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ANALYSIS OF DEBRIS FROM APG-3, THE SIMULATED DESTRUCT SYSTEM TEST OF A FULL-SCALE ROVER/NERVA REACTOR

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ABSTRACT

Analysis of fragments from one of four jets of debris of a high-explosive destruct test of a nuclear reactor showed that the distribution of weight with particle size was bimodal, with a major peak near 4 mm and a minor peak near 0.2 mm. The distribution of activity also was found to be bimodal, with a more pronounced peak at 0.2 mm. Specific activity calculations showed that the peak centered about the 0.2 mm size range contained the debris that was the most highly enriched in uranium. Little uranium activity was noted in particles below this size.

Comparison with results of other investigations showed that a small sampling effort such as was undertaken provides adequate sampling of the debris from one jet. However, variation in particle characteristics from one jet to another would require sampling all jets in a future operation.

SUMMARY

APG-3 was the high-explosive destruct test of a full-scale simulated ROVER/NERVA nuclear propulsion engine. The test was conducted to provide data on the distribution of frequency, weight, and fuel content of the fragments as a function of size. This information is desired for determining the safety aspects of using a NERVA reactor for space exploration.

This laboratory mounted a 27-station collection array for the project. The debris collected was separated into 16 size-fractions by hand agitation through standard sieves. The resulting fractions were weighed, and the uranium content was estimated by comparing the counting rate of the fraction to that of a reference standard of ground-up fuel rod. These counting rates were determined in a gamma scintillation well-crystal detector. Necessary corrections were made for variations in sample weights.

Reported are the size distribution of the debris weight and activity. Results are presented as frequency histograms and cumulative percent graphs.

INTRODUCTION

PURPOSE

APG-3 was a test conducted by the Rover Flight Safety Program of the Space Nuclear Propulsion Office (SNPO) to determine the effects of destroying a full-scale NERVA* reactor by conventional explosives. The need for such destruction could result from an accident at the launch of a space vehicle, or destruction could be planned to occur upon re-entry of such a vehicle from orbit. The radiological hazard resulting from the destruction of a reactor by any method must be evaluated and a characterization of the debris is essential to this evaluation.

BACKGROUND

To be safely utilized, the method of reactor destruction should cause the radioactive material in the atmosphere to be suspended above the earth or dispersed over the earth's surface so as to produce low levels of contamination. One method of accomplishing this is to produce micron-sized particles that would burn up on entering the earth's atmosphere.

As an alternative to the nuclear excursion system which had been investigated as Kiwi-TNT,[1] a workable destruct system employing conventional explosives had been developed by Aberdeen Proving Ground (APG) and Picatinny Arsenal, and several scale-model tests had proved its feasibility. The destruction of a full-scale NERVA reactor mockup was planned as a joint operation of APG, Picatinny Arsenal, and Sandia Corporation.

*Nuclear Engine for Rocket Vehicle Applications.

OBJECTIVES

The broad objectives of the test were to determine: (1) the destructive effects of four 105-mm special projectiles on a full-scale mockup of a nuclear engine reactor, (2) the frequency, weight, and fuel content distribution of the fragments as a function of particle size, (3) the velocity and direction of dispersal of the fragments of the reactor core, and (4) the size of particles of the smoke cloud produced during the destruct.

This laboratory was asked to participate in the test and to augment the collection of debris by using NRDL fallout collectors. The debris was to be separated into size fractions by hand-sieving and weighed, and the uranium content of the size fractions was to be related to the response of a gamma scintillation well-counter. The collected debris was to be analyzed to provide data on weight distribution and uranium content as a function of size of the debris particles. This information will serve as input data for a computer analysis of the safety aspects of reactor use in space exploration.

DESCRIPTION OF REACTOR AND TEST SITE

SIMULATED REACTOR

The reactor mock-up was composed of reject components or of similar components that had been modified as described in the final report on APG-3 from APG.[2] Exclusive of a simulated exhaust nozzle, the full-scale model measured approximately 50 in. in diameter and was 92 in. long. The assembled test reactor weighed approximately 8400 lb. and consisted of an outer aluminum casing plus the reactor assembly. The latter included simulated control drums and reflectors, a graphite barrel and sleeve, and the core which was composed of nuclear fuel and an inner reflector.[2] The nuclear fuel in the core closely approximated that of the NERVA reactor in size and configuration but was fabricated of depleted uranium rather than the normally used U-235.

DESTRUCT SYSTEM

Voids were left in the simulated core assembly to accept four 105-mm special projectiles that were detonated to destroy the reactor. The projectiles were positioned approximately 1-foot from the core center at 90° intervals and contained a total of 111.17 lb of explosives.

In the scaled tests, the simultaneous detonation of four symmetrically positioned charges had resulted in four radial jets of debris and one vertical jet. The full scale reactor model was positioned vertically with the core center 9 ft above the ground and oriented so that one of the jets was directed across a paved collecting area.

TEST SITE

A cleared area, 600 ft in radius, had been filled and rolled flat to serve as a test area. An asphalt pad, 300 ft in diameter, was situated between the center and the perimeter of this cleared area in the downwind sector. This pad had been painted white and marked off in 25 x 25-ft squares to aid in photographic documentation and in sample identification.

The simulated reactor was mounted in the center of the cleared area with one of the jets directed across the center of the pad. The material ejected in this jet was to be swept up and analyzed to estimate the spatial distribution of the whole core.

NRDL FALLOUT TRAYS

The NRDL collector tray or pan is a 2-in. deep, 24 x 24-in., 20-gauge, aluminum tray, fitted with a gasketed cover. The tray is uncovered just prior to an event, and the fallout or debris landing in a tray is retained by a baffle of 19 aluminum louvers inclined 45° from the horizontal (Fig. 1). All trays are positioned with the baffle opening facing Ground Zero.

NRDL STATION ARRAY

In field test operations, NRDL has attempted, whenever possible, to simulate an infinite plane or collecting surface when sampling fallout. Consequently, 9 pans, in three rows of three pans each, made up a collecting station, with the outer pans protecting the center pan from the effects of wind bias. The NRDL station array for this test is shown in Fig. 2.

There were 27 9-pan stations located on the pad, within 300 ft of Ground Zero, and another 10 stations located downwind on arcs 400, 500, and 600 ft from ground zero. Each of these outer stations consisted of 16 pans, in 4 rows of 4 pans each, with the center four pans being considered an unbiased sample.

NRDL 377-65

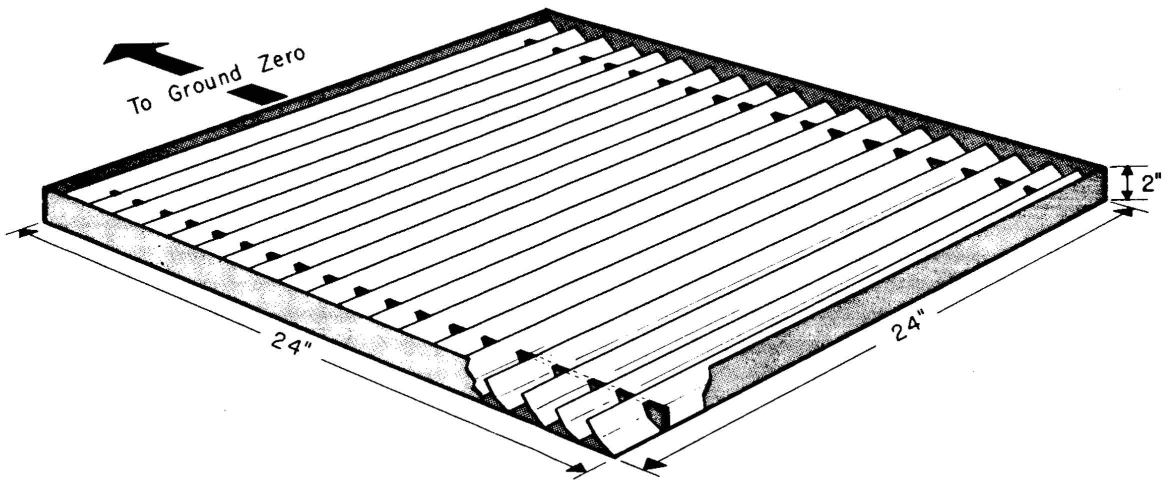

Fig. 1 A Cut-away View of an NRDL Collection Tray Used in Assembling a Collection Station.

