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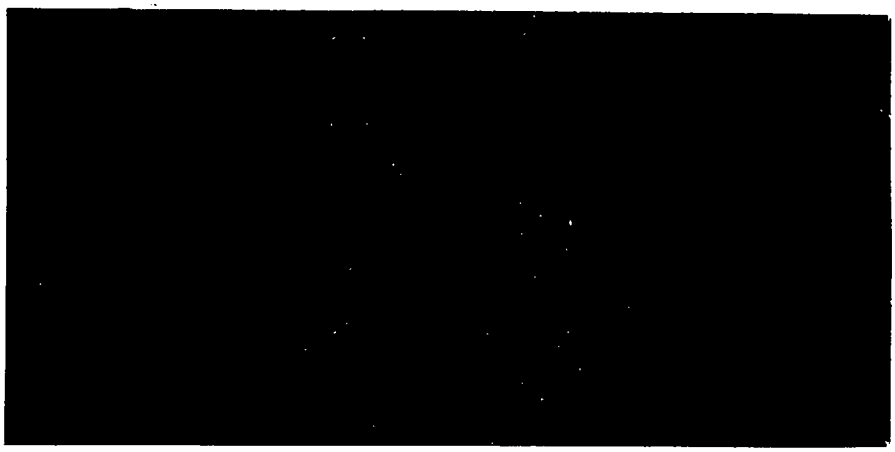

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SOME OBSERVATIONS ON AIR SAMPLING TECHNIQUES USED AT THE NEVADA PROVING GROUND

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The development of sampling methods and some field results of the off-site air sampling stations at the Nevada Proving Ground are reviewed. A technique of radioautography is presented which yields information about the activities of individual fall-out particles. This technique gives a comparison of particle activities from air drops and tower shots and a reason for the greater contamination associated with the latter. It also indicates that air samplers do not capture the most active fall-out particles, presumably because of their large size.

1. Introduction

It is the purpose of this document to contribute additional information relative to the beta radiation associated with fall-out particles from continental test operations as derived from past air sampling results. Further, certain instruments and techniques developed for this type of field operation are described.

In an atomic detonation, certain phenomena take place which cause fission products to "plate out" on or to be mixed in outside materials. These materials are swept up into the atomic cloud and, depending on wind conditions, are carried many miles beyond the test area before falling out. The rate and location of fall is dependent upon many variables, which up to this time are not fully understood. In any event, these particles must be described as both beta and gamma hazards.

Seemingly the greatest hazard to individual properties and persons would be that from gamma rays because of their greater penetration. This radiation is the easiest to detect and interpret with calibrated film badges and survey instruments. However, the amount of gamma radiation in any given fall-out area has not been fatal to anyone or caused any known injury to persons or their properties, whereas the beta hazard has produced burns on the backs of livestock that have been close to the test area. During the most recent test series at the Nevada Proving Ground (NPG), Spring 1953, a number of incidents

contributed to interest in beta burns. Several horses were burned quite badly by beta radiation and several hundred sheep showed lesions that might be attributed to beta particles. Reports have been made of these incidents and have been published and distributed to the public.[1]

When the Nevada Proving Ground was established, it was planned to use this area for tests that would not be highly contaminating. Subsequent events made it necessary to use NPG for types of tests that would be more contaminating than was originally planned. Prior to Operation Buster-Jangle, a group of experts, the Jangle Feasibility Committee, placed certain limitations on the amount of radiation that could be allowed to fall out on the areas adjacent to the Proving Ground. The restrictions that applied to the work of the air sampling group of Group H-5 from the Los Alamos Scientific Laboratory (LASL) and later to that of the Off-Site Radiological Safety Group were the following: The average air concentration for the first 24 hours following a detonation should not exceed 100 microcuries per cubic meter. Any portion of that value that is respirable should not exceed 1/100 of it, and no such particle should exceed 10^{-2} microcurie measured at H + 4 hours.

With these criteria in mind, a group of available collecting devices was selected. The air samplers that have proven most satisfactory, and that have been used until this time, are the high-volume sampler (or modified Electrolux), the cascade impactor, and the fallout tray.

The high-volume sampler, which is now produced commercially under the name of "Staplex Sampler", was used to collect a large volume of air that contained fall-out particles. This provided a gross value for the air concentration during the sampling period. Recent data, which will be given later, indicate that this type of sampling is more selective than representative in its sampling characteristics.

