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INVESTIGATION AND CORRELATION OF SOME PHYSICAL PARAMETERS OF FALLOUT MATERIAL

Research and Development Technical Report USNRDL-TR-152
NS 081-001

28 March 1957

by

W. Williamson, Jr.

U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

SAN FRANCISCO 24 · CALIFORNIA

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SAN FRANCISCO 24, CALIFORNIA

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Encl: (1) U.S. Naval Radiological Defense Laboratory Report USNRDL-TR-152 entitled "Investigation and Correlation of Some Physical Parameters of Fallout Material"

1. An attempt was made to relate the radioactivity of a fallout particle to its physical parameters (size, shape, color, density and weight). In enclosure (1), it was found that there is a trend for the radioactivity to increase as the particles get heavier and larger.

Floyd B. Schultz

FLOYD B. SCHULTZ

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Physics and Mathematics

Technical Objective
AW-7

Radiological Capabilities Branch
T. Trufet, Head

Chemical Technology Division
E.R. Tompkins, Head

Scientific Director
P.C. Tompkins

Commanding Officer and Director
Captain Floyd B. Schultz, USN

U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY
San Francisco 24, California

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ABSTRACT

An attempt has been made to correlate some of the fundamental physical parameters of fallout material. Parameters discussed are color and shape, activity, size, weight, and density. What little correlation that was possible among the accumulated data is presented together with the residual error.

SUMMARY

The Problem

The problem was to investigate possible correlation between activity, color and shape, size, weight, and density of primary fallout particles.

Findings

The investigation revealed a significant difference in density and activity in different types of fallout.

ADMINISTRATIVE INFORMATION

This work was done under Bureau of Ships Project No. NS 081-001, Subtask 1, Technical Objective AW-7, as described in U.S. Naval Radiological Defense Laboratory Annual Progress Report (DD Form 613) to the Bureau of Ships, July 1956.

The fallout studies were made at Operation REDWING, Project 2.6.3, as described in DD Form 613, NS 088-001, Subtask 4B, Encl (1) to CO USNRDL Secr ltr 3-905-335 Ser 0014173 of 16 March 1956.

The work also is part of the technical program for the Department of the Army established between Department of the Army, Office, Chief of Research and Development, and Bureau of Ships (Joint Agreement, 23 November 1955).

ACKNOWLEDGMENTS

Appreciation is expressed to D. Pupione and B. Sine for aid in measuring the parameters, J. Mackin for permission to publish Fig. 2 and M. Sandomire for aid in statistical computations.

1. INTRODUCTION

Operation REDWING provided NRDL with numerous field samples which were shipped to the Laboratory from the test site. Two of the shots, Zuni and Tewa, provided particles adequate for the measurement of physical parameters. The samples which were analyzed were designated as whim samples. The whim samples from both events were collected in the same manner, from the decks of a barge and a ship. The samples, which consisted of a large number of small particles, were scraped up, put into containers and sent back to the Laboratory for analysis or storage. There was one whim sample from Zuni which came from a barge, YFNB 29 and two whim samples from Tewa, one from the YFNB 29 and the other from a ship, YAG 39.(1)

The particles were analyzed to see what, if any, correlation existed between activity and a physical parameter. Activity of a particle refers to the net counts per minute, as detected under four-pi geometry by a thallium activated sodium iodide crystal.

2. PARAMETERS INVESTIGATED

The whim samples were scooped off the deck of a vessel which had been strategically located in the fallout area. It is assumed that the samples were chosen without discriminating against any particular size, color, weight, or shape. When the samples reached the Laboratory a small portion of the total sample was selected for analysis. In general, the particles selected for these analyses were randomly chosen, but some of their physical characteristics had been disturbed in handling the sample itself.* Some of the particles were extremely fragile and were broken before, during, and after their selection.

* Zuni particles were sieved.

The physical parameters observed were color and shape, size, weight, and density. Each of these parameters merits further discussion about the method of measurement and the reproducibility and validity of the results.

2.1 Color and Shape

The color and shape of each particle chosen from the selected portion of the original whim sample were observed under a stereoscopic microscope. A field of view was chosen with an adequate number of single particles and then stripped of all particles. The particles were classified according to their apparent color under the microscope. The most prominent colors observed were yellowish-orange and white. The particles were also classified according to their shape (Fig. 1). The two most frequent shapes were irregular (Fig. 1a) and approximately spherical (Fig. 1b). Figure 1c shows an interesting feature common to most of the spheres observed; they were hollow.

It is interesting to note from the data given in Appendix A that among the colors seen were brown, brilliant yellow and sometimes even a greenish tinge. The frequency of these odd colored particles can sometimes be explained by the method of collecting the sample.

The number of gray porous particles found is of interest. It is possible that they represent particles formed in a different region of the cloud than are the spherical and irregular type. This would require further investigation and analysis of these particular types of particles.

2.2 Size

The parameter chosen to measure the size of a particle was the maximum projected diameter seen under a microscope. This method yielded reproducible measurements of size. The size of all Tewa particles selected was recorded.

