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Radiation Measurements of the Effluent
from the NRX-A6 Reactor

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Radiation Measurements of the Effluent
from the NRX-A6 Reactor

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RADIATION MEASUREMENTS OF THE EFFLUENT FROM THE NRX-A6 REACTOR

By

Robert V. Fultyn

ABSTRACT

The results of studies on the effluent from the NRX-A6 EP IIIA test are presented, including work performed with large particles. Doses due to cloud passage as determined by several methods of measurement are compared. Sampling and analysis procedures and equipment are also described.

INTRODUCTION

Experimental Plan IIIA (EP IIIA) of the NRX-A6 reactor was conducted on December 15, 1967, at Test Cell C of the Nuclear Rocket Development Station, Jackass Flats, Nevada. The duration of the full power test was 60 minutes (1059 to 1159 PST); the nominal neutronic power level was 1250 MW.

Prior to the test, a limited effluent sampling array was established by the LASL Health Division Field Studio Group, H-8. Objectives of the effluent monitoring program were to determine cloud composition, measure effluent concentrations in the air, and compare doses due to cloud passage as determined by air samples, film, thermoluminescent dosimeters (TLD's), and recording Geiger-Mueller instruments.

This report presents information on the

radioactive effluent from the NRX-A6 reactor as determined from data collected by the H-8 sampling array.

AIR SAMPLING

Experiment Design.

An air-sampling network (Table I) of 29 stations on arcs 12 and 24 miles from the test cell was established for the NRX-A6 reactor test. On the 12-mile arc, 23 stations were set up and checked prior to the test, and six mobile stations were dispatched on run day to predicted downwind locations on the 24-mile arc. These sampling locations encircled the reactor except for the northwest quadrant which is most unlikely to be downwind from the test cell and where rough terrain makes sample placement and recovery impracticable.

TABLE I. NRX-A6 SAMPLING ARRAY

12-Mile Arc	24-Mile Arc
356°	
014°	
024°	
031°	
045°	
057°	
069°	
085°	
102°	
117°	
132°	
146°	
162°	
172°	
188°	
<hr/>	
203°	
211°	211°
215°	Portion of the
221°	array activated
230°	to collect samples
241°	during the reactor
251°	test.
268°	268°

Each sampling station was equipped with trailer-mounted high volume and sequential air sampling equipment and pairs of resin-coated trays. This equipment and the analytical procedures for evaluating samples are described in Appendix A.

Discussion and Results.

A strong wind was blowing toward the southwest at run time. Sampling stations were set up and operated in that sector; the 12-mile-arc samplers were turned on at 1047 PST, and the 24-mile-arc samplers were started at 1054. All trailers functioned normally except the one at 268° on the 12-mile arc which did not receive the radio signal and was started manually.

Because of rain and snow, the sampling was terminated earlier than planned. Sample recovery began at about 1335 PST with some 12-mile-arc stations running until a recovery team could reach the sampler. Filters were dampened by the precipitation.

Effluent Cloud Composition. The charcoal car-

tridge from station 221° on the 12-mile arc was selected as representative and was used to determine the composition of gaseous effluent. Isotopic composition of the particulate material was assumed to be that collected on the filter at station 215° on the 12-mile arc, and ground deposition from the reactor was represented by the deposition tray sample from station 236° on the 24-mile arc.

Table II summarizes the apparent zero-time composition of the material collected by the filter papers, charcoal cartridges, and resin-coated trays as determined by curve-stripping techniques.

TABLE II. APPARENT ZERO-TIME COMPOSITION OF SAMPLES, NRX-A6

Airborne Particulate Material	
Isotope	%
^{134}I	95.3
$^{90}\text{Sr}-\text{Y}$	2.7
^{135}I	1.5
^{133}I	0.49
^{131}I	0.063
$^{132}\text{Te}-\text{I}$	0.060
$\text{LL}^{\text{a}}_{\beta}$	0.008
<hr/>	
Airborne Gaseous Material	
Isotope	%
^{134}I	97.7
^{135}I	1.8
^{133}I	0.38
$^{132}\text{Te}-\text{I}$	0.040
^{131}I	0.035
<hr/>	
Ground-Deposited Material	
Isotope	%
^{134}I	96.0
$^{90}\text{Sr}-\text{Y}$	2.2
^{135}I	1.2
^{133}I	0.44
$^{132}\text{Te}-\text{I}$	0.065
^{131}I	0.058

^aUnidentified long-lived beta activity, probably ^{90}Sr and $^{140}\text{Ba-La}$.

Air Radioactivity Concentration. Table III presents the total dosages ($\mu\text{Ci}\cdot\text{sec}/\text{m}^3$) and deposition concentrations ($\mu\text{Ci}/\text{m}^2$). The activity has been corrected to an estimated time of cloud passage based on a wind speed of 24.0 mph. Airborne particulate dosages were calculated from data generated by the analysis of filter papers, and the airborne gaseous dosages from an analysis of the charcoal cartridges. The deposited activity per

TABLE III. MEASURED EXPOSURE DOSAGES AND GROUND-DEPOSITION CONCENTRATIONS. NRX-A6 EP IIIA

Station	Dosage ^a ($\mu\text{Ci-sec}/\text{m}^3$)			Ground Deposition ($\mu\text{Ci}/\text{m}^2$)
	Airborne Particulate	Airborne Gaseous	Total	
<u>12-mile arc</u>				
203°	5.17×10^{-1}	1.12×10^0	1.64×10^0	1.72×10^{-2}
	3.27×10^{-1}	1.41×10^0	1.73×10^0	
211°	1.54×10^2	1.01×10^2	2.55×10^2	9.44×10^{-1}
	1.50×10^2	1.04×10^2	2.54×10^2	
215°	4.31×10^2	2.95×10^2	7.26×10^2	1.92×10^0
	4.58×10^2	2.80×10^2	7.39×10^2	
221°	1.48×10^3	1.30×10^3	2.77×10^3	7.98×10^0
	1.06×10^3	1.25×10^3	2.31×10^3	
230°	1.25×10^2	3.03×10^2	4.28×10^2	3.28×10^0
	1.83×10^2	1.92×10^2	3.76×10^2	
241°	4.83×10^0	2.06×10^0	6.89×10^0	1.10×10^{-2}
	4.41×10^0	2.17×10^0	6.58×10^0	
251°	7.79×10^{-1}	6.71×10^{-1}	1.45×10^0	1.42×10^{-2}
	7.41×10^{-1}	8.02×10^{-1}	1.54×10^0	
268°	5.39×10^{-1}	9.60×10^{-1}	1.50×10^0	2.07×10^{-2}
	8.36×10^{-1}	3.50×10^{-1}	1.19×10^0	
<u>24-mile arc</u>				
211°	5.50×10^1	2.52×10^1	8.02×10^1	8.51×10^0
	8.54×10^1	4.08×10^1	1.26×10^2	
225°	7.84×10^1	2.46×10^1	1.03×10^2	9.35×10^0
	4.96×10^1	2.30×10^1	7.26×10^1	
236°	2.04×10^0	1.60×10^1	1.80×10^1	2.57×10^1
	6.23×10^0	1.75×10^1	2.37×10^1	
250°	5.17×10^{-1}	4.42×10^{-1}	9.58×10^{-1}	2.35×10^{-2}
	6.52×10^{-1}	1.85×10^{-1}	8.36×10^{-1}	
263°	5.25×10^{-1}	1.62×10^0	2.14×10^0	0.0
	5.59×10^{-1}	1.84×10^0	2.40×10^0	
268°	2.53×10^{-1}	1.02×10^0	1.27×10^0	0.0
	6.59×10^{-1}	1.51×10^0	2.17×10^0	