The cascade impactor was used to find the size distribution of the fall-out particles. Particle sizes, measured with this instrument, indicated that the greatest amount of active material collected was in the respirable range. Hence, the air tolerance, 1 microcurie per cubic meter, was assumed to be applicable.

The material reaching the ground, as opposed to strictly airborne particles, was collected on a fall-out tray. These samples gave information on the activity per particle and per unit area.

2. Development of Techniques*

2.1 The Fall-out Tray

For pure convenience a fall-out tray was made of 9-1/2 by 11 inch 20-gauge aluminum with a 1-inch right angle bend on the shorter dimension (Fig. 1). A non-drying alkyd resin mixture (10 per cent tributyl phosphate, 35 per cent resin, and 55 per cent toluene) was applied to the exposed surface to retain the particles. The resin (Du Pont RL-233, J-523527) was mixed with technical grade toluene to give a solution

*The actual field results are largely omitted from this report. These data are contained in references 2 to 6.

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which was easily applied to the tray surface. The tributyl phosphate was added as a plasticizer to keep the resin tacky at cool temperatures.

The tray was placed in an area where fall-out might be expected, and after an exposure period of approximately 12 hours, was brought into the laboratory. It was then covered with rubber hydrochloride film (0.0002 inch thick) or sprayed with Krylon plastic and exposed to x-ray film for varying periods of time depending on the approximate activity. The number of spots that appeared on the film was counted. The average activity of the particles on the tray was determined by dividing the total activity by the number of spots, but still no good method was known for determining the activity of the individual particle.

2.1.1 Radioassay. The trays have been used for three test series and in each case the total tray activity has been determined with a different technique. During Operation Buster-Jangle each sampling station had two fall-out trays, one for radioautography and one for radioassay (counting). No facilities were available for a direct count of the activity on the trays so the trays were stripped with toluene and the volatile washings boiled away. The residue was ashed with a strong oxidizing solution (perchloric acid, nitric acid, and sulphuric acid). The solution was transferred to stainless steel planchets, dried, and counted under an end-window Geiger-Mueller tube. This method contained several inherent errors. Loss of count occurred

during the stripping and ashing procedures. In addition, the counting techniques available limited the counting rate to approximately 400,000 disintegrations per minute. Hence it was often a month before the more active samples could be counted. The assumption used in extrapolating back to fall-out time with the $t^{-1.2}$ law introduced another source of error. The same method of ashing the sample was continued through Operation Tumbler-Snapper, but the counting was done on equipment with an upper limit of 2 million disintegrations per minute.

Prior to Operation Upshot-Knothole the CMR-7 Electrical Section of LASL developed a technique for the direct counting of fall-out trays. The tray was counted immediately before radioautography by means of a scanning device shown in Fig. 2. The tray was fixed to a traveling carriage (Fig. 3). It passed a methane flow chamber (Fig. 4) with a narrow open slit at the rate of about 3/4 inch per minute. The tray was mounted (Fig. 2) so the geometry of the sample, as it passed the chamber, remained constant. The recording of the count as the tray passed the probe, which had an interchangeable slit of either 1/8 by 11 inches or 1/16 by 11 inches, represented an integrated total count. A count-rate meter, placed in a parallel circuit with an Esterline-Angus Recorder (0 to 1.0 milliampere) or a recording instrument of similar characteristics, was used to determine this integrated count. Both the traveling carriage and the recorder moved simultaneously giving a large area as shown in Fig. 5. The carriage and the recording paper were returned to their original starting points and the tray

was then counted a second time with a beta-infinite-thickness absorber (1/4-inch brass plate) in place to determine the contribution of gamma rays to the total count. The resulting curves shown in Fig. 6 were essentially a gamma plus beta count and a gamma count. The area between the two curves was measured in square inches using a compensating polar planimeter. A standard tray of known and similar activity was scanned in the same way and the number of known microcuries divided by the resulting number of square inches to give microcuries per square inch. This is the standardization factor. The area between the curves on the unknown sample is multiplied by this factor to give the total number of microcuries on the tray. The tray was covered with a standard solution of Sr^{90}-Y^{90} previously calibrated in a 4 pi geometry chamber.