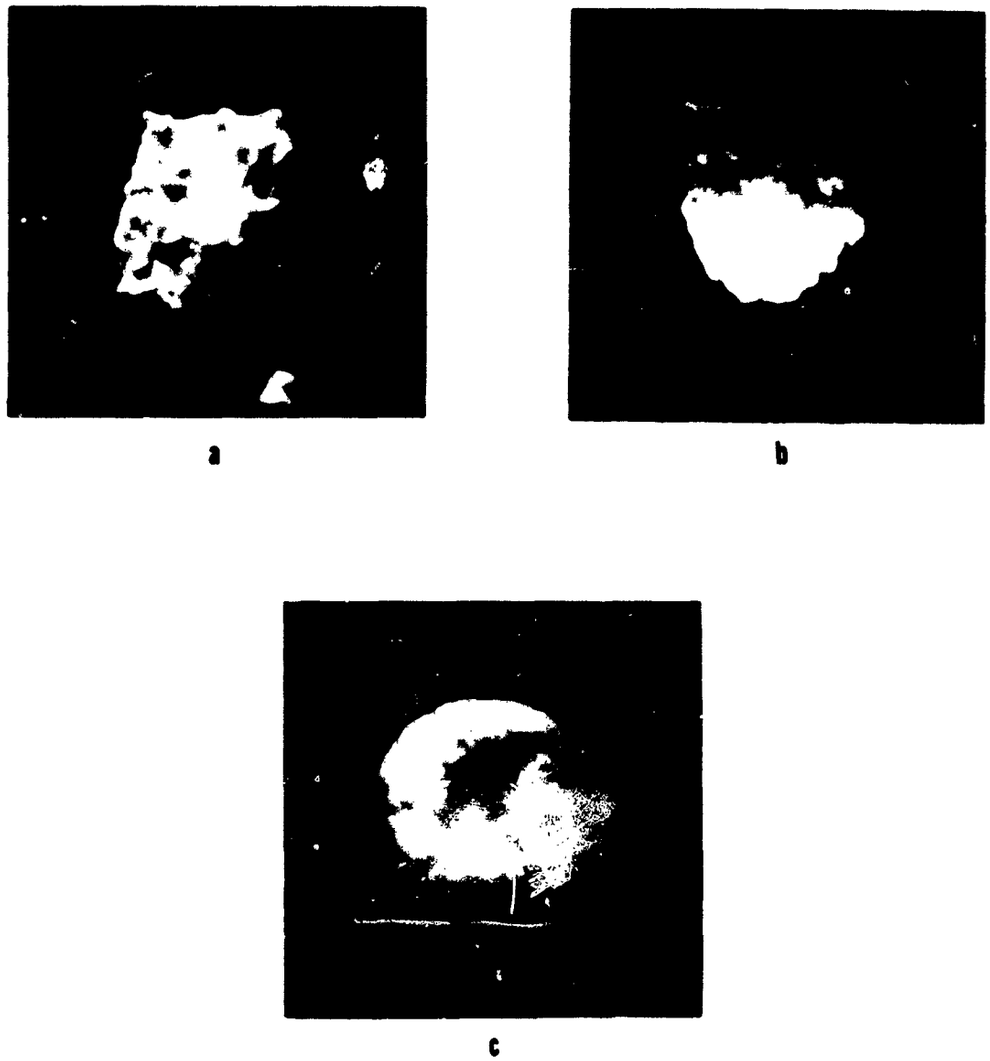


Fig. 1 Examples of Sizes and Shapes of Fallout Particles Analyzed:
(a) Irregular particle,
(b) Spherical particle,
(c) Spherical with hollow center.

2.3 Activity

All of the particles from both events were counted in a crystal well counter. Since the particles were counted over a period of many days, the counts had to be corrected to a common time in order that activities of the particles could be compared.

A general decay curve for each location and event of interest was plotted. The curve used for Zuni was the doghouse counter* decay of YFNB 29-H-79, that for Tewa the doghouse decay of YFNB 29-H-79 and the well counter decay curve of YAG 39-C-21.(1) It was necessary to make two assumptions: (1) that the doghouse and well counter decay curves have the same slope, and (2) that all particles decay with slopes similar to the general decay curves from the same location as the particle. Both of these assumptions are open to justifiable criticisms. A plot showing the decay of two particles picked off the same collector is shown in Fig. 2. This plot illustrates the weakness of the second assumption. When considering the difference in decay slope for individual particles, as well as the difference in slope which characterizes a counter's efficiency, then the validity of correction to a common time is questionable. Although the activity (c/m) of a particle is reproducible, the ratio of the activities of two particles counted on D+40 and corrected to D+30 is not necessarily a constant and the error introduced is not a constant one.

2.4 Weight

A number of particles from Tewa whim samples were weighed with an Ainsworth microbalance. The principal error introduced in weighing was due to crumbling of particles during handling.

* A large shielded scintillation counter, colloquially termed "doghouse" because of its size and shape.