^aTwo air samplers were operated at each station.

unit area was determined by assuming that the ground deposition was the same in composition and magnitude as that collected on the resin-coated trays.

Dose Due to Cloud Passage. Tables IV and V show the results of calculations based on the analysis of the air samples and resin-coated trays collected during this experiment.

Cycling (Sequential) Samplers. Analysis of the sequential cycling sampler data indicated that several charcoal cartridges from inactive units contained gamma radioactivity of about 1500-2000

pCi. Therefore, cartridge activities ≤ 2000 μpCi were considered to be insignificant.

Histograms of the significant cartridge gamma activity as a function of the sampling interval are superimposed on the chart records of the gamma dose rate recording instrument (RM-11) program in Figs. 1 and 2. With the exception of station 64-230°, there is good agreement between the two systems.

From the cycling sampler system, it was assumed that the cloud arrival time was either

TABLE IV. CLOUD PASSAGE EFFECTS
NRX-A6 EP IIIA

Station	Whole-Body Dose Due to Cloud Passage (rads)	Adult Inhalation Thyroid Dose (rads)
<u>12-mile arc</u>		
203°	2.87×10^{-7}	1.13×10^{-6}
	3.03×10^{-7}	1.20×10^{-6}
211°	4.46×10^{-5}	1.75×10^{-3}
	4.44×10^{-5}	1.75×10^{-3}
215°	1.27×10^{-4}	5.00×10^{-3}
	1.29×10^{-4}	5.08×10^{-3}
221°	4.85×10^{-4}	1.91×10^{-2}
	4.05×10^{-4}	1.59×10^{-2}
230°	7.48×10^{-5}	2.95×10^{-3}
	6.58×10^{-5}	2.59×10^{-3}
241°	1.21×10^{-6}	4.73×10^{-5}
	1.15×10^{-6}	4.52×10^{-5}
251°	2.54×10^{-7}	9.98×10^{-6}
	2.70×10^{-7}	1.06×10^{-5}
268°	2.62×10^{-7}	1.03×10^{-5}
	2.08×10^{-7}	8.15×10^{-6}
<u>24-mile arc</u>		
211°	1.40×10^{-5}	5.91×10^{-4}
	2.21×10^{-5}	9.30×10^{-4}
225°	1.80×10^{-5}	7.58×10^{-4}
	1.27×10^{-5}	5.34×10^{-4}
236°	3.16×10^{-6}	1.34×10^{-4}
	4.16×10^{-6}	1.76×10^{-4}
250°	1.68×10^{-7}	7.07×10^{-6}
	1.46×10^{-7}	6.15×10^{-6}
263°	3.75×10^{-7}	1.59×10^{-5}
	4.20×10^{-7}	1.78×10^{-5}
268°	2.23×10^{-7}	9.43×10^{-6}
	3.80×10^{-7}	1.61×10^{-5}

the midtime of the first significant sampling interval or the beginning of the only significant sampling interval. The arrival time values, with these assumptions, are compared with the RM-11 results in Table VI. Again, the agreement between the two systems is surprisingly good.

GAMMA DOSE AND DOSE-RATE MEASUREMENTS

A film badge, TLD's, and gamma dose rate recording instruments (RM-11's) were placed at all stations which were activated for the reactor

test (Table I). These instruments are described in Appendix B.

Results.

No film badges received a dose large enough to be measured; no dosimetry film data are reported.

Cloud passage doses were so low that only a few TLD's received measurable doses. These measurements are listed along with the results of the RM-11 program, in Table VII.

Four 12-mile-arc stations, 64-211°, 64-215°, 64-221°, and 64-230°, showed usable RM-11 data. Two mobile stations, 128-211° and 128-225°, yielded usable data. The data are presented in Table VII. The cloud passage time was taken to be from the first rise (about three times background) to the time the dose rate started decaying according to $t^{-1.2}$. The total integrated doses have been calculated using a rectangular type of numerical integration; background has been subtracted. The recorder traces, uncorrected for calibration discrepancies, from the six usable stations are shown in Figs. 1 and 2.

For comparison, the cloud passage doses, computed from air-sampler data, are also listed in Table VII, along with the ratio of the RM-11 to "effluent" cloud passage dose. Again, the variability that is characteristic of Rover effluent measurements is present. There were too few measurements for conclusive comparisons.

EXPERIMENTS TO STUDY LARGE PARTICLES

Three related experiments were conducted to study the large particles released by the NRX-A6 reactor. Because of the very small amount of material released as large particles by this reactor, no data were obtained in two of these experiments, and only limited data were obtained in the third. A factor which further complicated matters, and may have resulted in loss of some data in these experiments, was the rain and snow which fell over the Test Site on the day of the test and the following day.

TABLE V. GROUND-DEPOSITION EFFECTS, NRX-A6 EP IIIA.