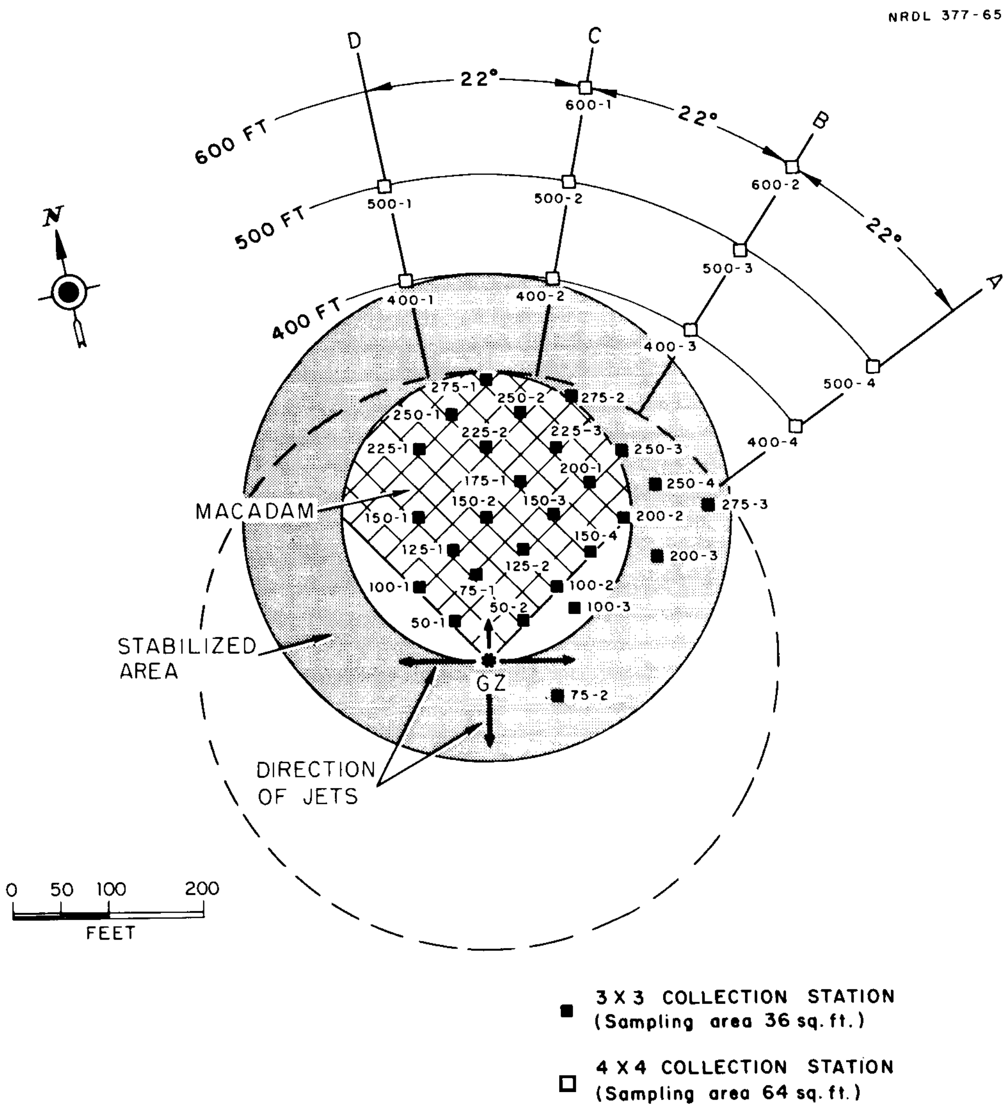

Fig. 2 The Constructed Test Site and the Location of all NRDL Collection Stations on the Macadam Pad and Soil Area.

All stations were located as close to Ground Zero as the boundaries of each particular square allowed, with the pans at the 50-ft and 75-ft distances taped to the asphalt pad to keep them stationary. Wire bands had been wrapped around these close-in collectors to prevent the louvers from being scattered by the shock wave.

SHOT-DAY OPERATIONS

The projectile destruct system destroyed the simulated reactor at 1400 on 22 June 1965. One of the jets produced fell across the center of the pad.

Visual examination after the event revealed that all stations on the pad collected core debris, the amount being a function of the proximity of the station to the jet. No louvers were lost and no displacement of the pans was detected. As soon as access to the area was permitted, the pans were covered and were removed from the test area. The center pan from each station was packaged for shipment to NRDL for analysis and the remaining pans were delivered to APG personnel for mass balance studies.

SAMPLE PROCESSING

TRASH REMOVAL

No processing was attempted in the field. Bits of wood, metal, or plastic material that were obviously not core fragments were discarded as the trays were emptied at NRDL. Fragments of high density (1.8 lb/ ft^3) foam plastic from damaged Sandia collectors were removed from the four largest-sized fractions in the processing of samples. No additional systematic cleaning of samples was attempted except that the fragments larger than 4.76 mm were assayed in the counter to separate fuel fragments from reflector graphite.

WEIGHING AND SIEVING OPERATIONS

After initial weighings of the samples collected by the pans on the pad, each gross sample was hand agitated through a nest of sieves for a 10-min period. Hand agitation was used instead of mechanical agitation to minimize breaking and abrading of the particles by the sieving operation. A gross sample was thus separated into 16 sized fractions from 4.76 mm to 0.044 mm. Five additional fractions, larger than 4.76 mm, are included in the Aberdeen and Sandia reports but these mesh sizes were not available locally on short order and were eliminated. The 16 sized fractions were weighed to determine the distribution of weight as a function of particle size and to plot the cumulative weight percent for each size range of the pad samples.

The four center pans of the outer stations were counted for gross gamma activity and only those samples with a net count rate greater than 100 counts per minute were given further treatment.

COUNTING PROCEDURES

The sized fractions were counted in a 3 x 3-in. gamma scintillation well-crystal, with related amplifiers and a Systron scaler. Fractions weighing less than 5 g, or aliquots of heavier fractions, were counted long enough to realize at least 10,000 net counts or for a maximum counting period of 20 min per sample.

Samples with a count rate greater than 10,000 cpm were counted for a minimum of 2 min with a reproducibility of $\pm$ 2 %. A reproducibility of $\pm$ 6 % was calculated from a 20-min count of the sample with the lowest count rate.

Sample self-absorption required a correction in count rate as a function of weight. The counter response to 100-mg increments of a ground-up fuel rod furnished by Aberdeen was determined and compared to a response curve calculated on the basis of negligible self-adsorption. Aliquots of the heavier fractions were taken, and all samples weighing more than 200 mg were adjusted for self-shielding effects. Appendix A describes the treatment of counting data in detail, showing the calibration curve used and illustrating the procedure with a sample calculation.

RESULTS

INDIVIDUAL SAMPLES

Each of the 27 gross samples from the center pans on the pad was weighed and sieved, and the material suspended on each screen was weighed and counted. The percent of total sample weight and the cumulative weight percent of each size range were determined. The particles in the coarse fractions varied greatly in size, shape and activity as shown in Appendix A. These fractions were separated into active and inactive particles and photographed. Appendix B lists the particle data from the individual samples and shows the photographic documentation of the coarse fraction from stations in the path of the jet.

The center pans of the NRDL pad stations collected a total of 1102.78 g of debris, with gross sample weights varying from 188.89 to a low of 0.31 g. After sieving, the fraction weights ranged from 37.83 to 0.011 g.

The cumulative weight data for each sample show some degree of curvature from a straight line when plotted on log-probability paper. The differential weight distribution curves of the individual samples cannot be described as log normal and the shape indicates a bimodal distribution.

Each sized fraction was counted to determine the uranium content of the debris. After weight corrections were applied to adjust the count rate, plots were made of the percent of the total activity retained per size fraction and cumulative percent activity as a function of size range.

The activity distribution of these sized samples generally followed the weight distribution, with most of the activity in the large fragments, very little activity in the size ranges from 1.19 to 0.210 mm, but a larger percentage in the size ranges below 0.210 mm. The data, but not the plots, are shown in Appendix C.

COMPOSITE SAMPLE

In order to obtain data which would represent a composite of all material collected on the pad, the weights in each size range were summed over all close-in stations. The adjusted count rate of each fraction was converted to uranium content on the basis of the uranium content of the counting standard supplied by APG. The uranium content in each size range was then summed over the pad stations to obtain a composite uranium content-size distribution. The composite weight and activity results are shown both as histograms and cumulative plots in Figs. 3 through 6. Figure 7 shows the specific activity of the debris as a function of particle size. Because each laboratory used a slightly different set of sieves, histograms are normalized to unit area by dividing each weight or uranium content by $\Delta \log_{10} x(\mu)$, the increment of the logarithm of successive size ranges.

OUTER STATIONS

None of the pans at stations 400-2 or 400-4 had a net count rate that exceeded 100 cpm. At all other stations, at least one pan of the four collected enough core material to warrant additional processing.

Stations 400-1 and 500-1 were in the path of the jet and contained significantly more active material than the other stations off the pad. Initial measurements of the samples from station 400-1 showed that the four center pans collected an average of 0.786 g of debris with an estimated average uranium content of 30.4 mg per pan. The pans at station 500-1 collected an average weight of 1.331 g of debris with an average estimated gross content of 12.3 mg of U per pan. The closer stations to the pad collected less dirt than the more distant collectors because of the stabilizing effect of the calcium chloride that had been spread for a distance of 100 feet beyond the pad.

The stations at 400, 500, and 600 feet, adjacent to the path of the jet, collected mainly dust but had an estimated U content of 1.5 to 5.0 mg per pan.

Table B.4 presents the results obtained by sieving the gross samples that contained significant activity. These values are based on count rates only. In order to allow a valid comparison with the APG and Sandia Corporation results, they have not been incorporated into the composite sample data.