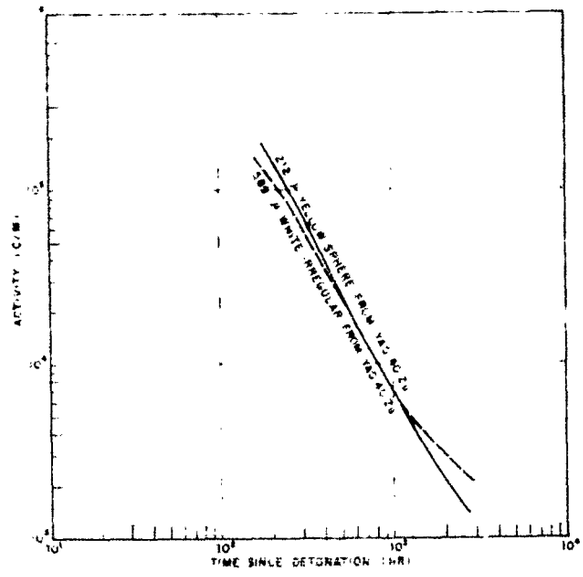


Fig. 2 Decay curves of two particles from the same collector.

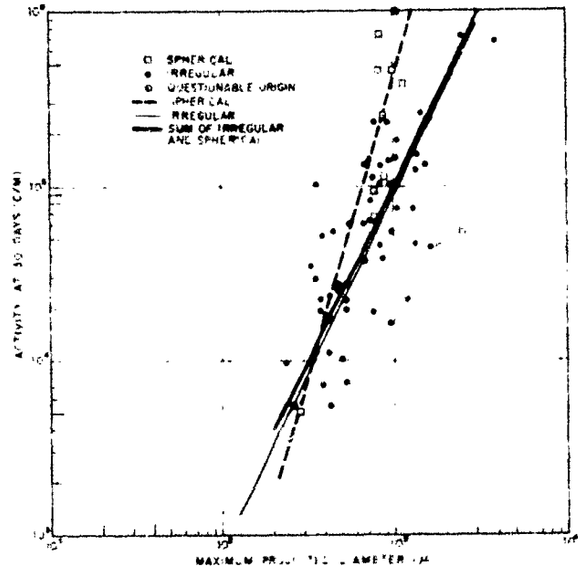


Fig. 3 Activity as a function of maximum projected particle diameter.

2.5 Density

The density of a particle was determined by letting it come to an equilibrium point in a density gradient tube. The gradient was made with mixtures of bromoform and bromobenzene with density ranges from 2.0 to 2.8 g/cu cm. The ratio of bromoform to bromobenzene to yield a given density mixture was first calculated. Then the density of the mixture was checked with a refractometer.

The errors introduced in determining the density of small porous particles are numerous and a few are quite critical. The most significant error is introduced by the amount of air trapped in any cavities the particle possesses. This error can be minimized by giving the gradient tube a sharp rap on the side after a particle has entered. This rap releases most of the trapped air and allows a particle to fall to an equilibrium position. Some other errors are; (a) the amount of the particle dissolved by the mixture, (b) the slowing down of a particle as it crosses a boundary layer which frequently introduces faulty recording of density, and (c) convection currents in the tube.

3. CORRELATION OF PARAMETERS

Having in mind the above errors which are introduced when physical measurements of small particles are made will aid in understanding the difficulty of attempting to correlate the parameters.

3.1 Size vs Activity

The size-activity plot for the combined particles from the test vessels,YAG 39 and YFKB 29,Event Tewa,is shown in Fig. 3. It indicates that there is a trend

of increasing activity with particle size. Some of the prominent scattering can be explained by highly irregular particles. By examining some of the particles on the periphery of the plot a better insight into the scattering can be gained. Four of these particles and their characteristics from Appendix A are shown in Fig. 4. The two particles circled in Fig 3 are shown in Fig. 4b and c, thus some of the scattering can be attributed to background particles that had become contaminated.

The correlation between size and activity for all sixty nine Tewa particles was found by least squares, assuming a logarithmic relationship, to be

$$A_{(D+30)} = 9 \times 10^{-2} D^{2.01} \qquad (1)$$

with a residual error* of 206%

where

$A_{(D+30)}$ = activity (c/m) at thirty days since detonation.

D = maximum projected diameter (microns).

It is evident that the activity range for any given diameter is so large that no definite function can adequately describe the correlation.

The spherical particles in Fig. 3 are identified by squares. The relation found using the same assumptions as above is