Station	Deposition Dose Rate (R/hr)	1-Year Integrated Deposition Dose (rads)	Iodine in Milk (pCi/liter)	Child Thyroid Dose (rads)
<u>12-mile arc</u>				
203°	2.15×10^{-7}	4.81×10^{-7}	1.37×10^0	1.65×10^{-4}
211°	1.18×10^{-5}	2.64×10^{-5}	7.54×10^1	9.05×10^{-3}
215°	2.40×10^{-5}	5.36×10^{-5}	1.53×10^2	1.84×10^{-2}
221°	9.98×10^{-5}	2.23×10^{-4}	6.38×10^2	7.65×10^{-2}
230°	4.10×10^{-5}	9.18×10^{-5}	2.62×10^2	3.15×10^{-2}
241°	1.37×10^{-7}	3.07×10^{-7}	8.76×10^{-1}	1.05×10^{-4}
251°	1.78×10^{-7}	3.98×10^{-7}	1.14×10^0	1.37×10^{-4}
268°	2.59×10^{-7}	5.80×10^{-7}	1.66×10^0	1.99×10^{-4}
<u>24-mile arc</u>				
211°	1.06×10^{-4}	2.81×10^{-4}	9.87×10^2	1.18×10^{-1}
225°	1.17×10^{-4}	3.08×10^{-4}	1.08×10^3	1.30×10^{-1}
236°	3.21×10^{-4}	8.48×10^{-4}	2.98×10^3	3.58×10^{-1}
250°	2.93×10^{-7}	7.73×10^{-7}	2.72×10^0	3.27×10^{-4}
263°	0.0	0.0	0.0	0.0
268°	0.0	0.0	0.0	0.0

TABLE VI. COMPARISON OF CLOUD ARRIVAL TIMES AS DETERMINED BY THE CYCLING SAMPLERS AND THE RM-11 PROGRAM

Station	RM-11 Arrival Time	Cycling Samplers Arrival Time
64-211°	1132 PST	1130 PST
64-215°	1134	1130
64-230°	1207	1245
128-211°	1252	1250
128-225°	1237	1235

The first experiment, which yielded no data, was the "cho-cho" experiment, to study the impaction of large particles on upright, volumetric structures.

"Cho-chos" (a name given to the apparatus by one of the technicians who fabricated them) were fiber drums, 15½ in. diam and 24½ in. long, placed about 3 ft above the ground on metal poles. The drums were covered with a number of differ-

ent types of surfaces to attempt to study the effects of different surfaces on particle retention. Single cho-chos were placed around the test point at 15° intervals at 4,000 ft and 20° intervals at 2,000 ft. These cho-chos were covered with tight fitting bur-lap to simulate coarse fabric clothing and were placed within a few yards of hopper samplers located at these stations. Four cho-chos and a hopper were located at each station at 20° intervals

Fig. 1. Comparison of cycling sampler data with RM-11 chart record.

Fig. 2. Comparison of cycling sampler data with RM-11 chart record.

TABLE VII. CORRECTED RM-11 RESULTS AND
CLOUD PASSAGE DOSE MEASUREMENTS

Station	Peak Dose Rate (mr/hr)	Time of Peak (PST)	Cloud Passage Time (PST)	Cloud Passage Dose (mr)			
				RM-11	"Effluent" ^a	TLD	Dose Ratio RM-11: "Effluent"
64-211°	3.0	1155	1132 to 1202	0.327	0.0445	low	7.35
64-215°	2.8	1206	1134 to 1236	0.667	0.128	~0.2	5.21
64-221°	9.2	1208	1134 to 1236	1.33	0.445	2.6	2.99
64-230°	2.3	1241	1207 to 1250	0.469	0.0703	0.75	6.67
128-211°	0.24	1300	1252 to 1315	0.036	0.018	low	2.00
128-225°	1.2	1255	1237 to 1302	0.20	0.0154	low	12.99

^aArithmetic average of the two values, computed from air sample data, at each station (Table IV).

1,000 ft from the reactor. At each of these stations, one cho-cho was burlap covered, like the more distant ones, and one was completely painted with "Silastic" rubber compound and lightly sanded to simulate human skin. (This method was suggested by the Prosthetic Devices Division of the U.S. Navy Dental School, National Naval Medical Center, Bethesda, Maryland.) One cho-cho was painted with rubber cement to give a sticky surface, and the fourth had the unmodified fiberboard drum surface.

We hoped that the number of particles striking and retained by the cho-chos could be related to the number of particles found in the associated hopper samplers, to give some indication of the impaction and retention characteristics of these volumetric forms as compared to ground deposition of particles determined by the hoppers. Unfortunately, only a single particle was found on one of the 114 cho-chos placed in the field--a result which allows no conclusions to be drawn.

Hopper samplers, described in detail in Appendix C, were located with the cho-chos. This experiment yielded no data because not a single hopper was struck by large particles, as determined by careful monitoring of each hopper funnel, and the ground under each hopper in case precipi-

tation had washed the particles out of the hoppers onto the ground.

Sandbox samplers, described in Appendix C, were located at 10° intervals completely around the reactor at 4,000, 8,000, and 16,000 ft. The latter ring of samplers is somewhat irregular because of the rugged terrain and because existing roads and trails are used to economize in sampler location and servicing. The results of the sandbox surveys are given in Tables VIII and IX. When few sandboxes showed significant numbers of large particles, other locations on the sampling arcs between established stations were surveyed to determine particle deposition, and to recover samples for particle examination. Surveys to determine particle deposition and particle sample recoveries were conducted on the two days immediately following the test. As many particles as possible were recovered from the wet and snowy ground at each survey location. In all, 30 samples of sand and soil thought to contain large particles were brought in from the field for laboratory examination.

Particles were not recoverable from all the sand and soil samples collected. In several instances, the sample radioactivity was uniformly distributed throughout the sand and soil grains in the sample, and no distinct concentration of radio-

TABLE VIII. LARGE PARTICLE DEPOSITION DENSITY AS DETERMINED BY MONITOR SURVEYS

<u>Distance (ft)</u>	<u>Azimuth</u>	<u>Survey Results (Particles/Area)</u>	<u>Density (Particles/100 ft²)</u>
2,000	225°	7/100 ft ²	7
4,000	221.5°	6/100 ft ²	6
		(14/900 ft ²) ^a	(1.6)
	225°	3/100 ft ²	3
		(6/1600 ft ²)	(0.38)
8,000	225°	1/100 ft ²	1
		(12/2500 ft ²)	(0.48)
16,000	215°	2/500 ft ²	0.4
	220°	(6/3000 ft ²)	(0.2)
	225°	6/500 ft ²	1.2

^aValues in parenthesis indicate that dimensions of surveyed area were only estimated.

activity could be found. In other samples, the radioactivity was definitely associated with one or more grains of mineral material, and could not be physically removed from the mineral granules. In each of these cases, the results have been excluded from Table IX; only particles that could be said to definitely originate in the reactor are listed. Particle characteristics that were directly determined, using the methods described in Appendix C, were size, activity 61 days after the reactor run, and terminal settling velocity in air. Equivalent fissions per particle were calculated from particle activity assuming that all activity was due to unfractionated fission products in the particle, and that the fissions-to-activity ratios given in Bolles and Ballou⁽¹⁾ were applicable.