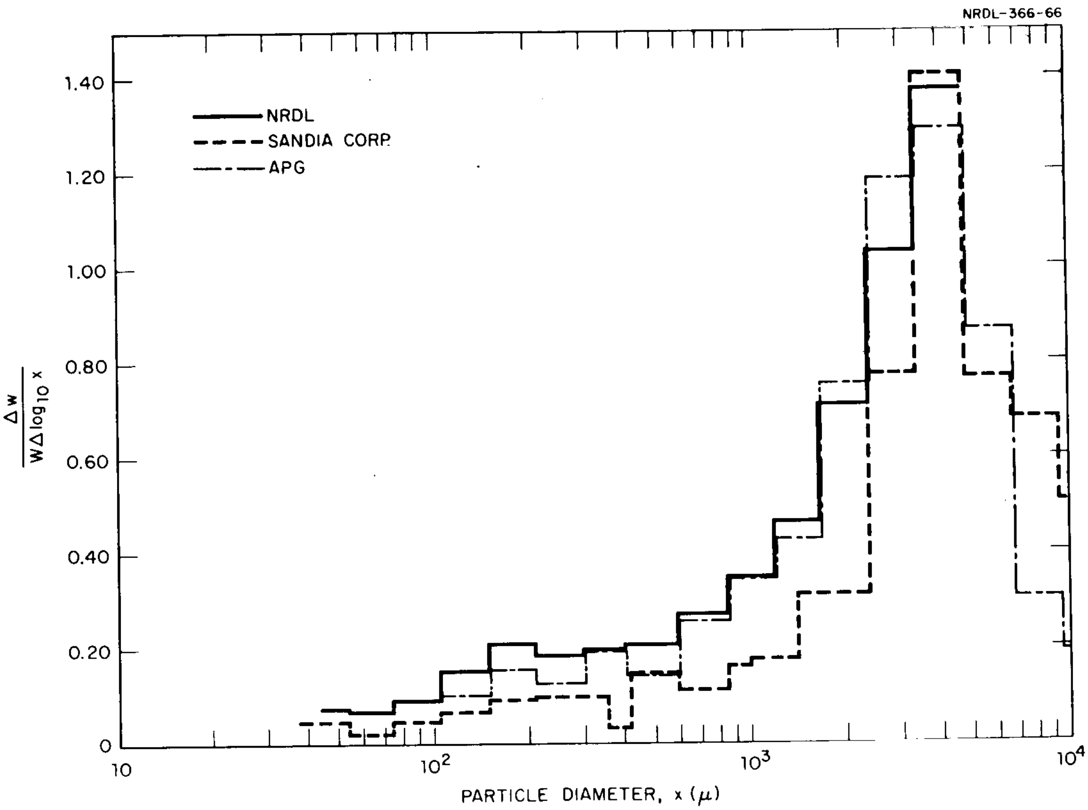

Fig. 3 Particle Mass Distribution - Normalized Frequency Curves

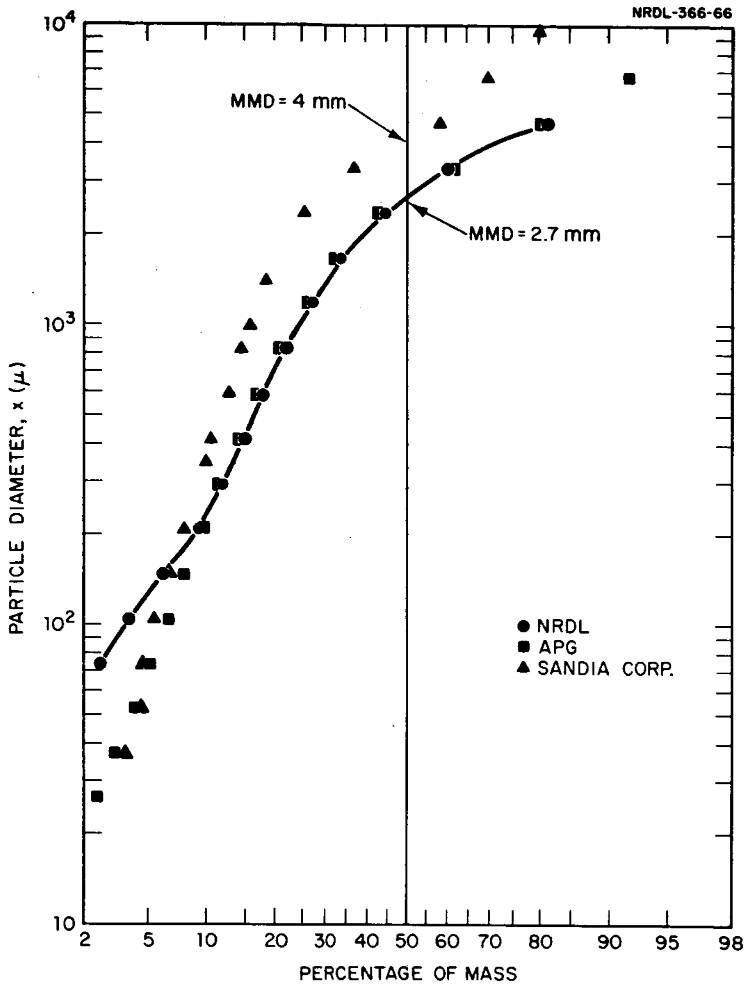

Fig. 4 Particle Mass Distribution - Cumulative Curves

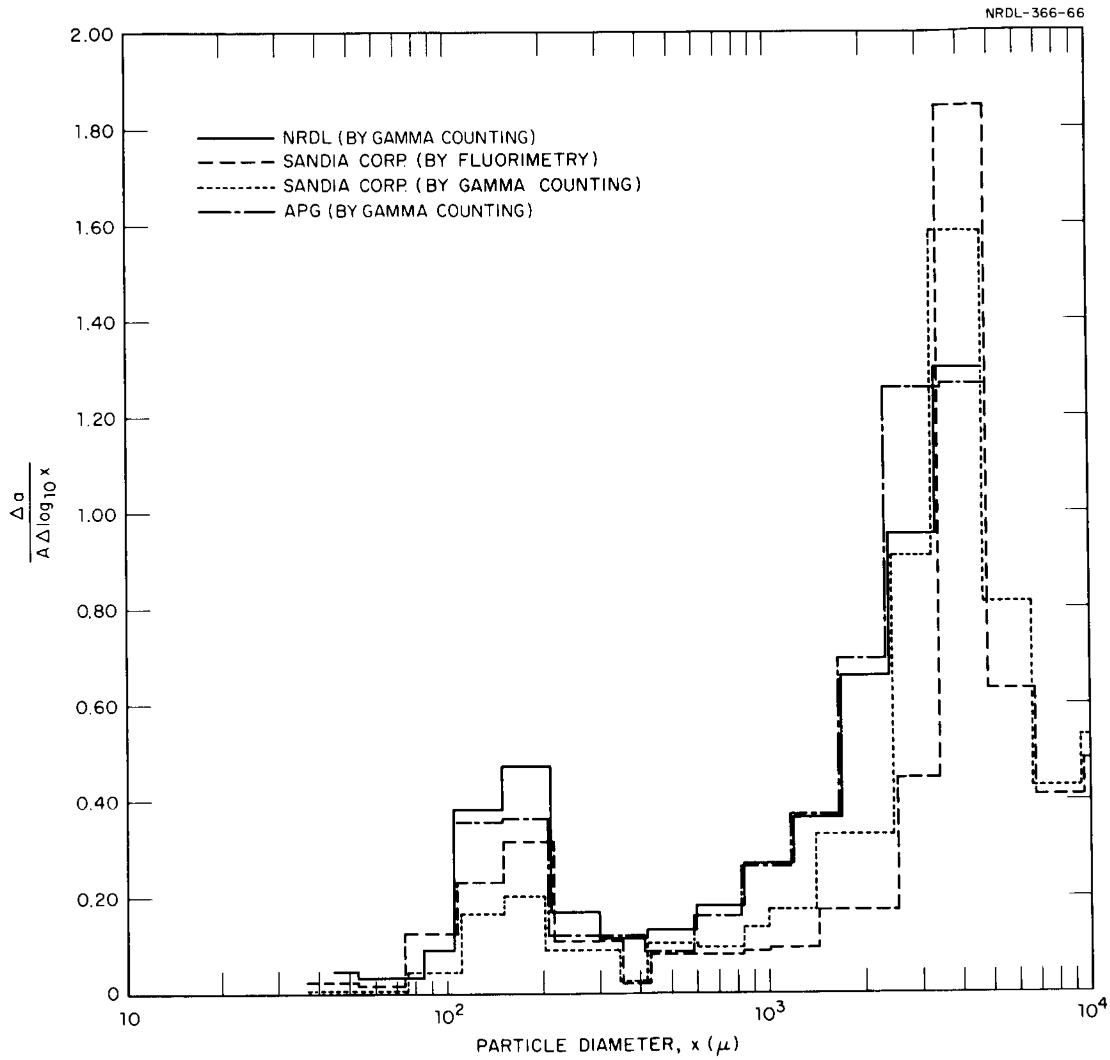

Fig. 5 Uranium Distribution - Normalized Frequency Curves

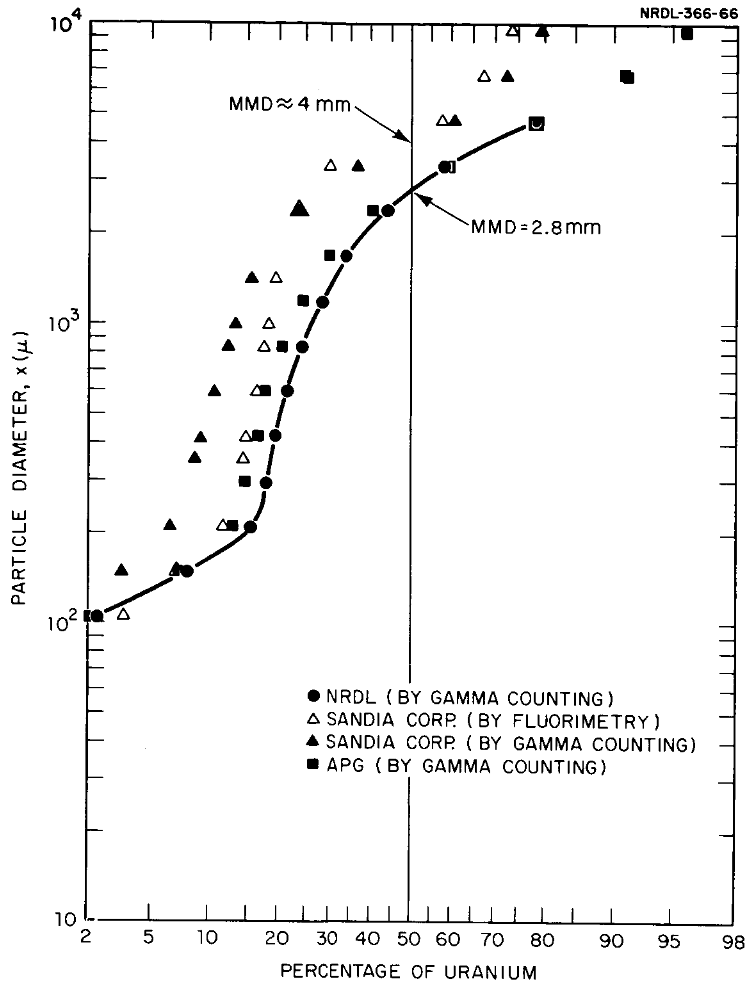

Fig. 6 Uranium Distribution - Cumulative Curves

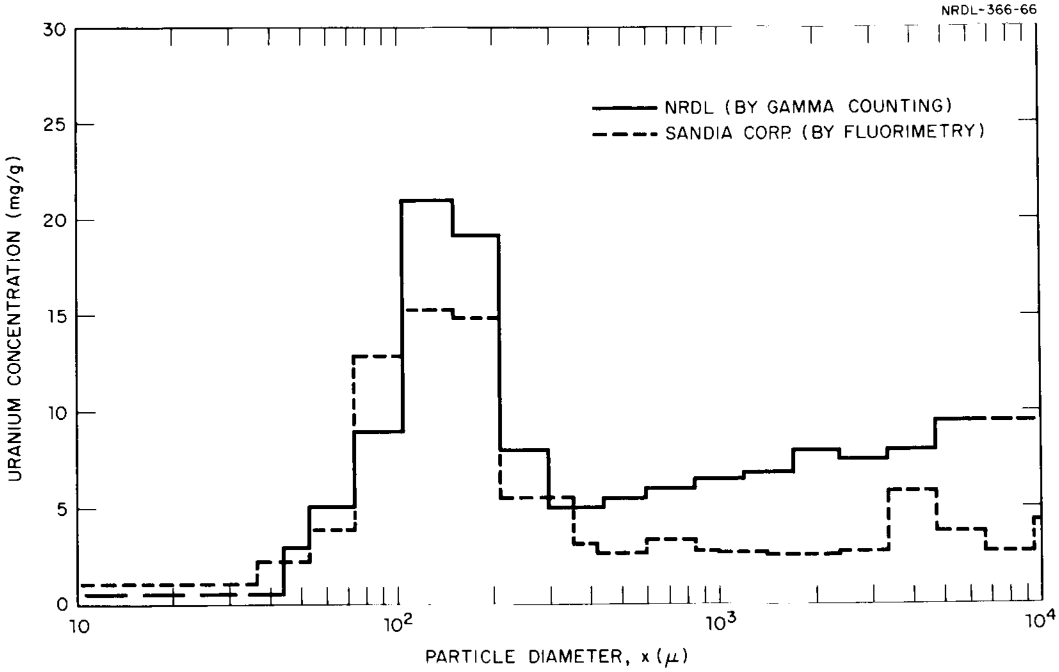

Fig. 7 Variation of Uranium Concentration with Particle Size

DISCUSSION OF RESULTS

GENERAL CONSIDERATIONS

The values reported in Tables B.1, B.2, and B.3 are considered to be a valid characterization of the debris that landed on the pad, even though the composite sample weight was small in relation to the reactor weight and the weights treated by APG and Sandia Corporation. The results obtained by the NRDL collection and analysis techniques, which involved a minimum of sample processing, compare favorably with results reported by APG,[2] wherever comparisons can be made. This is shown by Figs. 3-7 which include APG and Sandia data for comparison. This agreement demonstrates the representativeness of NRDL's sampling. The Sandia Corporation results[3] show some differences, however, particularly in that Sandia collected and measured a greater proportion of large fragments than were retained in the NRDL pans. This difference cannot be attributed to wind because the particles are too large. It may be explained by the fact that different jets were sampled by Sandia Corporation than by APG and NRDL. However, the smaller mass median diameter (MMD) of the debris reported by NRDL, as compared to that of Sandia Corporation may reflect the influence of the wind in addition to the difference in particle size distribution from the jet.

PARTICLE WEIGHT DISTRIBUTION

Figure 3 illustrates the bimodal character of the mass distribution of the composite sample. This is shown by a large peak at 4000 μ and a small peak in the neighborhood of 200 μ. Both the size fractions at the low end and the high end of the curve contained proportionately more debris than the intermediate size range from 0.210 to 1.19 mm. This bimodal character is also shown by the Sandia data and the original, unsmoothed APG data.

A MMD of 2.8 mm is indicated from Fig. 4, the graph of the cumulative weight percent versus the particles in the fractions less than the size noted.

The size fraction 3.38 to 4.76 mm contained 21 % of the total weight collected, with less than 10 % of the weight in the sizes smaller than 0.210 mm. Approximately 18 % of the total weight was in the largest size class, greater than 4.76 mm, while one percent of the composite sample was in the smallest size-fraction, < 0.044 mm.

URANIUM CONTENT

As illustrated by Fig. 5, the composite sample shows a bimodal activity distribution with the smaller peak between 0.105 and 0.210 mm and the major activity concentration building up in the fragment sizes greater than 2.38 mm.

Figure 6 shows that more than 55 % of the activity is associated with fragments larger than 2.38 mm, and that about 12 % is associated with fragments in the size classes 0.105 to 0.210 mm. The fact that only 0.2 % of the activity detected was found in the smallest size range (< 0.044 mm) indicates that for the most part, the core material was ejected either in the form of large fragments or as small particles of discrete size.