$$A_{(D+30)} = 2.76 \times 10^{-5} D^{3.37} \qquad (2)$$

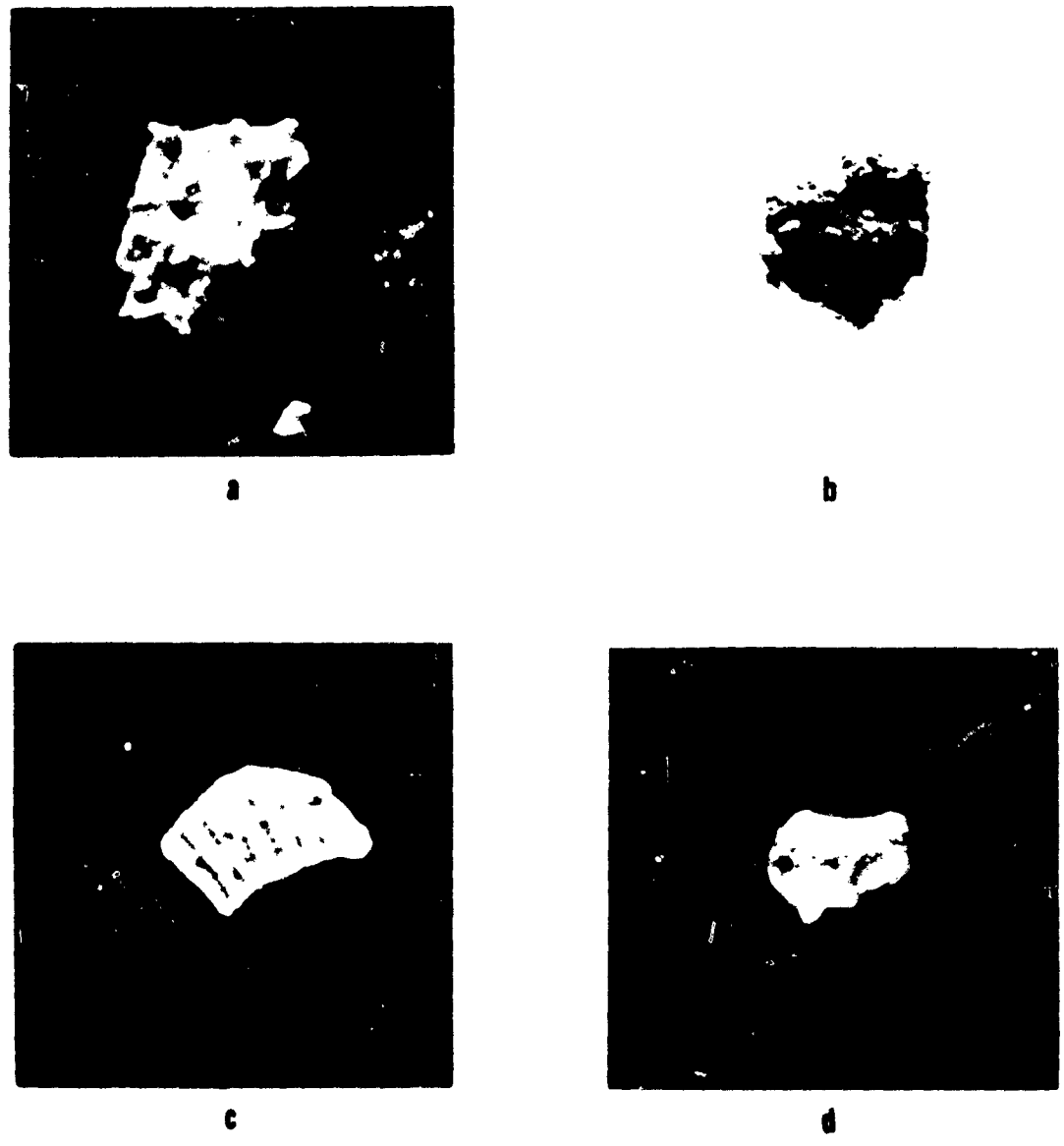
with a residual error of 430% and a total of only nine particles.

The relationship for all sixty irregular particles is

$$A_{(D+30)} = 1.36 \times 10^{-1} D^{1.92} \qquad (3)$$

---

* Residual error is the error which cannot be attributed to the linear regression.



a b c d

Fig. 4 Assorted Fallout Particles:
(a) Particle 158, white irregular, 2508 μ 7.2×10^5c/m at D+30,
(b) Particle 166, brown irregular, 2508 μ, 5.4×10^4c/m at D+30, presumably not a fallout particle,
(c) Particle 177, white irregular (grooves like a shell), 1881 μ, 4.4×10^4c/m at D+30, believed to be a piece of shell on the barge before the shot,
(d) Particle 195, white irregular 2112 μ, 4.4×10^5c/m at D+30.

and the residual error, 191%.

From the above results, it would seem any estimates for activity of a number of spherical particles would be expected from Eq. 1 to be low while the same measured D for a number of irregular particles would yield a high activity value.* This indicates one must not speak of activity vs size but rather activity vs size vs particle type. The resulting dispersion and the above fact seems to indicate that a new size parameter which describes the irregularity of a particle may merit further investigation.

3.2 Weight vs Activity

Figure 5 shows a weight-activity plot. A linear relationship on log log paper was hypothesized and a curve fitted using the method of least squares. The relationship is

$$A = 3.2 \times 10^3 W^{0.7} \qquad (4)$$

and the residual error = 136%

where W = weight, (μg).

The dashed lines on Fig. 5 represents 95% confidence intervals. A relationship between activity, weight, and maximum projected diameter was found by treating each as variables and using least squares.

$$A = 178 W^{0.35} D^{0.63} \qquad (5)$$

It has been hypothesized[2] that fallout particles, which in the Eniwetok Proving Ground are chiefly calcium compounds, are influenced by the following reaction:

* As seen on Fig. 3., this is only true for particles greater than 320 microns.

