. N. R. French, Idaho Operations Office, unpublished data, May 1957.
107. P. H. Wilks, "The Release of Fission Products from Reactor Fuel," Report APEX 474, General Electric Company, March 23, 1959. (Classified)
108. Slide NRTS 57-1763, Isodose Curves, Phase A. (Classified)
109. Fallout Data from Phase A (p. 16, Fig. 12, Ref. 101). (Classified)
110. Phase A Smoke Trajectory (Reference 102, p. 15). (Classified)
111. Slide NRTS 57-1767, Isodose Curves, Phase B. (Classified)
112. Slide NRTS 57-1770, Radiation Survey Results, Phase B. (Classified)
113. Phase B Smoke Trajectory (attached to preliminary meteorology report, Idaho Operations Office, USAEC).
114. GM and Vegetation Readings Along 31° Radial, Phase B (Fig. 21, Reference 101, p. 25). (Classified)
115. H. P. Himsworth, "Accident at Windscale No. 1 Pile on 10th October, 1957," Her Majesty's Stationery Office, London, November 1957.
116. H. J. Dunster, H. Howells, and W. L. Templeton, United Kingdom Atomic Energy Authority, "District Surveys Following the Windscale Incident, October 1957," A/CONF.15/P/316, Prepared for the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, September 1958.
117. G. E. Creek, W. J. Martin, and G. W. Parker, "Experiments on the Release of Fission Products from Molten Reactor Fuels," Report ORNL-2616, Oak Ridge National Laboratory, July 22, 1959.
118. B. Lustman, "Release of Fission Gases from UO_2," Report WAPD-173, Westinghouse Electric Corporation, March 1957.
119. J. M. Markowitz, R. C. Koch, and J. A. Roll, "Release of Fission Gases from Irradiated Uranium Dioxide," Report WAPD-180, Westinghouse Electric Corporation, July 1957.
120. S. J. Rodgers and G. E. Kennedy, "Fission Product Release During A Simulated Meltdown of a PWR Type Core," Report NS-200-021, Department of Scientific and Industrial Research, New Zealand, October 1958.
121. C. I. Whitman, V. Compton, and R. B. Holden, "Zone Melting of Uranium," Report SEP-179, Sylvania Electric Products Inc., June 15, 1955.
122. A. R. Gilman, "Removal of Fission Product Gases by Transient Melting," Report NMI-1167, Nuclear Metals, Inc., May 6, 1957.