Figure 7 illustrates the variation in uranium concentration with particle size and compares NRDL and Sandia values in milligrams of uranium per gram of sample. A uranium concentration peak appears in both collections in the size ranges between 105 μ and 210 μ, with the NRDL values concentrated in these sizes, while Sandia Corporation values are distributed more evenly over the size ranges from 74 to 210 μ.

The maximum uranium concentrations of 22 mg/g reported by NRDL and of 15.3 mg/g reported by Sandia Corporation could reflect the variations between jets or the wind influence on the debris collection.

The presence of some uranium in the smallest size fraction is shown also in Fig. 7. Sandia Corporation reports slightly more than 1 mg/g in the size class less than 37 μ, and NRDL shows about 0.5 mg/g in the fraction less than 44 μ.

OUTER STATION DISCUSSION

Most of the activity found in these samples was associated with the stations located in the path of the jet of debris or in the pans of the stations adjacent to the jet. An exception to this pattern was the U concentration found in the smaller fractions at station 400-3. The collection might have been influenced by the simulated nozzle falling in this general area.

Except for two fragments that measured between 840 and 4760 μ, all of the particles were in size ranges less than 590 μ. The activity in these samples was concentrated in a peak covering the size range 105 to 210 μ. The maximum U concentration detected in the sieved samples was 14 mg in the 105-149 μ fraction of one of the pans of station 400-1, a station that collected an average of 30.4 mg of U per pan.

The highest values observed in the < 44 μ fraction of these outer stations, 1.2 and 1.4 mg of U, were found in four of the pans from stations 400-1 and 500-1. The U content in this size range varied between 0.1 and 0.6 mg in the remainder of the samples processed with three pans indicating no U present.

Except for the lack of larger sized particles, the uranium-size distribution of samples obtained from the stations off the pad resembled that of samples collected closer-in; namely, both had a peak in the size range between 105-210 μ and both had a negligible amount of activity in the fraction less than 44 microns.

It cannot be determined from these measurements of the debris collected whether any significant quantity of fuel fragments has been reduced to the fine sizes that might constitute an inhalation hazard. The examination of fine particulate was beyond the scope of this project.

CONCLUSIONS

The close agreement of the values reported, despite variations in collection and processing techniques, indicates that the use of the NRDL arrays alone could provide a sufficient sample to characterize future tests of this sort. The use of an increased number of pans to provide close-in samples and the grinding of the largest fragments to provide a homogeneous sample would provide the same data with a minimum of sample handling and expense. A portion of the effort saved could then be used to sample the other jets and determine the variability of particle weight distribution.

The large particle size of the debris and the lack of activity in the smallest sizes indicate that the core elements were not reduced to micron particles. The destruct system effects on a reactor that had operated for some time might result in a different particle size distribution due to changes in the core materials at operating temperatures.

The debris remains in its original state if further analyses are desired. Such analyses might include better definition of the distribution of larger particles or of the fraction of small particles that contain uranium.