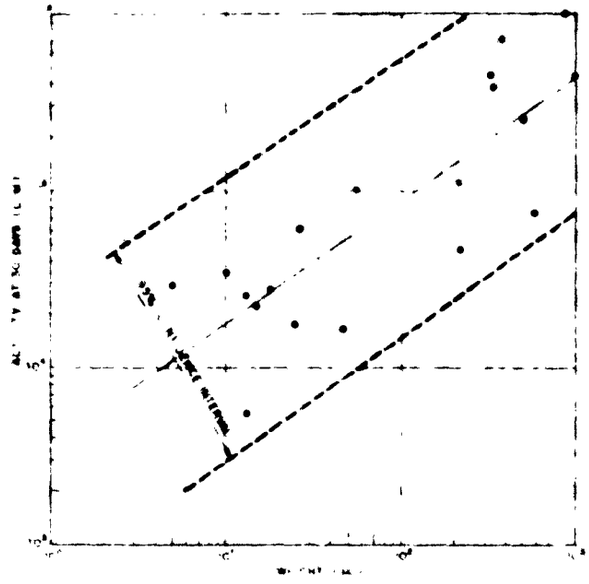


Fig. 5 Activity as a function of the particle weight.

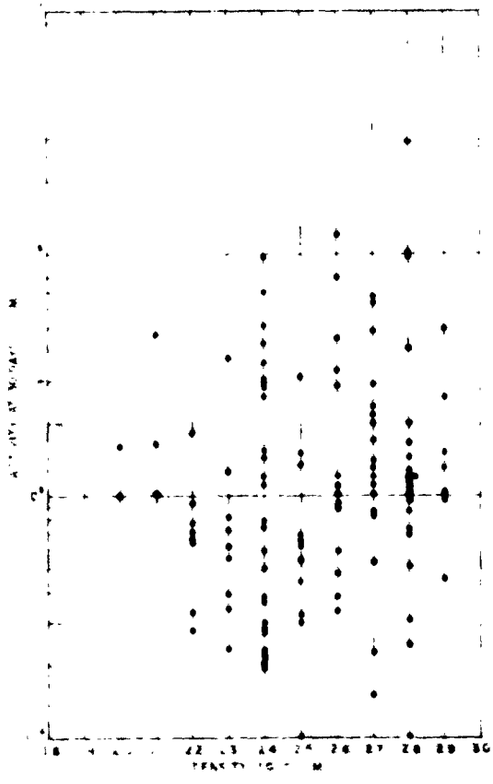


Fig. 6 Activity as a function of the particle density.

$CaCO_3 \longrightarrow CO_2 + CaO \xrightarrow{H_2O} Ca(OH)_2 + CO_2 \xrightarrow{\sim 10\%} CaCO_3 + H_2O$, which has an adverse effect on any weight or density parameter measured. The increase in weight as a function of time would depend upon the quantity of $CaCO_3$ present, porosity, surface area, and the atmosphere surrounding the particle. It is evident that as a function of time the activity of each particle would decrease while its mass increases. The change in mass as a function of time is only significant at early times, such as 2 to 8 hr after detonation.

The preceding equations can be considered only approximate functional relationships with sizeable residual errors. It appears, however, that the activity is functionally related to the weight and projected diameter of a particle, this function still not being adequately described.

3.3 Density vs Activity

A density-activity plot is shown in Fig. 6. These particles were selected from the Zuni samples. The plot shows no apparent correlation between activity and density.

Inspection of Fig. 6 shows a clustering of particles at $\rho = 2.3$ and $\rho = 2.7$. A plot of the percentage of particles falling in a given density range vs density is shown in Fig. 7. The heavy line, percentage of total particles falling in a given density, most clearly demonstrates the clustering. The prominent peaks are at $\rho = 2.3$ and $\rho = 2.7$. To further examine these peaks a plot was made showing the percentage of yellow and white spheres with a given density. The maximum of the white spheres fall at $\rho = 2.3$, and the maximum of the yellow at $\rho = 2.7$. The density distribution is recorded in Table 1. It seems valid to say that the yellow spheres are more dense than the white.