1187910

123. A. M. Saul, "Pyrochemical Separation Methods: III. The Removal of Fission Products from Molten, Irradiated Uranium by Solid Oxides," Report NAA-SR-1361, North American Aviation, Inc., September 1, 1955.
124. George Wehman, "Preliminary Report Fission Products Field Release Test-I," Report IDO-12006, Idaho Operations Office, February 1959.
125. K. Low and R. Bjornerstedt, "Health Hazards from Fission Products and Fall-out, I-Products of Instantaneous Fission of U-235 with Thermal Neutrons," Arkiv Fysik, 13 (Paper 7): 85-90 (1957).
126. R. E. Baker, C. C. Gamertsfelder, and R. F. Gentzler, "First Meltdown Experiment–Final Report," Report APEX-445, General Electric Company, Jan. 2, 1959. (Classified)
127. "Report of the AEC Ad Hoc Committee on the Transportation of Radioactive Materials," Reactor Development Division, AEC, Washington, D. C., unpublished.
128. H. C. Paxton et al., "Nuclear-Critical Accident at the Los Alamos Scientific Laboratory on December 30, 1958," Report LAMS-2293, Los Alamos Scientific Laboratory, February 20, 1959.
129. Harold A. Knapp, "A Review of Information on the Gamma Energy Radiation Rate from Fission Products, and its Significance for Studies of Radioactive Fallout," Report TID-5557, Office of Operations Analysis and Forecasting, AEC, April 24, 1959.
130. R. F. Reitemeier, "Soil and Plant Relationships of Fission Products," Report TID-5558, U. S. Atomic Energy Commission, May 1959.
131. Jerome E. Dummer, Jr. (Comp. and Ed.), "General Handbook for Radiation Monitoring," Report LA-1835 (3rd Ed.), Los Alamos Scientific Laboratory, November 1958.
132. "Handling of Bodies Containing Radioactive Materials," NBS Handbook 65, 1959.
133. "Radiological Decontamination in Civil Defense," Technical Manual 11-6, prepared by the Federal Civil Defense Administration (now Office of Civil and Defense Mobilization, Washington 25, D. C.).
134. H. Goldstein, "The Attenuation of Gamma Rays and Neutrons in Reactor Shields," Division of Reactor Development, AEC, 1957.
135. Gladys White Grodstein, "X-Ray Attenuation Coefficients from 10 kev to 100 Mev," NBS Circular 583.
136. John Moteff, "Miscellaneous Data for Shielding Calculations," Report APEX-176, General Electric Company, Dec. 1, 1954.
137. R. L. Ashley, "Graphical Aids in the Calculation of the Shielding Requirements for Spent U-235 Fuel," Report NAA-SR-1992, North American Aviation, Inc., Nov. 15, 1957.
138. "Emergency Monitoring Team Training Manual," Radiological Safety Division, Reynolds Electrical and Engineering Company, Mercury, Nevada, March 1959.
139. Theodore Rockwell, III (Ed.), "Reactor Shielding Design Manual," Report TID-7004, Division of Reactor Development, AEC, March 1956.
140. W. C. Francis and L. L. Marsden, "Experimental and Theoretical Values of the Gamma Decay Dose Rate and Heating from Spent MTR Fuel Elements," Report IDO-16247, Phillips Petroleum Company, Jan. 13, 1956.
141. "Report of the Joint Program of Studies on the Decontamination of Radioactive Waters," Report ORNL-2557, Oak Ridge National Laboratory and Robert A. Taft Sanitary Engineering Center, February 1959.
142. David Spielberg and Arthur Duneer, "Dose Attenuation by Soils and Concrete for Broad, Parallel-Beam Neutron Sources," Report AN-108, Associated Nucleonics, Inc., May 1, 1958.
143. G. P. Smith et al., "Protection of Structures from Chemical, Biological and Radiological Decontamination," Report ENCR-30, Chemical Corps Engineering Command, Army Chemical Center, Maryland, June 1959.
144. Alfred W. Klement, Jr., "A Review of Potential Radionuclides Produced in Weapons Detonations," Report WASH-1024, Division of Biology and Medicine, AEC, July 30, 1959.
145. J. D. McLendon, "Accidental Radiation Excursion at the Oak Ridge Y-12 Plant-II Health Physics Aspects of the Accident," Health Physics 2(1) (July 1959).
146. Dixon Callihan and Joseph T. Thomas, "Accidental Radiation Excursion at the Oak Ridge Y-12 Plant–I–Description and Physics of the Accident," Health Physics 1(4) (March 1959).