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1. L. D. P. King, "Description of the Kiwi-TNT Excursion", Transactions of the American Nuclear Society, Vol. 8, No. 1, June 1965.

2. W. Dutschke, "Final Report of Engineer Design Test of NERVA Countermeasures (Full Scale)" (U), Aberdeen Proving Ground, Maryland, DPS-1876, February 1966. (Classified)

3. R. E. Berry, J. P. Martin "ROVER/NERVA Destruct System Test Results - Aberdeen Proving Ground-3 (Final Report)", Sandia Corporation, SC-RR-65-620, December 1965.

APPENDIX A

COUNTER CALIBRATION

Figure A.1 illustrates the decrease in response of the counting system due to increasing sample weights. The calculated curve is a projection of the count rate of a 0.100-g aliquot of a ground-up fuel rod counting standard through multiple increments. The observed curve resulted from combining 0.100-g increments, initially, and later 1.000-g aliquots, of ground-up fuel rod and determining the count rate of the total.

In Fig. A.2 the ratio, R, of the calculated count rate to the observed count rate is plotted versus increasing sample weight.

An example of how these curves were used to determine the values reported in Table B.2 is as follows:

1. A 3.2021-g aliquot of the 3360- to 4760-μ fraction of Sample 75-1 counted 34,558 net cpm.

2. The correction factor, 1.31 in this case, was read from Fig. A.2.

3. Using this correction factor, the count rate was adjusted to 45,271 net cpm to reflect the reduction in count rate with increasing sample weight.

4. The total count rate of the whole fraction was estimated from the count rate of the aliquot by multiplying the corrected count rate by the inverse ratio of aliquot weight to total weight of the fraction, 33.6591 g/3.2021 g or 10.5115.

The resulting net count rate expected from this weight of material, after correcting for self-shielding, was 475,866 cpm.

In cases where multiple aliquots of heavier samples were measured, the average of the adjusted count rates and the average weight of the aliquots were determined. These values were used when relating the count rate of the aliquot to that of the total fraction.

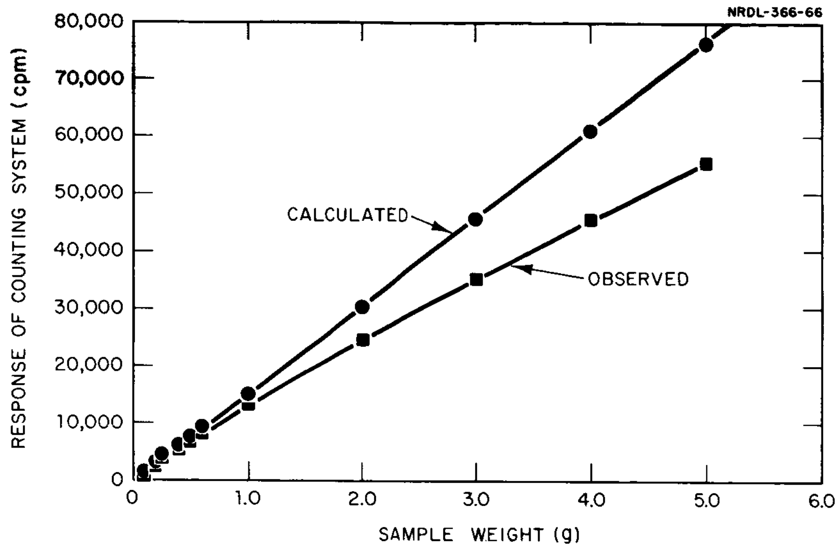

Fig. A.1 Relation of Response of Counting System to Sample Weight for Ground Fuel Rod

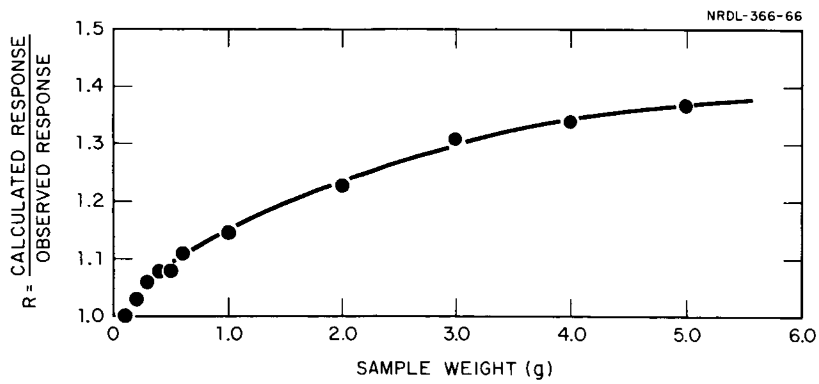

Fig. A.2 Curve Used to Correct for Self-adsorption of Weak Gamma Radiation

5. The adjusted count rate of a fraction was divided by the extrapolated count rate of 15,270 cpm/g of standard rod to determine the equivalent fuel rod content of the fraction. In the present example this is 31.3 g of standard.

6. This fuel rod equivalent was multiplied by the fraction of U in a rod to realize the U content of the fraction.

A limitation in this manner of analysis was the variation in count rate per gram among multiple aliquots of fractions of large-sizes and irregular shape. A variation of from 3 to 7 % was found in most of the 14 multiple aliquots weighed and counted but there were two instances of deviations of 13 and 15 % from the average count rate.

For this reason, the count rates and uranium content values are assumed to be reproducible to within 15 % in the size fractions greater than 2.38 mm. This deviation could be reduced by grinding up the fraction, similar to the processing at APG.

The size fractions smaller than 2.38 mm weighed less and were more homogeneous in character, and the lowest count rates were subject to a 6 % variation, when the counting increment was 20 min.

APPENDIX B

INDIVIDUAL PAN DATA AND COMPOSITE DATA

Table B.1 presents the mass of material determined in the various size fractions from the individual center pans. The total mass collected by each pan is also shown. Table B.2 gives the corrected counting rates of uranium determined in the various fractions and pans and the pan totals. These data were summed by size fraction to obtain the mass and counting-rate distributions shown in Table B.3. The sums were divided to give the specific activities shown in the third data group of that table.

Table B.4 summarizes the estimated content determined by processing the pans from the outer stations. This data is not included as part of the composite sample.

Figures B.1 through B.4 show photographs of material from the coarse fractions of the four stations along the centerline. They illustrate the variety in size and shape of particles in these fractions.

Table B.1

Grams of Debris in Size-Separated Fractions from Indi

Particle Size (μ) Greater Than	Less Than	Station 50-1	50-2	75-1	75-2	100-1	100-2
4760	∞	14.0615	35.8879	12.0579	0	0.1503	7.1022
3360	4760	10.1732	22.9478	31.6134	1.6880	7.0851	7.7019
2380	3360	10.5969	17.3891	33.6591	1.5544	4.3970	4.0845
1680	2380	11.1229	14.6382	30.2106	1.2145	2.4000	1.5781
1196	1680	11.0576	10.4145	20.9327	0.5447	0.5913	0.8685
840	1190	10.8337	8.2440	15.2738	0.2384	0.5710	0.6819
590	840	9.3159	6.3300	11.7588	0.1460	0.3436	0.5062
420	590	6.2848	4.2994	7.6902	0.2038	0.4301	0.5406
297	420	5.1664	4.6020	5.8197	0.4510	0.5952	0.7217
210	297	4.5442	3.2665	5.0545	0.3135	0.8452	0.5761
149	210	5.1724	3.0249	6.4503	0.2137	0.9676	0.5906
105	149	4.3580	2.1460	4.2087	0.1019	0.8040	0.3700
74	105	2.2549	1.0869	1.8233	0.0650	0.7769	0.2217
53	74	1.5127	0.6289	1.1719	0.0600	0.5930	0.1516
44	53	0.7749	0.4956	0.5847	0.0323	0.4372	0.0621
0	44	1.8719	1.0290	0.5844	0.1030	0.8362	0.1916
Total Sample Weight		109.1019	136.4307	188.8940	6.9302	21.8237	25.9493

Ta

Corrected Counts of Uranium in S

Particle Size (μ) Greater Than	Less Than	50-1	50-2	75-1	75-2	100-1	100-2
4760	∞	242,026	533,438	202,850	0	5,635	116,231
3360	4760	152,709	314,553	389,108	15,289	73,271	99,183
2380	3360	50,931	196,504	475,866	13,440	53,929	49,977
1680	2380	106,347	175,925	421,061	14,665	29,372	17,140
1190	1680	99,663	121,070	216,908	4,612	5,099	5,600
840	1190	121,384	84,291	157,702	2,122	5,581	3,935
590	840	99,363	54,907	112,236	1,110	2,340	3,809
420	590	49,836	33,355	71,005	1,002	3,135	3,969
297	420	42,891	29,747	55,266	1,066	3,684	5,461
210	297	99,014	34,180	69,882	799	5,950	5,932
149	210	197,011	106,250	324,643	2,460	15,469	14,974
105	149	190,038	69,085	201,954	1,975	15,208	10,326
74	105	52,513	27,002	30,410	693	1,825	3,551
53	74	29,020	4,646	16,761	255	1,749	863
44	53	8,195	3,418	3,093	101	1,165	206
0	44	7,009	2,533	1,267	145	1,741	499
Total Sample Count		1,539,950	1,790,904	2,750,012	59,734	225,153	341,656