Particle volumes were calculated from the particle dimensions, taking into account, where applicable, particle shape as recorded on photomicrographs. Particle dimensions given in Table IX are the long and short dimensions of irregular particles where two or three dimensions are given, or, if a single dimension is given, the diameter of the spherical particle. A logarithmic mean particle dimension, or equivalent spherical diameter, was assigned to each particle for calculation

of particle size statistics. That is, for an irregular particle for which two diameters had been measured, the equivalent diameter was taken to be the square root of the product of the two diameters. If three diameters were known, the equivalent diameter was the cube root of the product of the three diameters.

Particle specific gravities were calculated from the terminal settling velocities measured in air, using relations discussed in Drinker and Hatch.⁽²⁾ Care was taken to calculate the Reynolds number for each particle so that the appropriate region of motion, either Stokes, intermediate, or turbulent, was determined, and the correct relation was used for settling velocity. All the particles in this study were in the intermediate region of motion. The equivalent spherical diameter as described above was used in the Reynolds number and settling velocity equations.

As with particle experiments made for the Phoebus 1B reactor test,⁽³⁾ particle characteristics were found to be variate quantities, with wide ranges of values.

Particle size was found to be log-normally distributed, as was particle activity. Particle specific fissions, or fissions per unit volume,

TABLE IX. CHARACTERISTICS OF INDIVIDUAL LARGE PARTICLES

Sample Id.	Location	Size (μ)	Activity (μ Ci)	Fissions	Fissions/ cm^3	Fall Velocity (cm/sec)	Specific Gravity (g/cm^3)
1-1	16-220	40 x 20	0.074	8.6×10^{10}	7.3×10^{18}		
2	16-220	135	2.892	3.3×10^{12}	2.6×10^{18}	227	10.24
3-1	16-220	80 x 45	0.289	3.3×10^{11}	2.9×10^{18}		
4-1	16-220	110	2.224	2.6×10^{12}	3.7×10^{18}		
5	16-220	100	1.986	2.3×10^{12}	4.4×10^{18}		
6	16-220	60	0.962	1.1×10^{12}	9.7×10^{18}		
8	8-225	150 x 135	2.351	2.7×10^{12}	1.8×10^{18}	179	6.62
9	8-225	410 x 370 x 120	3.054	3.5×10^{12}	6.4×10^{17}	219	3.56
10	8-225	115	6.243	7.2×10^{12}	9.0×10^{18}	201	10.85
11	8-225	90, 90, 70 ^a	1.016	1.2×10^{12}	1.0×10^{18}		
14-1	4-221.5	80 x 65	0.614	7.1×10^{11}	3.6×10^{18}		
14-2	4-221.5	60 x 45	0.164	1.9×10^{11}	2.6×10^{18}		
14-3	4-221.5	20 x 20	0.012	1.4×10^{10}	3.3×10^{18}		
15	4-221.5	120 x 115	6.648	7.7×10^{12}	9.1×10^{18}	133	5.71
16-1	4-221.5	75 x 60	0.581	6.7×10^{11}	4.2×10^{18}		
16-2	4-221.5	60 x 40	0.400	4.6×10^{11}	7.5×10^{18}		
16-3	4-221.5	70 x 50	0.459	5.3×10^{11}	4.9×10^{18}		
17	4-221.5	120 x 70	1.238	1.4×10^{12}	3.5×10^{18}		
18-2	4-221.5	65 x 55	0.356	4.1×10^{11}	3.7×10^{18}		
19	4-225	420 x 320 x 120	0.294	3.4×10^{11}	2.1×10^{18}		
20	4-225	140 x 135	6.243	7.2×10^{12}	5.3×10^{18}	174	6.68
21	4-225	110 x 95	0.756	8.8×10^{11}	1.6×10^{18}		
22	4-225	100	0.630	7.3×10^{11}	1.4×10^{18}		
23-1	4-225	200 x 160	0.943	1.1×10^{12}	3.7×10^{17}		
23-3	4-225	160 x 70	0.159	1.8×10^{11}	2.9×10^{17}		
23-4	4-225	90 x 55	0.083	9.6×10^{10}	5.3×10^{17}		
23-8	4-225	90 x 90	0.098	1.1×10^{11}	2.9×10^{17}		
23-9	4-225	90 x 65	0.067	7.7×10^{10}	3.3×10^{17}		
24	2-225	540 x 300	68.648	7.9×10^{13}	2.1×10^{20}	495	7.42
26	2-225	450 x 350	5.243	6.1×10^{12}	7.7×10^{17}	342	3.75
27	2-225	195 x 150	10.486	1.2×10^{13}	4.6×10^{18}	167	4.53
29	2-225	135	3.568	4.1×10^{12}	3.2×10^{18}	168	6.52
30	2-225	480 x 335	36.216	4.2×10^{13}	1.2×10^{18}	388	4.48
Geometric mean		103.7	0.945	1.09×10^{12}	1.95×10^{18}		6.40 ^b
Geometric std. dev.		1.98	6.56	6.56	3.78		2.31 ^b

^a Three spherical particles in a single agglomeration.^b Arithmetic mean and std. deviation.

were not log-normally distributed, but rather contained a disproportionate number of larger values than would be found in a log-normal distribution. These results were just the contrary of those found in the Phoebus 1B study reported by this group.⁽³⁾ In that study, specific fissions were log-normally distributed, but neither particle size nor activity were. In that study, particle sampling was suspected of being biased, whereas in this study attempts were made to recover every particle

that was found during the field surveys.

Regardless of their distributions, however, logarithmic means and standard deviations were calculated for the distributions and are given in Table IX. The logarithmic mean is the antilog of the average of the logarithms of the set values, and the geometric standard deviation is the antilog of the standard deviation of the logarithms of the set values.

Compared to the Phoebus 1B particles studied by Group H-8, the particles recovered during this study were larger and more radioactive, both in an absolute and a specific sense. In this study, the logarithmic mean value of 2×10^{18} fissions/cm³ is relatively closer to the value of 9×10^{18} fissions/cm³ that might be calculated for a reactor average than was found for Phoebus 1B. Also, individual particles equaled or exceeded this calculated average, which was not the case with Phoebus 1B. The mean particle size of 103 μ and geometric standard deviation of 1.98 were both larger than for Phoebus 1B, which had values of 63 μ and 1.67, respectively.

The individual values for particle specific gravity given in Table IX and the average value of 6.40 gm/cm³ appear to be consistent with values that might be expected for various mixtures of uranium-carbide and graphite.