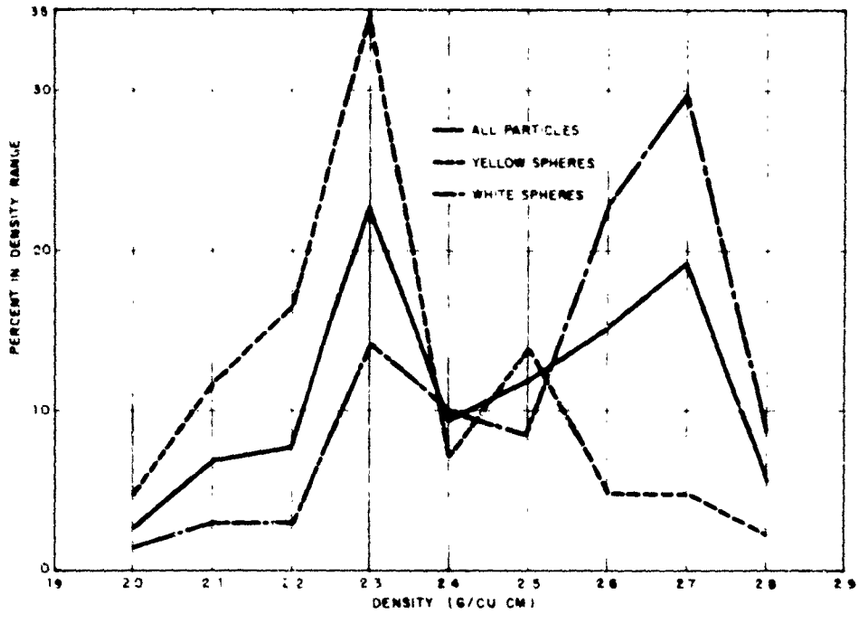


Fig. 7 Density distribution of the particles analyzed.

Table 1 Density Distribution

Total number of particles (N) - 120

Total number of yellow spheres - 71

Total number of white spheres - 43

Mean density of all spheres ($\bar{\rho} = \frac{\Sigma f_i \rho_i}{N}$) = 2.46

Mean density of yellow spheres - 2.53 gm/cm^3

Mean density of white spheres - 2.33 gm/cm^3

Density (g/cm^3)	Percentage of Total Particles	Percentage of Yellow Spheres	Percentage of White Spheres
2.0	2.5	1.4	4.7
2.1	6.7	2.8	11.6
2.2	7.5	2.8	16.3
2.3	22.5	14.0	35.0
2.4	9.2	9.9	7.0
2.5	11.7	8.5	13.9
2.6	15.0	22.6	4.7
2.7	19.2	29.6	4.7
2.8	5.8	8.5	2.3

The activity range of the particles is shown in Table 2.

Table 2 Activity Range

		Activity at D+30 (c/m)			
		10^3-10^4	10^4-10^5	10^5-10^6	10^6-10^7
Percentage of spheres in activity range	yellow	-	36	60	4
	white	5	55	40	-

Thus it would appear that the yellow spheres are more active than the white ones. Combining these results could mean that the yellow spheres are produced in a different region of the cloud than the white.

4. SUMMARY

The results of this investigation may be summarized as follows; (a) $A = K_1 D^n$ and $A = K_2 W^n$ each of which must be derived and applied to its own species, after this is done there is still a sizeable residual error, (b) the yellow spheres are more dense than the white ones, and (c) the order of increasing activity seems to be white irregular, white spheres, and yellow spheres.

The hope of finding better defined functions between particle activity and physical parameters awaits improvements in defining these parameters and the collection of more data.

Approved by:
E. R. Tompkins
E.R. TOMPKINS
For the Scientific Director

References

1. T. Triffet and others, "Characterization of Fallout", Operation REDWING, USNRDL-ITR-1317. (CLASSIFIED).

2. C.E. Adams, "The Nature of Individual Radioactive Particles, V. Fallout Particles from Shots Zuni and Tewa", Operation REDWING, USNRDL-TR-133, 1 Feb. 1957 (CLASSIFIED).

Appendix A

SINGLE PARTICLE ANALYSIS

The results of the analyses of 196 particles are listed below:

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Zuni	Whim Sample YFNB 29					
1			White Sphere		1.51×10^4		
2			White Irregular		3.05×10^4		2.4
3			White Irregular		2.23×10^4		2.3
4			Yellow Sphere		2.30×10^5		2.6
5			Yellow Sphere		6.30×10^5		2.6
6			Yellow Sphere		3.25×10^5		2.5
7			White Sphere		1.40×10^5		2.6
8			Yellow Sphere		9.6×10^5		2.3
9			Yellow Sphere		3.7×10^5		2.2
10			Yellow Sphere		7.9×10^5		2.5
11			Yellow Sphere		7.0×10^5		2.3
12			Yellow Sphere		1.1×10^5		2.6
13			Yellow Sphere		2.05×10^5		2.6
14			White Sphere		3.8×10^4		2.3

SINGLE PARTICLE ANALYSIS

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Zuni	Whim Sample YFNB 29					
29			Yellow Irregular		1.21×10^6		2.5
30			White Sphere		7.4×10^3		2.3
31			Yellow Sphere		2.25×10^4		2.6
32			Yellow Sphere		4.4×10^5		2.5
33			White Sphere		3.4×10^4		2.2
34			Yellow Sphere		1.5×10^5		2.7
35			Yellow Sphere		6.8×10^4		2.4
36			White Sphere		3.1×10^5		2.4
37			1/2 White Sphere		1.5×10^5		2.3
38			3/4 Yellow Sphere		6.25×10^4		2.1
39			White Sphere		7.7×10^4		2.1
40			White Sphere		2.8×10^5		2.3
41			Yellow Sphere		2.5×10^5		2.7
42			White Sphere		2.8×10^5		2.5