idual Center Pans

Number										
100-3	125-1	(125-2	150-1	150-2	150-3	150-4	175-1	200-1	200-2	20(
7.0377	8.8141	8.3583	1.5539	23.9325	3.6574	3.1814	3.5918	0.3593	0	1.:
.0.7089	11.9723	7.8868	1.5513	32.4020	1.3890	1.0100	8.0546	0.1744	0	0.:
8.4580	10.8245	5.6084	0.5096	28.7551	0.4017	0.7285	1.5016	0.1045	0.0826	0.(
4.0107	5.9861	2.0677	0.3193	20.9908	0.2948	0.3126	0.3305	0.0802	0.0294	0.(
1.7654	2.5465	0.6503	0.1716	12.3754	0.2045	0.1754	0.1247	0.0394	0.0490	0.(
1.3043	1.5234	0.4746	0.1323	7.9602	0.2643	0.1577	0.2392	0.0860	0.0432	0.(
1.1295	1.1739	0.4546	0.1407	4.6934	0.3420	0.1964	0.2594	0.1289	0.0705	0.(
1.0126	1.1690	0.4141	0.1593	1.7306	0.5515	0.3208	0.2890	0.2940	0.1692	0.(
0.9054	1.6277	0.5890	0.2380	1.2869	0.6762	0.4933	0.3159	0.3766	0.2284	0.:
0.7633	1.8856	0.6108	0.2679	1.1098	0.7312	0.4054	0.5081	0.3731	0.2256	0.:
0.7189	2.4051	1.2032	0.4782	1.4881	0.9937	0.2458	0.7555	0.3487	0.2022	0.:
0.4489	1.2761	0.8970	0.5051	1.1677	0.6854	0.1478	0.6235	0.2325	0.1285	0.(
0.2235	0.8644	0.6893	0.4006	0.6676	0.2646	0.0662	0.5409	0.1343	0.0692	0.(
0.1328	0.6502	0.5052	0.3910	0.6627	0.1579	0.0669	0.4492	0.0700	0.0448	0.(
0.0810	0.4622	0.3351	0.2487	0.3479	0.0960	0.0569	0.2729	0.0447	0.0224	0.(
0.2047	0.8965	0.5900	0.4586	1.2227	0.1325	0.0693	0.5181	0.1030	0.0467	0.:
8.9056	54.0776	31.3344	7.5261	140.7934	10.8427	7.6344	18.3749	2.9495	1.4117	2.!

ble B.2

ize-Separated Fractions From Center Pans

	Station Number									
00-3	125-1	125-2	150-1	150-2	150-3	150-4	175-1	200-1	200-2	200-
10,928	148,024	136,699	25,995	399,786	53,218	53,282	61,173	5,424	0	18,3
28,778	144,731	91,563	19,867	411,712	14,816	12,964	109,433	2,400	0	1,5
14,568	146,455	71,337	5,695	369,754	4,940	9,100	21,607	1,573	680	
51,408	81,600	23,358	3,866	295,802	3,156	4,104	3,501	1,064	149	
19,677	31,763	6,119	1,672	164,190	1,585	1,754	1,272	229	470	1
14,864	17,779	4,246	1,305	99,634	1,889	1,358	2,594	411	350	
11,364	9,303	2,981	904	51,177	2,590	2,156	2,412	800	425	1
9,687	7,564	2,556	989	20,030	4,077	2,013	2,637	1,936	988	3
8,223	10,457	3,097	1,291	14,729	4,752	2,585	1,640	2,570	992	5
10,102	16,823	3,523	1,522	19,351	6,292	2,349	3,676	3,459	1,033	8
25,951	58,960	13,735	5,553	61,137	19,809	2,785	9,781	7,310	1,717	2,3
20,085	49,068	12,209	5,933	51,291	15,813	2,087	9,526	5,976	1,105	2,6
5,035	18,039	3,599	1,708	9,085	4,158	471	2,346	1,892	301	7
1,196	7,034	1,347	873	2,228	1,668	174	1,468	726	120	3
255	2,139	350	278	822	326	108	532	177	60	(
361	2,499	1,008	846	2,290	422	155	879	345	117	1(
32,482	752,238	377,727	78,297	1,973,018	139,511	97,445	234,477	36,292	8,507	28,3(

-3	225-1	225-2	225-3	250-1	250-2	250-3	250-4	275-1	275-2	275-3
591	0.7228	13.7485	0.2071	10.4918	8.0121	0	0.8403	37.8316	1.1757	0
00	0.5587	38.7788	0.1640	4.8007	2.2590	0	0.1381	29.4049	0	0
598	0.2207	25.1231	0.0347	1.9319	0.9445	0	0.0385	15.0382	0.0776	0
343	0.1052	12.8441	0.0122	0.5601	0.3157	0.0072	0.0366	8.0219	0.0357	0
458	0.1112	6.9036	0.0159	0.6232	0.1982	0.0151	0.0123	4.7454	0.0275	0
714	0.1339	4.3502	0.0269	0.8402	0.2068	0.0250	0.0112	3.3743	0.0705	0
783	0.2150	2.9668	0.0542	1.6438	0.2111	0.0326	0.0113	2.4340	0.0893	0.0133
956	0.3335	2.0783	0.1165	2.2177	0.2661	0.0734	0.0136	1.9548	0.1518	0.0157
388	0.4528	1.7596	0.2009	3.1434	0.3829	0.1064	0.0189	2.2253	0.2080	0.0436
627	0.5836	1.2888	0.2547	3.3387	0.6543	0.0707	0.0262	2.0849	0.2400	0.0748
545	0.8608	1.4614	0.3960	4.0365	0.6804	0.0579	0.0505	1.9546	0.2886	0.0760
966	0.6674	1.0029	0.3340	2.4550	0.6734	0.0439	0.0585	1.1892	0.2026	0.0429
550	0.4833	0.7164	0.1806	1.2988	0.5492	0.0413	0.0470	0.8565	0.1326	0.0169
333	0.4842	0.4578	0.1354	0.7003	0.4407	0.0516	0.0434	0.3772	0.1017	0.0115
244	0.2269	0.3875	0.0497	0.4635	0.3503	0.0367	0.0277	0.2161	0.0395	0.0055
025	0.4139	0.7924	0.0991	0.9702	0.5724	0.1400	0.0999	0.4818	0.1142	0.0120
221	6.5739	114.6602	2.2819	39.5158	16.7171	0.7018	1.4740	112.1907	2.9553	0.3122

	225-1	225-2	225-3	250-1	250-2	250-3	250-4	275-1	275-2	275-3
2	11,439	228,404	3,153	174,688	134,667	0	9	642,494	19,578	0
5	4,535	525,414	2,456	114,876	32,253	0	16	432,967	0	0
8	2,976	349,959	508	29,562	14,074	0	5	231,949	727	0
4	1,002	174,196	19	7,562	4,305	7	17	116,881	205	0
7	520	92,214	75	7,651	2,557	11	30	66,579	130	0
3	546	55,203	113	9,196	2,086	55	13	45,280	309	0
3	1,078	35,313	319	18,465	1,719	100	22	29,894	423	28
3	1,950	24,973	694	23,080	1,865	314	16	27,357	967	55
3	2,706	20,686	1,073	29,777	2,363	215	38	27,408	1,194	178
7	3,740	22,058	1,464	40,658	4,468	171	42	34,365	1,613	412
3	11,463	54,087	1,363	109,696	9,211	451	292	71,127	4,042	882
9	11,067	41,416	1,616	85,901	9,237	341	416	41,678	3,345	1,004
4	3,137	9,284	1,257	27,753	3,240	106	247	6,809	948	316
3	1,596	1,758	584	7,539	1,199	57	133	2,023	458	227
5	324	2,918	153	4,777	417	21	49	422	112	52
3	801	1,710	250	2,514	855	36	105	1,113	227	51
3	58,880	1,639,593	15,097	693,695	224,516	1,885	1,450	1,778,346	34,278	3,205

Table B.3

Composite Sample Data

Particle Size (μ)		Weight Data			Activity Data		Specific Activity		Uranium Content[a]
Greater Than	Less Than	Total g in Size Fraction	Pct. in Size Fraction	Cumulative Pct.	Total Corrected cpm in Size Fraction	Pct. in Size Fraction	Cumulative Pct.	c/m Corrected Per Gram in Size Fraction	Normalized
4760	∞	203.9351	18.492	99.990	3,327,443	21,583	99.961	1.6316×10^4	0.8525
3360	4760	232.5629	21.088	81.498	3,094,479	20.072	78.378	1.3306×10^4	0.6952
2380	3360	172.1245	15.608	60.410	2,216,134	14.374	58.306	1.2875×10^4	0.6727
1680	2380	117.5594	10.660	44.802	1,536,716	9.967	43.932	1.3071×10^4	0.6830
1190	1680	75.2097	6.819	34.142	843,597	5.471	33.965	1.1216×10^4	0.5860
840	1190	57.1384	5.181	27.323	632,329	4.101	28.494	1.1067×10^4	0.5783
590	840	44.7395	4.056	22.142	445,391	2.889	24.394	9.955×10^3	0.5202
420	590	32.8760	2.981	18.086	296,373	1.922	21.534	9.014×10^3	0.4710
297	420	32.7740	2.971	15.105	274,657	1.781	19.612	8.380×10^3	0.4379
210	297	30.2602	2.743	12.134	393,715	2.553	17.831	1.3011×10^4	0.6798
147	210	35.2861	3.199	9.391	1,132,472	7.345	15.278	3.2094×10^4	1.6769
105	149	24.8675	2.254	6.192	860,359	5.580	7.933	3.4597×10^4	1.8077
74	105	14.5269	1.317	3.938	216,459	1.404	2.353	1.490×10^4	0.7785
53	74	10.0859	.914	2.621	86,090	.558	.949	8.536×10^3	0.4460
44	53	6.1824	.560	1.707	30,556	.198	.391	4.9424×10^3	0.2582
0	44	12.6566	1.147	1.147	29,886	.193	.193	2.3612×10^3	0.1234
Totals		1102.7851			15,416,656				

a. Based on a specific activity of $UO_2(NO_3)_2 \cdot 6H_2O$ of 1.914×10^6 c/m of rod.