APPENDIX A

AIR SAMPLING PROCEDURES AND EQUIPMENT

A highly mobile sampling capability has been achieved by the use of self-contained trailer-mounted dynamic sampling units. These sampling trailers are positioned on arcs around the test point at locations determined by wind direction probabilities. The surveyed array for sampler placement extends from 2,000 to 128,000 ft. Approximately 100 dynamic sampling units are available for the documentation of tests. Each unit is equipped with a 3.5-kW generator, a high volume air sampler, and a radio receiver and decoder. The radio equipment allows for complete remote operation of the components of the system from the Control Point (CP) area. A majority of the trailers are equipped with cascade impactors and a sequential sampler. In addition to the dynamic sampling equipment, static stations can be established to provide 360° coverage on all arcs. These stations consist of a pair of 7 x 10 $\frac{1}{2}$ in. resin-coated trays and a film badge. This array can provide minimal coverage of the test

in the event of a wind shift that causes the effluent cloud to miss the dynamic array.

Description of Sampling Equipment.

High Volume Air Sampler. The high volume air sampler is a Staplex air sampler fitted with a transition piece to accommodate a 6 x 9 in. Whatman No. 41 filter paper. This particulate filter is backed up by a pair of organic vapor-type respirator cartridges (activated charcoal) in parallel. This arrangement of sampling media allows for the gross separation of the airborne material into two distinct fractions. The material collected on the filter is assumed to be particulate, and that on the charcoal cartridges is assumed to be gaseous at the time of collection. The sampling rate for this system is a nominal 1 m³/min.

Cascade Impactor. The cascade impactor is a Unico design impactor and rotometer, operated at a flow rate of 1 cfm. The unit provides a first approximation to the size distribution of the airborne particles. The design of the sampler provides for the grading of the aerosol in its airborne state, the sizing being determined by the effective aerodynamic diameters of the particles.

Sequential Sampler. The eight vacuum cleaner motor samplers in the sequential unit are fitted with filter paper and charcoal cartridges and are equipped with timers to provide sequential running. Sampling timers are set depending on the distance from the test point. Running times can vary from 5 min to 1 hr per sampler. As one sampler is turned off, the next one in the sequence is turned on.

Resin-Coated Trays. Samples of ground deposited material are collected on two flat trays, 7 x 10 $\frac{1}{2}$ in., coated with a nondrying resin. The trays are placed horizontally on stakes approximately 30 in. above grade. To avoid neutron activation problems, Lucite trays are used on arcs out to 8,000 ft and aluminum trays are used beyond.

Counting Equipment. Because of the desirability of obtaining gross beta and gamma counts from a

large number of individual samples, a system was developed to provide a simultaneous count of both beta and gamma activities. Beta counting is done by means of a $7 \times 10\frac{1}{2}$ -in. methane gas flow proportional counter located in the top of an iron counting shield. The gamma-counting probe consists of a 10-in.-diam by 5-in.-thick plastic phosphor (Nuclear Enterprises NE102) coupled to five Dumont 6363 photomultiplier tubes. The probe outputs are fed into a standard single-channel analyzer, and counter-scaler unit.

The mechanical arrangement of the components allows for variation of counting geometries inside the shield. The counting positions are calibrated using ^{90}Sr -Y for the beta counter and ^{137}Cs for the gamma counter prior to each operation. These systems are used for counting filter papers, charcoal cartridges, and resin-coated trays. Specially designed systems are used to count samples collected by the cascade impactors. These systems use only beta proportional counters.

Qualitative isotopic information about selected samples is derived by use of multichannel gamma pulse height analysis. The basic component of the system is a 400-channel analyzer from Radiation Instrument Development Laboratory (RIDL), Model 34-12. The input for the system is from a Harshaw Integral Line 3×3 -in. thallium-activated sodium iodide crystal with a Dumont 6363 photomultiplier tube. Readout of the system is by a Mosley Autograph X-Y recorder and a Hewlett-Packard Corporation printer. Provision is made in the $3\frac{1}{2}$ -in.-thick steel shield for varying the counting geometry of the sample. This allows for the highest possible counting rate while at the same time avoiding serious problems with shifts due to saturation of the photomultiplier or analyzer dead time.

Data Analysis Procedures. Most quantitative radiological data are derived from measuring the gross beta activity of the samples. An exception is the charcoal cartridges where beta counting is

not reliable and radioactivity is measured by gamma counting. All samples collected from the downwind sector of the array are subjected to at least one count as soon after the event as possible. On the basis of this first gross count, samples are selected for more complete analysis. This set of samples is referred to as decay samples.

Decay samples are selected immediately following the first count on the basis of activity, location, and type. Samples are repeatedly counted for an extended period at intervals that depend on the age of samples. The gross activity versus time relationship is plotted during the process of decay counting. Simultaneous gamma pulse height analysis is carried out on all decay samples. After sufficient data have been generated (usually at about 3,000 min after the event), curve comparisons are made to determine the need for further decay analysis of samples with identical characteristics. Samples are eliminated from the decay set after it is determined that another sample has the same isotopic composition. Comparisons are made both of the gross time-activity relationship and gamma ray spectra.

Sample decay is followed until the longest-lived component can be determined and measured or until the level of activity becomes so low as to cause serious counting problems. When the decay pattern has been determined, a technique of curve stripping is employed to quantitatively determine the isotopes making major contributions to this pattern. In the ideal case, the samples can be followed until only a single long-lived isotope is present. The activity of this isotope or isotopic chain is then determined and back-extrapolated to all previous count times and run midpoint or zero time. The contribution of this isotope is then subtracted from the gross activity at each time. The residual curve thus produced is plotted and the process repeated using the isotope of the next longest half-life as determined from the gamma pulse-height analysis. This process of extrapolation and

subtraction is repeated until the entire observed decay curve has been matched. A theoretical plot of the determined isotopes is then made and compared to the original measured decay curve as a check for fit. No attempt is made to account for short-lived parents which cannot be observed at the time of the first count (usually about 200 to 600 min after the event).

The analysis thus yields the theoretical amounts of the various isotopes that would have had to be present at zero time to produce the observed decay curve. The fractionation of the effluent material makes extrapolation from 200 min to zero time by chains very difficult and uncertain. Therefore, the values used are only for the isotopes actually observed and stripped from the various curves. Exceptions are made for the 140 chain, the 133 chain, and the 132 chain, which are assumed to be free of lanthanum and iodines at zero time.

The decay curves so generated are assumed to be representative of the other samples of the same type and location, and the activity measured on the samples is extrapolated to times of interest using such decay curves. The composition at any specific time of interest is also calculated and recorded for further calculations involving specific isotopes.

Calculations Performed with Raw Data. Airborne particulate dosages are calculated from material collected on the filter papers, and the airborne gaseous dosages are from the charcoal cartridges. Dosages are obtained by dividing the sample activity by the air sampler flow rate. The deposited activity is calculated from material collected on the resin-coated trays, divided by the tray area.