SINGLE PARTICLE ANALYSIS

Specification of Particle No.	Event	Location	Parameters: Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Zuni	Whim Sample YFNB 29					
43			White Sphere		2.7×10^4		2.3
44			Yellow Sphere		6.5×10^4		2.4
45			1/2 White Sphere		5.9×10^4		2.3
46			White Sphere		9.2×10^4		2.5
47			White Sphere		7.0×10^4		2.1
48			Yellow Sphere		2.9×10^6		2.7
49			Yellow Sphere		4.4×10^4		2.41
50			White Sphere		5.0×10^5		2.3
51			3/4 White Sphere		3.5×10^5		2.3
52			White Sphere		8.7×10^4		2.5
53			White Irregular		2.45×10^3		2.6
54			White Sphere		4.2×10^5		2.3
55			Yellow Sphere		6.7×10^5		2.6
56			Green Irregular		9.2×10^4		2.1

SINGLE PARTICLE ANALYSIS

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Zuni	Whim Sample YFNB 29					
57			White Sphere		7.4×10^4		2.3
58			White Sphere		1.58×10^5		2.0
59			Yellow Sphere		2.6×10^5		2.3
60			Yellow Sphere		4.8×10^5		2.6
61			Green Sphere		3.8×10^4		2.5
62			Yellow Sphere		1.25×10^5		2.7
63			White Sphere		6.6×10^4		2.1
64			Yellow Sphere		5.9×10^4		2.5
65			Yellow Sphere		1.2×10^5		2.5
66			Yellow Sphere		1.12×10^5		2.3
67			White Sphere		5.4×10^4		2.2
68			Yellow Sphere		1.2×10^5		2.7
69			Yellow Sphere		5.2×10^4		2.4
70			Yellow Sphere		3×10^4		2.7

SINGLE PARTICLE ANALYSIS

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Zuni	Whim Sample YFNB 29					
71			Yellow Sphere		1.7×10^5		2.6
72			White Sphere		6.1×10^4		2.2
73			Yellow Sphere		1.53×10^5		2.4
74			White Sphere		2.85×10^4		2.3
75			White Sphere		1.0×10^5		2.5
76			Yellow Sphere		1.18×10^5		2.6
77			White Sphere		7.2×10^4		2.2
78			Yellow Sphere		1.42×10^5		2.3
79			White Sphere		2.3×10^4		2.2
80			White Sphere		2.1×10^4		2.3
81			Yellow Sphere		6.9×10^4		2.7
82			Yellow Sphere		1.03×10^4		2.7
83			Yellow Sphere		2.05×10^5		2.7
84			Yellow Sphere		1.28×10^5		2.4

SINGLE PARTICLE ANALYSIS

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Zuni	Whim Sample YFNB 29					
85			Yellow Sphere		9.6×10^4		2.8
86			Yellow Sphere		1.02×10^5		2.7
87			White Sphere		9.8×10^3		2.4
88			Yellow Sphere		1.2×10^5		2.3
89			Yellow Sphere		8.0×10^4		2.2
90			1/2 Yellow Sphere		5.3×10^4		2.6
91			Yellow Sphere		2.9×10^4		2.3
92			Yellow Sphere		2.35×10^5		2.6
93			Yellow Sphere		1.05×10^6		2.7
94			Yellow Sphere		1.3×10^5		2.6
95			Yellow Sphere		9.9×10^5		2.7
96			White Irregular		2.4×10^4		2.7
97			Yellow Sphere		8.6×10^4		2.6
98			Yellow Sphere		1.3×10^5		2.8

SINGLE PARTICLE ANALYSIS

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Zuni	Whim Sample YFNB 29					
99			White Sphere		3.2×10^4		2.4
100			White Sphere		1.43×10^5		2.7
101			Yellow Sphere		5.1×10^4		2.7
102			Yellow Sphere		1.09×10^5		2.6
103			White Sphere		5.0×10^3		2.4
104			Yellow Sphere		6.9×10^4		2.7
105			Yellow Sphere		1.63×10^5		2.7
106			White Sphere		1.08×10^5		2.5
107			Yellow Sphere		4.8×10^4		2.5
108			White Sphere		3.3×10^4		2.5
109			White Sphere		5.0×10^4		2.3
110			Yellow Sphere		1.1×10^5		2.7
111			Yellow Sphere		1.05×10^5		2.7
112			Yellow Sphere		8.6×10^4		2.7

SINGLE PARTICLE ANALYSIS

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Zuni	Whim Sample YFMB 29					
113			White Sphere		4.5×10^4		2.8
114			Yellow Sphere		1.2×10^5		2.7
115			Yellow Sphere		8.5×10^4		2.6
116			Yellow Sphere		6.5×10^4		2.4
117			White Sphere		1.5×10^4		2.6
118			Yellow Sphere		1.1×10^5		2.7
119			Yellow Sphere		2.0×10^4		2.3
120			Yellow Sphere		7.0×10^4		2.7
121			Yellow Sphere		1.0×10^5		2.8
122			Yellow Sphere		1.2×10^5		2.7
123			White Sphere		3.9×10^4		2.2
124			White Irregular		2.3×10^4		2.3
125			Yellow Sphere		9.8×10^4		2.7
126			White Sphere		1.8×10^5		2.1