1187911

147. G. M. Dunning, "External Beta-Doses from Radioactive Fallout," Health Physics 1(4) (March 1959).
148. Ann T. Nelms and J. W. Cooper, "U-235 Fission Product Decay Spectra at Various Times After Fission," Health Physics 1(4) (March 1959).
149. R. H. Ritchie and G. S. Hurst, "Penetration of Weapons Radiation: Application to the Hiroshima-Nagasaki Studies," Health Physics 1(4) (March 1959).
150. P. J. Barry, "Some General Considerations in Chemical Decontamination," Health Physics 1(2) (September 1958).
151. S. G. Pearsall, L. Gemmell, and A. Breslin, "Possible Health Hazards Associated with the Laundering of Radioactively Contaminated Protective Clothing," Health Physics 1(2) (September 1958).
152. G. S. Hurst, R. H. Ritchie, and L. C. Emerson, "Accidental Radiation Excursion at the Oak Ridge Y-12 Plant—III—Determination of Radiation Doses," Health Physics 2: 121 (October 1959).
153. G. A. Andrews, B. W. Sitterson, A. L. Kretchmar, and M. Brucer, "Accidental Radiation Excursion at the Oak Ridge Y-12 Plant—IV—Preliminary Report on Clinical and Laboratory Effects in the Irradiated Employees," Health Physics 2: 134 (October 1959).
154. A. L. Boni, "Rapid Determination of Mixed Beta-Gamma Radionuclides in Urine," Health Physics 2: 186 (October 1959).
155. N. I. Sax, R. J. Sherer, and R. T. Drew, "Emergency Monitoring Methods for the Determination of the Effective Bone-Seeking Fission Products in Milk," Health Physics 2: 216 (October 1959).
156. C. W. Sill and J. K. Flygare, Jr., "Iodine Monitoring at the National Reactor Testing Station," unpublished.
157. A. Brodsky, L. W. Fagg, and T. D. Hanscome, "Techniques for Using Fissionable Deposits in Neutron Measurements," Report NRL-4746, Naval Research Laboratory, April 19, 1956.
158. G. S. Hurst and R. H. Ritchie (Eds.), "Radiation Accidents: Dosimetric Aspects of Neutron and Gamma-Ray Exposures," Report ORNL-2748 (Pt. A), Oak Ridge National Laboratory, November 16, 1959.
159. Alan A. Jarrett, "Evaluation of Fallout Data," Am. Ind. Hyg. Assoc., 20(4) (August 1959).
160. S. Glasstone (Ed.), "Principles of Nuclear Reactor Engineering," D. Van Nostrand Co., Inc., N. Y., 1955.
161. S. J. Wyard, "Radioactive-Source Corrections for Bremsstrahlung and Scatter," Nucleonics 13(7) (July 1955).
162. James M. Jacobs (Comp.), "Fission Products Decay Energy," Report TID-3536, Technical Information Service Extension, September 1959.
163. William E. Bost (Comp.), "Radioactive Decontamination," Report TID-3535, Technical Information Service Extension, AEC, September 1959.
164. Raymond L. Scott (Comp.), "Criticality Studies," Report TID-3533, Technical Information Service Extension, AEC, August 1959.
165. Karl Z. Morgan, Division of International Affairs, AEC, "Immediate Evaluation of Doses from External Radiation and from Internal Contaminations in the Event of a Radiation Accident," p. 46 of "Symposium on Technical Methods in Health Physics, Risö, Denmark, May 25-28, 1959," Report TID-7577, August 1959.
166. "Shelter from Radioactive Fallout," FCDA Technical Bulletin TB 5-2, Office of Civil and Defense Mobilization, Washington 25, D. C.
167. "Effects of Nuclear Explosions Upon Drugs," FCDA Technical Report TR 11-1, Office of Civil and Defense Mobilization, Washington 25, D. C.
168. P. W. Reinhardt et al., "Procedures and Techniques for Measuring Neutron Dose with Threshold Detectors and Blood Na^{24} Counting," (preliminary draft of manual), Health Physics Division, Oak Ridge National Laboratory, 1959.
169. "Technical Information Bulletin on Atomic Weapon Accident Hazards, Precautions, and Procedures," U. S. Atomic Energy Commission—Department of Defense, Washington 25, D. C., September 30, 1958.
170. W. E. Bost et al. (Comps.), "Radioactive Fallout—A Literature Search," Report TID-3528, Technical Information Service Extension, AEC, April 1959.

1187912

171. T. G. Schleiter, "Nuclear Safety Bibliography," U. S. Atomic Energy Commission, unpublished data, August 1959.
172. G. W. Smith and D. R. Farmelo, "Gamma Ray Spectra," Nucleonics 16(2): 80 (February 1958).
173. S. Katcoff, "Fission Product Yields from U, Th, and Pu," Nucleonics 16(4): 82 (April 1958).
174. Raymond L. Scott (Comp.), "Criticality Studies," A Literature Search, Report TID-3620, Technical Information Service Extension, AEC, August 1959. (Classified)
175. R. J. Feinberg, Knolls Atomic Power Laboratory, "Design of a Neutron Analyzer for Criticality Incidents," in Semiannual Progress Report of Radiological Development Activities in Health and Physics, July-December 1958, Report KAPL-2045, September 1959.
176. R. L. Mather et al., "Gamma Radiation Field Above Fallout Contaminated Ground," Report WT-1225, October 28, 1959.
177. "Fission Products Field Release Test-I," Report NARF-59-32T, Convair, Fort Worth, Texas, September 1959.
178. T. J. Burnett, "Reactor Hazards vs. Power Level," Nuclear Sci. and Eng. 2: 382-393 (1957).
179. E. L. Christensen, "Procedures for Decontamination of Plutonium from Various Surfaces," Report LAMS-2319, Los Alamos Scientific Laboratory, April 1959.
180. "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure," NBS Handbook 69, June 1959.
181. J. H. Harley et al., "Data on the Strontium-90 Content of Milk and Other Foods During 1958," Health and Safety Laboratory, AEC, New York, May 1959.
182. "Fallout from Nuclear Weapons Tests," Hearings Before the Special Sub-committee on Radiation of the Joint Committee on Atomic Energy, Eighty-Sixth Congress, May 5, 6, 7, and 8, 1959, Volume 1, p. 290.
183. J. M. White, "Health Physics Problems Following a Reactor Accident," Am. Ind. Hyg. J. 20: 478 (December 1959).
184. E. L. Saenger, "Planning for a Radiation Accident," Am. Ind. Hyg. J. 20: 482 (December 1959).

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