Deposition velocities are determined for all dynamic stations which exhibit significant sample activity. Deposition velocities can be calculated for total material (total deposited concentration/airborne particulate dosage + gaseous dosage), particulate material (total deposited concentration/

airborne particulate dosage), and for total and particulate airborne ^{131}I . The ^{131}I deposition velocities are calculated using only the amounts of ^{131}I assumed to be present in the respective samples, as calculated from isotopic composition of the samples.

Decay curve tables show the apparent zero-time composition of each decay curve used for extrapolation of the data. The curve assignment data are also given.

A first approximation to the particle size distribution is provided by the cascade impactors. The various impactor stages are counted, one immediately after another, within each set. Maximum spread of count times is about 10 min from the first stage to the last. Count time activity and silica sand density are used to determine the size characteristics of the aerosol.

Calculated Cloud Effects. Whole-body dose due to cloud passage is calculated assuming that the station in question is in a semi-infinite cloud of uniform concentration represented by the measured dosage extrapolated to time of cloud passage. This assumption, in spite of its shortcomings, is widely used for predicting doses due to cloud passage in hazards evaluations.

The adult thyroid inhalation dose is calculated from the airborne dosages of the various iodine isotopes. The adult thyroid dose due to a cloud dosage of 1 Ci-sec/m³ of each iodine isotope is as follows:

Isotope	Thyroid dose resulting from inhalation of 1 Ci-sec/m ³ (R)
^{131}I	340
^{132}I	12.3
^{133}I	91.5
^{134}I	5.7
^{135}I	28.4

These data arise from standard calculations based on Federal Radiation Council recommendations.

The ground deposition effects are based on measured levels of material deposited on the ground. The dose due to ground deposition of radioactivity is calculated by extrapolating the activity on the

resin-coated trays to time of cloud passage. It is assumed that the radiation is from an infinite plane source with an area source strength equal to, and of the same isotopic composition as, the material collected by the resin-coated tray at the station. The 1-year integrated dose assumed a clean area before arrival of the cloud and no further contamination after cloud passage. One year was chosen because of the recognized problem of leaching and weathering of the deposited material. The integration is done using the exponential decay of each individual isotope.

The data for iodine in milk are hypothetical values, calculated under the assumptions (based almost entirely on Windscale experience in the United Kingdom) that 1 Ci/m² of ¹³¹I deposited on the pasture (and represented by the concentration as measured on the resin-coated tray) will result in 1.0 x 10¹¹ pCi of ¹³¹I per liter of milk as a maximum level of contamination. The child thyroid dose is another hypothetical value, based on the assumption that a child will continue to drink a liter per day of milk contaminated as previously described, with no corrective measures, until the ¹³¹I has decayed from the pasture and from the milk produced by the cattle grazing on the contaminated pasture. These assumptions, again, are somewhat unrealistic, especially when applied to the milk sheds within several hundred miles of the Nevada Test Site where dairy cattle infrequently graze on pasture but are usually fed baled feed. Nevertheless, these assumptions are widely employed in hazards evaluations.

APPENDIX B

GAMMA DOSE AND DOSE-RATE MEASUREMENTS

A film badge, thermoluminescent dosimeters (TLD's), and gamma dose-rate recorders are placed at selected sampling stations. The TLD's are placed in the field in polyethylene bottles mounted on poles. On the 4,000- and 8,000-ft arcs the film packets are placed in card-

board containers in the ground. At all other stations, they are placed in the same manner as the TLD's.

Description. The dose-rate recording system is a low-level (0.001 to 100 mR/hr), dose-rate indicator driving a strip chart recorder. The dose-rate indicator, manufactured by Eberline Instrument Corporation, is called a radiation monitor, RM-11-8507, or simply an RM-11; it consists of a Geiger-Mueller (G-M) detector tube, amplifier, trigger circuit, logarithmic converter, voltmeter circuit, and associated power supplies. The 5-in. G-M tube is in the upper half of a chrome-plated brass detector housing; the instrument case contains the rest of the components and circuitry. The unit is dust-proof, splash-proof, and capable of operating unattended in the environmental extremes associated with field tests. Other desirable features include a filter in the 110-V, 60-Hz input, an oven for thermostatic control of the logarithmic converter output, a discriminator adjustment for nonsaturation in fields up to 10 R/hr, and separate span- and zero-calibration controls. The output voltage to the recorder and/or indicating meter is proportional to the logarithm of the external field over the four-decade range without need of external switching.

The recorder is an Esterline-Angus Type AW Graphic, a spring-driven, pen-and-ink type, 0- to 1-mA dc, strip-chart recorder. An external resistor in the feedline provides an exact impedance match between the RM-11 and the recorder. The recording pen inks directly onto a four-decade log-scale chart paper that permits direct reading of the dose rates. One roll of chart paper is sufficient for 52 hr of recording.

Calibration. Each system is calibrated as a unit; once calibration is completed, no interchanges are made. The operating instructions recommend calibration points at 0.1 and 10 mR/hr; but, since H-8 does not have the facilities to field calibrate below 0.4 mR/hr, the zero and span controls are

adjusted so that their indicated responses are correct at 0.5 and 10 mR/hr, respectively. The response is then checked at 0.5, 1, 5, 10, 30, 50, and 100 mR/hr. In most cases the error at all check points is less than 15%; for the few instruments with check-point error greater than 15%, calibration curves were made and retained for future reference.

Thermoluminescent Dosimeters. Integral gamma measurements are made at selected stations with EG&G, Inc., Model TL-12, TLD's which use CaF_2 : Mn as the sensing material. The TLD's have a range of approximately 1 mR to greater than 5,000 R. For low dose measurements, a background buildup record and a low dose calibration record are maintained for each dosimeter. This enables low dose measurements in the presence of a long time (6 to 7 days) between "zeroing" and reading. The TLD's are zeroed as late as possible before field placement. An EG&G Model TL-2B reader is used to record the dose received by the dosimeters. Background doses measured by use of control dosimeters are subtracted from the reported readings.

Film Badges. DuPont Type 544 film packets are used to measure the integral gamma doses at all stations. This packet contains a sensitive film, Type 555, which indicates doses from 0.01 to 6 R and an insensitive film, Type 834, which measures doses from 2 to 10^3 R. A 40-mil lead strip covers a portion of the film so that gamma exposures can be distinguished in the presence of beta radiation. The film packet is contained in a protective plastic wrapper for placement in the field.