SINGLE PARTICLE ANALYSIS

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Teva	Whim Sample YAG-39					
127			White Sphere	281	5.0×10^3		
128			White Irregular	841	1.0×10^5	55	
129			White Irregular(a)	429	1.7×10^4	25	
130			White Irregular(b)	858	1.3×10^5		
131			White Irregular	495	2.7×10^4	18	
132			White Irregular	330	3.4×10^4	10	
133			White Irregular	380	2.2×10^4	15	
134			White Irregular	479	2.5×10^4	13	
135			White Irregular	330	8.5×10^3		
136			White Irregular	264	5.4×10^3		
137			White Irregular	957	1.6×10^4	47	
138			White Irregular	363	2.9×10^4	5	
139			White Irregular(c)	561	6.0×10^4	27	
140			White Irregular	1386	4.6×10^4	216	

SINGLE PARTICLE ANALYSIS

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Tewa	Whim Sample YAG-39					
141			White Irregular	429	5.4×10^3	13	
142			White Irregular	1056	2.8×10^5		
143			White Irregular(d)	792	5.4×10^4		
144			White Irregular	462	5.2×10^4		
145			White Irregular	429	1.1×10^4		
146			White Irregular	528	2.7×10^4		
147			White Irregular	1221	2.2×10^4		
148			White Irregular	957	2.0×10^5		
149			No sample				
150			White Irregular	1386	1.2×10^5		
151			White Irregular	528	7.5×10^3		
152			White Irregular	495	1.0×10^4		
153			White Irregular	363	1.0×10^5		
154			White Irregular(e)	660	6.0×10^4		

SINGLE PARTICLE ANALYSIS

Specification of Particles			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Teva	Whim Sample Yag-39					
155			White Irregular	396	$5.1x10^4$		
156			White Irregular	693	$1.3x10^5$		
157			White Irregular	396	$7.2x10^3$		
158			White Irregular(f)	2508	$7.2x10^5$		
159			White Irregular(f)	528	$1.9x10^4$		
160			White Irregular(f)	396	$1.9x10^4$		
161			White Irregular	231	$9.5x10^3$		
162			White Irregular	429	$2.3x10^4$		
	Tewa	Whim Sample YFNB 29					
163			Yellow Sphere(f)	821	$4.5x10^5$	310	
164			Yellow Sphere	1122	$3.8x10^5$	321	
165			Yellow Sphere	825	$7.2x10^5$	397	
166			Brown Irregular(g)	2508	$5.4x10^4$		
167			White Sphere	891	$2.5x10^5$	505	

SINGLE PARTICLE ANALYSIS

Specification of Particles			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at B + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Teva	Whim Sample YFNB 29					
168			White Irregular	759	1.1×10^5	220	
169			Yellow Sphere	1056	1.0×10^6	866	
170			White Irregular	1320	7.2×10^4	584	
171			White Irregular(h)	1881	4.4×10^4		
172			White Irregular(i)	1683	4.4×10^5		
173			Grey Irregular(j)	990	5.4×10^4		
174			White Irregular	957	1.4×10^5		
175			White Irregular	1320	1.5×10^5		
176			White Irregular	924	2.3×10^5		
177			White Irregular	1023	1.4×10^5		
178			White Sphere	891	1.1×10^5		
179			White Irregular	1056	4.6×10^5		
180			White Irregular	1587	1.3×10^5		
181			White Sphere	792	9.2×10^4		

SINGLE PARTICLE ANALYSIS

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
	Tewa	Whim Sample YFNB 29					
182			White Irregular	759	1.9×10^4		
183			Grey Irregular	693	3.6×10^4		
184			White Irregular	825	3.8×10^4		
185			White Irregular	1386	1.5×10^5		
186			White Irregular	1452	2.6×10^5		
187			White Irregular	726	8.0×10^4		
188			White Irregular	528	2.2×10^4		
189			White Irregular	726	6.3×10^4		
190			White Irregular	1056	7.4×10^4		
191			White Irregular	1617	2.4×10^5		
192			White Sphere	792	6.5×10^4		
193			White Irregular	726	1.4×10^5		
194			1/2 White Sphere	759	2.3×10^5		

SINGLE PARTICLE ANALYSIS

Specification of Particle			Parameters				
No.	Event	Location	Shape and Color	Size (μ)	Activity at D + 30 (c/m)	Mass (μg)	Density (g/cm^3)
Tewa		Whim Sample YFMB 29					
195			White Irregular	2112	4.4×10^5		
196			White Irregular	3960	6.8×10^5		

(a) White irregular with two black dots.

(b) White irregular with one black dot.

(c) Conglomeration of smaller spheres.

(d) White irregular with dark yellow spot.

(e) Black discoloration on one end.

(f) Photographed.

(g) Yellow and silver discoloration.

(h) Had grooves like a clam shell.

(i) 1140.

(j) Very porous.

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DATE ISSUED: 1 August 1957