Table B.4

Uranium Content at Outer Stations (mg U per 16-ft^2 Collection)[a]

Particle Size (μ)		Station							
Greater Than	Less Than	400-1	500-1	400-3	500-2[b]	500-4[b]	500-3[b]	600-1[b]	600-2[b]
3360	4760	8.3	-	-	-	-	-	-	-
840	1190	-	0.2	-	-	-	-	-	-
420	590	-	0.2	-	0.2	-	-	0.9	-
297	420	8.9	1.1	0.4	1.6	-	-	-	-
210	297	7.6	2.9	0.5	0.7	2.2	-	-	-
149	210	31.2	13.9	3.4	1.6	2.6	0.5	-	0.5
105	149	47.1	19.6	3.5	2.0	0.6	0.1	-	-
74	105	14.9	8.5	1.8	1.0	0.2	-	-	-
53	74	7.8	6.0	2.0	0.7	0.4	0.2	-	-
44	53	2.0	1.5	1.6	0.4	0.3	0.1	-	-
0	44	3.3	3.9	1.5	0.3	0.5	0.6	0.6	-
Total mg detected		131.1	57.8	14.7	8.5	6.8	1.5	1.5	0.5

a. The debris collected by four pans, covering a 16-ft^2 area was analyzed at the outer stations, while the material collected by a single pan of 4-ft^2 area was analyzed from stations situated on the pad.

b. The core material collected at these stations was not evenly distributed among the four pans.

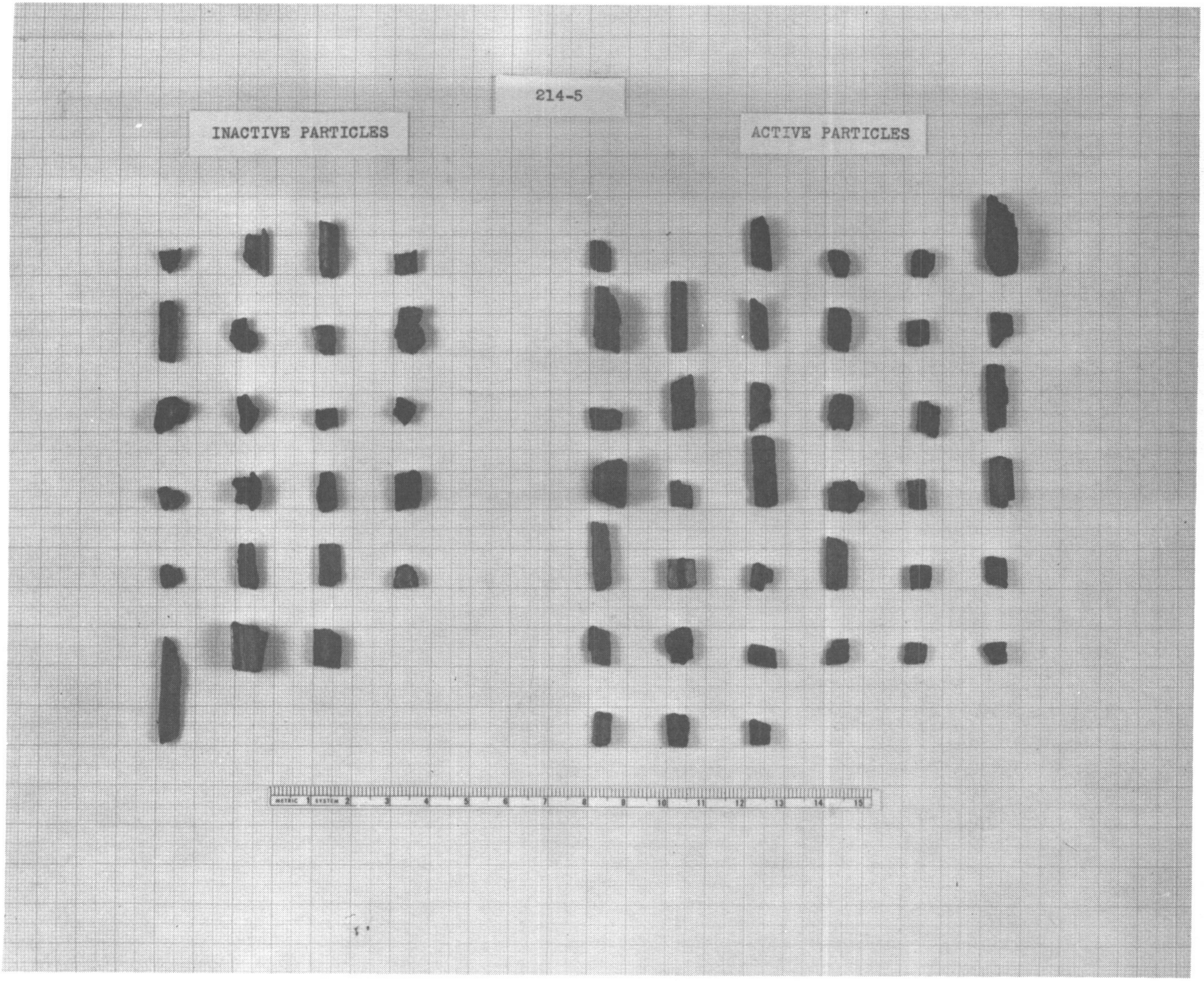

Fig. B.1 Active and Inactive Particles From Coarse Fraction of Pan 214-5, Center Pan at Station 75-1

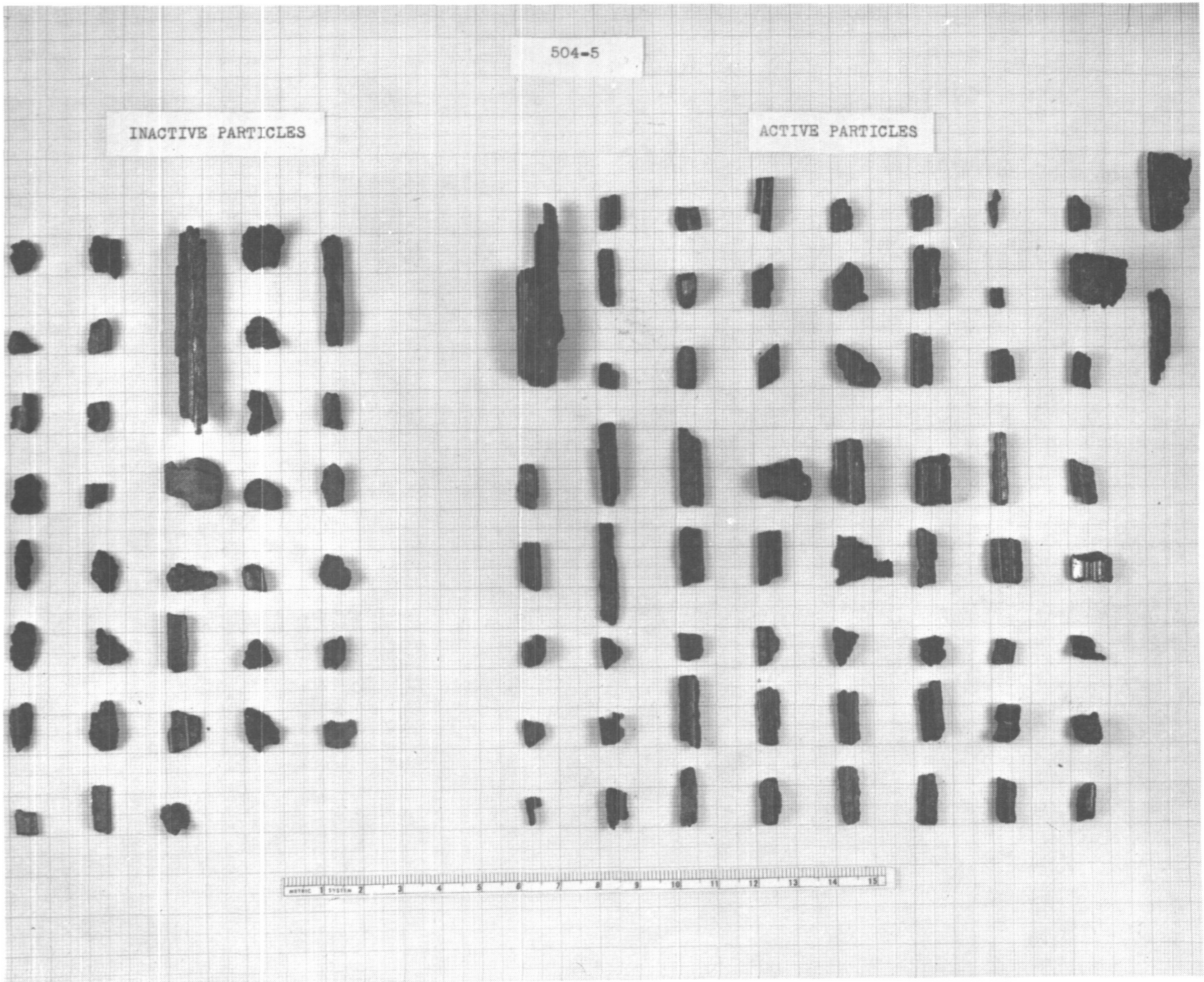

Fig. B.2 Active and Inactive Particles From Coarse Fraction of Pan 504-5, Center Pan at Station 150-3