Exposed films are developed by the LASL Group H-1 Photodosimetry Section by standard methods. (4)

APPENDIX C

LARGE PARTICLE SAMPLING EQUIPMENT AND PROCEDURES

Sand Box Samplers.

Surveying the desert to locate radioactive particles is complicated by the brush, rock, and other natural debris that shields some areas and

imposes a puncture hazard on survey instruments. Similarly, recovery of particles is inhibited by the pebbly soil, which makes it difficult to pick up a particle with only a very small amount of accompanying sand.

To improve survey and recovery, sand box samplers are used. These are wood frames, 10 ft square, of 2 x 4 lumber set on edge in a level plane and filled level to the top with screened sand. Sheet polyethylene is placed under the sand to inhibit vegetation growth. Just before a test, the sand boxes are examined, cleaned of debris, and raked smooth and level. At the time of recovery, they still usually present a smooth, clear surface, marred only by an occasional animal track or rodent burrow.

The particles are located on each sampler by surveying, using a Geiger-Mueller instrument (Eberline Instrument Co., E500B) with the open probe held an inch or so above the sand. The instruments are equipped with earphones or speakers so that the counting rate can be audibly monitored and any changes quickly noticed. When a particle is discovered, its location is marked with a colored stick. The color of the stick indicates the open shield meter reading produced by the particle when the probe was held as close as possible. White sticks may be used for particles giving readings less than 20 mr/hr, yellow for 20 to 50 mr/hr, blue for 50 to 100, and red for readings greater than 100 mr/hr. As each particle is located and monitored, the meter reading it produced with the probe in contact with the sand surface is recorded. The colored markers prevent the particles from being recorded more than once, since each sand box is surveyed twice, once skimming the probe in one direction over the entire surface, and the second time moving the probe in a direction at right angles to that of the first search. Particles only a couple of inches apart can be readily resolved, and interference due to background radiation is minimal while the probe is close to the

sand surface. After the survey, a colored Polaroid photograph may be taken to show the number and location of the particles in the box.

Particles are recovered from these samplers by picking up, with a teaspoon, a very small amount of sand from the radioactive area. If the material on the spoon is radioactive, the sand is placed in a small number-coded plastic vial, sealed, and brought to the laboratory. If the material on the spoon is not radioactive, the sand is discarded and another sample taken, until the particle has been successfully recovered.

Hopper Samplers.

Because of the difficulties encountered in recovering particles from soil, and subsequently extracting and mounting them for examination, a method was designed for collecting the particles so they can be examined directly with little further treatment. Transparent trays, or slides, upon which the particles can fall directly, are either too small to have a reasonable probability of collection, or are too large for easy handling. A compromise method was devised which offered a relatively large area for collection but a sample holder small enough for convenient handling. Sheet metal hoppers, 4-ft square on top, 4-ft deep, and tapering to 3-in. -square openings at the bottom, are still available after being used for a similar purpose on the Kiwi-TNT event. Many of the particles falling into the hopper roll down to the bottom where they fall onto a collecting tray. The design of these trays employs variations of methods described by Campbell et al. (5) The collecting trays are 6 x 5 in. plates of aluminum, with approximately $3\frac{1}{2}$ -in. -square holes cut out of the centers. A sheet of clear, 1-mil Mylar film is stretched over the tray as a collecting surface. This Mylar is attached to the sheet metal with double-coated transparent tape. Slight heating of the Mylar after attachment causes it to shrink taut. The trays are clipped to the hopper bottoms so that the particles will fall

on the Mylar over the cut-out portion of the aluminum tray. The Mylar collection surface is sprayed with a thin coat of Dow Antifoam A so that material will readily adhere and remain in place. As an added precaution, in case the particles remain hot enough to melt their way through the Mylar, the collection tray is backed underneath with a sheet of clear acrylic plastic. Each tray during placement is marked as to its location in the array. During collection, as the trays are removed, the collection surface is covered with an identical tray, so that any material collected is sandwiched between two layers of Mylar, tautly held in a rigid frame. This arrangement allows direct microscopic examination of any material collected, without further handling.

Particle Separation, Photomicrography, and Measurement.

The technique for separating the particles of interest from any surrounding material is as follows.

The particle of interest and a few grams of sand are in a container, usually a small, capped vial, in which the sample was placed when it was recovered from the field. The vial is carefully uncapped over a sheet of paper. The cap, vial, and paper are monitored for radioactivity to ascertain whether the particle is on the cap, has fallen on the paper, or is securely in the vial. If the particle has fallen on the paper, the separation is trivial, and the particle may be located on the paper and examined under the microscope. If on the cap, the particle may be either shaken off the cap onto the paper or examined while still adhering to the cap. Again the separation is trivial. If the particle remains in the vial, as it most frequently does, the separation must proceed further. A small fraction of the material in the vial is shaken onto the paper. The paper and vial are monitored with a survey meter to locate the particle. If radioactive material is found on the paper, the location of the radioactive particle (or particles)

is narrowed using a small area, surface barrier radiation detector. That area of the paper is then examined carefully with a wide field, relatively low power microscope to locate the particle.

An Ortec Type SBDJ025-60 surface barrier detector is mounted on the optical axis of a Bausch & Lomb, Model BVB-73, Stereozoom dissecting microscope, in a heavy aluminum plate attached to the microscope base. This very small detector is further shielded and held in place by a $\frac{1}{8}$ -in. steel plate which also serves as a stage for the microscope. A 0.030-in. hole is drilled through the $\frac{1}{8}$ -in. steel over the detector, the hole being exactly in the center of the microscope field. The detector is connected to a counter-scaler apparatus fitted with a loud speaker and wired so that the speaker pops on every pulse. The normal background counting rate of the detector is insignificant. Even in the presence of radioactive materials, it remains very low because the detector is sensitive only to particulate radiations and its aluminum housing serves as a rather effective shield against them. However, whenever a radioactive particle is held over the hole in the cover plate, the direct beta radiation causes a noticeable rise in count rate. Using this apparatus, radioactive particle identification is remarkably simplified.

A sample known to contain a radioactive particle or particles is first screened using another small, surface barrier detector to locate the particle to within several millimeters. The sample is then placed on the detector stage of the microscope with the general area of the particle in the field of view. The sample is then moved around on the stage, bringing every likely looking granule into the center of the field. When a radioactive particle is brought into the center of the field, over the unshielded area of the detector, a definite increase in count rate can be noted by listening to the loud speaker. The resolution of this system is such that a radioactive particle can be distinguished from a nonradioactive particle less than 500 mi-

crons away.

Although perhaps not so optically fine as a compound microscope, the dissecting microscope offers the advantages of adequate magnification, depth of field, a large field of view for scanning samples, and a large working distance between the sample and the objective lens.

The dissecting microscope used is not equipped with a camera attachment, so photomicrographs are taken using the following arrangement. The microscope is securely fastened to a heavy stand, and a 4 x 5 in. press camera is mounted on the stand and aligned so that the image formed by one of the microscope oculars is projected onto the focal plane of the camera. No lens is used in the camera. The camera mounting is fitted with stops to allow quick, positive alignment each time it is used. When a field of view is to be photographed, the camera is swung into position over one of the oculars, a light-tight coupling is placed between the ocular and the shutter, the image is focused on the ground glass screen, the shutter closed, Polaroid film inserted, and the picture taken. Exposure times are selected by trial and error. One exposure time is found to be suitable for an entire series of pictures taken under similar circumstances, but variations can be used occasionally to enhance certain desired aspects.

The magnification of the microscope-camera combination is calibrated by taking photomicrographs of a stage micrometer at each of several microscope magnifications. These photomicrographs are then used as rulers to measure the dimensions of particles photographed with identical microscope-camera arrangements. Using this system, particle dimensions can be determined with a standard error estimated to be about 5 microns.

Measurement of Particle Radioactivity.

Particle radioactivity is measured using two types of count systems. The first comprises a $1\frac{1}{2}$ -in.-diam beta phosphor and photomultiplier tube detector in a lead shield. This detector is connected

to a counter-scaler apparatus in a typical circuit for such apparatus.

The second method employs the radiation detector mounted in the stage of the microscope used to locate and photograph the particles. An Ortec Type SBDJ025-60 surface barrier detector is mounted on the optical axis of the Bausch & Lomb, Model BVB-73, Stereozoom dissecting microscope, in a heavy aluminum plate attached to the microscope base. This very small detector is held in place by a $\frac{1}{8}$ -in. steel plate. A 0.030-in. hole is drilled through the plate over the detector. The detector is connected to a counter-scaler apparatus through conventional amplifier-discriminator circuitry. Particles are placed on metal and Mylar mounts which allow reproducible counting geometry when the particle is placed over the center of the hole over the stage detector. Accurate placement of particles for counting is easy to accomplish with the microscope apparatus.

Experiments to calibrate and check the accuracy of the microscope count apparatus showed that determinations of radioactivity of a single particle using the microscope counting apparatus gave results reproducible with a standard error of $\pm 5\%$ if counting statistics were such as to introduce negligible variability. Cross calibration experiments using the microscope count apparatus and the more traditional count apparatus mentioned earlier resulted in a conversion factor between the two count systems that was reproducible with a standard deviation of $\pm 20\%$.

The traditional count apparatus is generally used for particles with relatively low amounts of radioactivity, whereas, because of its inefficient count geometry, the microscope count apparatus is used for particles with relatively high radioactivity.

Radioautography.

Two photographic emulsions have been found to be entirely suitable for radioautography of

radioactive particle samples. Polaroid, Speed 3000, Type 57 sheet film available in 4 x 5 in. packets, is most widely used to determine the distribution of particles on smaller sampling media. Kodak Blue Brand x-ray film is occasionally used to evaluate the distribution of activity on much larger samples.

Both emulsions have approximately the same exposure speed. This allows the conveniently processed Polaroid film to be used as a critical exposure guide for x-ray film. An approximate exposure guide number is also used, which allows exposure time to be based on survey meter readings of the samples. Eberline Instrument Co., Type E500 and E112 Geiger-Mueller survey instruments are the only types used to measure sample activities, and the validity of the exposure index for other instrument models has not been checked. For these survey meters, the exposure relation

$$\frac{\text{Radioautograph exposure time in minutes}}{1000} = \frac{\text{Open probe survey meter reading, mr/hr at contact}}{1000}$$

gives satisfactory exposure results for an initial trial. Other exposures, tailored to the results desired, can be determined from this initial exposure. During the first few days after the reactor test, when almost all radioautographs of the samples are made, open-probe meter readings of the samples are about 10 times higher than closed-probe readings. This relationship is still valid for highly active samples that cannot be measured with an open-probe instrument, if it is assumed that an open-probe contact reading is 10 times a closed-probe reading.

Although exposure speeds for the two emulsions are approximately the same, the x-ray film permits a much wider range of exposure times than does the Polaroid film. As a consequence of this greater latitude, more satisfactory radioautographs of samples containing particles of widely differing activities can be obtained using x-ray film.

Resolution, or the ability to form distinct images of two closely spaced particles, is enhanced by getting the particles as close to the sensitive emulsion as possible. Polaroid film is pressed tightly against the samples, with the side of the packet marked, "This side toward lens," away from the sample. X-ray film is protected from light exposure by using it in Kodak x-ray exposure holders. Exposures are made with the holder covers folded open so that only a single layer of black paper is between the sample and the film.

Since x-ray film is pressure-sensitive to a limited degree, the x-ray films can be permanently marked for identification by writing heavily with a ball point pen on the paper covering the film. The characters written on the protective paper appear on the film when it is developed.

Particle Settling Velocity.

Particle settling velocity is measured directly by timing the particle's fall through a measured distance in air.

The apparatus consists of a 9-ft-long vertical acrylic plastic tube, with an inside diameter of $2\frac{3}{4}$ in., open at both ends. Four sets of Ortec, type SBEJ300-60, surface barrier radiation detectors are inserted through the tube walls, flush with the inside surface 0.25, 0.75, 1.75, and 2.75 meters from the tube top. These detectors are connected in parallel, through suitable amplifiers and a discriminator, to a multichannel pulse height analyzer, Technical Measurement Corporation, Model 1004B. The multichannel analyzer is operated in the multiscaler mode. That is, all pulses received at the analyzer during a given interval are stored in a single channel. The duration of collection of pulses in any channel is pre-selected by a control on the analyzer; col-

lection times range from 0.1 to 1000 msec. The collection duration, or dwell time, is selected so that as a radioactive particle falls past the radiation detectors, the pulses collected by the first detector are stored in only a few channels, with subsequent channels having almost no registered pulses. Thus a record of the number of pulses per channel vs. channel number will clearly show four distinct peaks. The number of channels between peaks can be readily converted to the time required for the particle to fall between the 1st and 2nd, 2nd and 3rd, and 3rd and 4th detector sets, respectively. In general, the particle is falling at a constant velocity by the time it reaches the second detector from the top.

To determine the consistency of this method, repeated drop tests were conducted on spherical and fairly regular-shaped particles. These gave fall velocity measurements with a mean standard deviation of 2.4% of the average fall velocity. A range of fall velocities obtained for a particle by this method should therefore be about $\pm 5\%$ around the average for the particle.

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