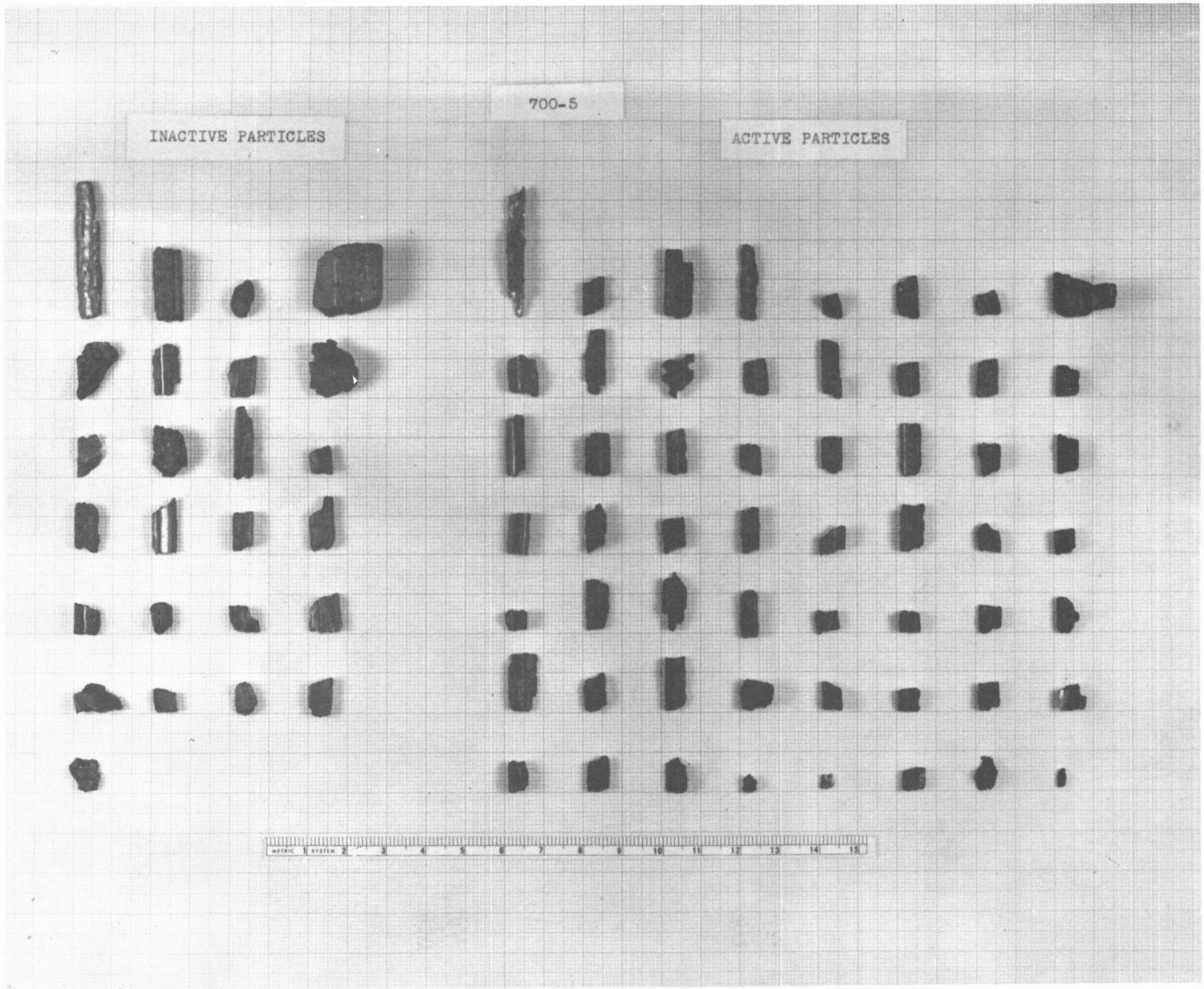

Fig. B.3 Active and Inactive Particles From Coarse Fraction of Pan 700-5, Center Pan at Station 225-2

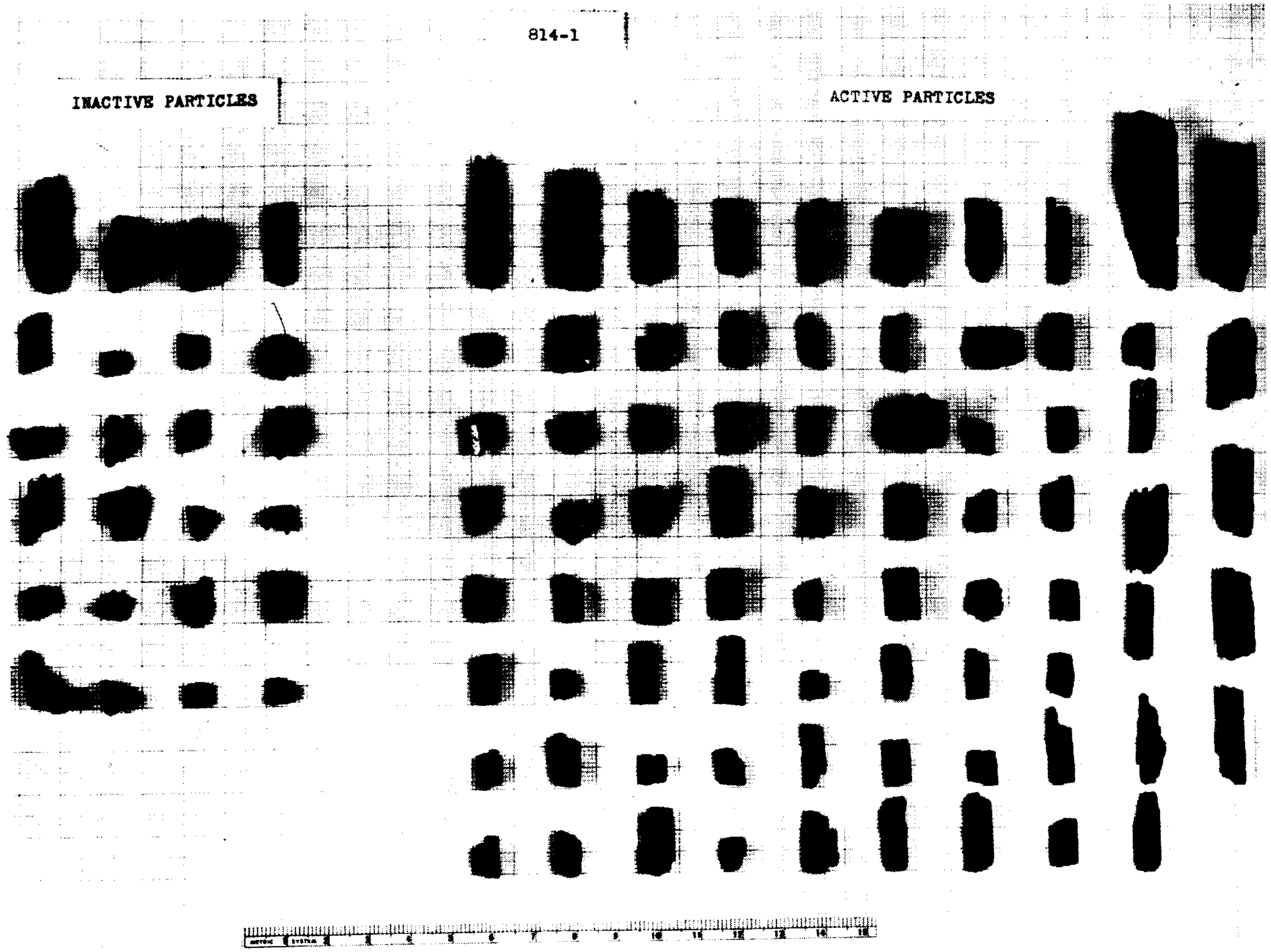

Fig. B.4 Active and Inactive Particles From Coarse Fraction of Pan 814-1, Center Pan at Station 275-1

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13. ABSTRACT Analysis of fragments from one of four jets of debris of a high-explosive destruct test of a nuclear reactor showed that the distribution of weight with particle size was bimodal, with a major peak near 4 mm and a minor peak near 0.2 mm. The distribution of activity also was found to be bimodal, with a pronounced peak at 0.2 mm. Specific activity calculations showed that the peak centered about the 0.2 mm size range contained the debris that was the most highly enriched in uranium. Little uranium activity was noted in particles below this size.

Comparison with results of other investigations showed that a small sampling effort such as was undertaken provides adequate sampling of the debris from one jet. However, variation in particle characteristics from one jet to another would require sampling all jets in a future operation.

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Reactor Destruct Debris Gamma counting technique Particle size						

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