2.1.2 Particle Activity. As these methods were used, it was apparent from the great variations in spot sizes appearing on the x-ray film that some individual particle activities were far in excess of the average value. Thus, individual particles could be above the tolerance of 10^{-2} microcurie per particle without the fact being noted. It was also apparent that the spot size was some function of particle activity (Fig. 7). The periphery of these spots seemed to be a beta fog, rendering any measurement of the diameter inaccurate (Fig. 8a). In a recent conversation with members of the Health and Safety Branch, New York Operations Office, AEC, the use of Kodalith Ortho Type-2 film as a print material was suggested. This was tried and a clear, reproducible outline was obtained (Fig. 8b).

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In order to interpret these data, spot size had to be calibrated with activities which approximated the energy spectrum of mixed fission products. Actual fall-out particles, from outside NPG, with an activity in excess of 1 microcurie were used for calibration. These particles had sufficient activity for "standards" but were too large for calibrating radioautographs. They were broken into smaller ones ranging from 50 to 300 microns in size, individually picked up, placed on a glass microscope slide, and spray-painted with Krylon plastic. The activities of these smaller particles were determined with a methane flow counter by comparing them to a Sr^{90}-Y^{90} standard (the standard was measured, in the same manner as the previous ones, on a 4 pi system) to determine their disintegration rates. The standard had similar backing and the geometry of the shelf and position of the samples were essentially the same. Knowing the activities of these particles, they were radioautographed with different exposure times as shown in Table 1.

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TABLE 1

CALIBRATION OF X-RAY FILMS

Film	Part. no.	Activity of particles* d/m	d/hr	Diameter, mm 1 hr	2 hr	3 hr	16 hr	17 hr	26 hr	72 hr	5 days	Size of particle,
Kodak Blue Line												
	3	5,170	3.1×10^5	0.5	0.65	0.9	2.9		3.0			
	1	68,250	4.095×10^6	2.0	3.0	3.15	8.0		8.75			
	4	22,300	1.34×10^6	1.1	1.35	1.85	4.8		5.0			
Kodak Type-K	1	66,582	3.99×10^6	2.1	2.6	3.2		5.1		8.3		250
	2	7,775	4.67×10^5	0.8	0.9	1.1		2.0		3.3		145
	3	4,840	2.9×10^5	0.6	0.8							
	4	21,164	1.27×10^6	1.2	1.4	1.8		3.2		5.2		200
	5	5,974	3.58×10^5	0.8	0.9	1.0		1.9		3.1		250
	6	16,380	9.8×10^5	1.1	1.3	1.8		3.1		5.2		225
	7	13,979	8.39×10^5	1.0	1.1	1.7		3.0		4.7		200
	8	21,878	1.3×10^6	1.2	1.5							
	9	12,209	7.3×10^5	1.0	1.2	1.6		2.9		4.9		300
	10	3,890	2.3×10^5	0.5	0.7	0.9		1.5		2.9		50
Ansco High Speed	1	66,582	3.99×10^6	1.5		2.0	6.1				11.5	
	2	7,775	4.67×10^5	0.5		0.8	2.2				6.0	
	5	5,974	3.58×10^5	0.3		0.5	2.0				5.4	
	6	16,380	9.8×10^5	0.8		1.0	3.9				8.2	
	9	12,209	7.3×10^5				3.0				7.0	
	10	3,890	2.3×10^5	0.2			1.8				4.1	

[redacted]

* All activities were compared to a Sr^{90} standard with a counting efficiency of 42.6 per cent.

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The radioautographic technique used was to place the x-ray film in close contact with the particles in an x-ray film holder, then tape it between two pieces of plate glass. After exposure, the x-ray films were developed in Ansco Liquidol Developer at a temperature of 20 ± 0.5°C for a period of 3-1/2 minutes, transferred to a tank of Kodak X-Ray Liquid Fix and Hardener bath for a period of 10 minutes, washed and dried. The Kodalith film was placed next to the x-ray film in a printing frame and exposed to a 100-watt light at 8 feet for 5 seconds and then developed in the Kodalith developer at 20 ± 0.5°C for 3 minutes or until the film displayed complete blackness under a Wratten Series 0A filter 6 feet away. A Kodak acid-fix bath was used to fix and harden the films before they were washed and dried.

The diameters of the resulting spots, which appeared as perfect circles on Kodalith positive prints, were measured in millimeters with a steel rule. The total disintegrations that would have been emitted in the exposure time were determined and plotted against the spot size on the Kodalith film. These two variables were plotted on log-log paper and gave a relatively straight line. This technique was used with three types of x-ray film: Kodak Blue Line, Kodak Industrial Type-K, and Ansco High Speed. The graphs of the three types are shown in Figs. 9, 10, and 11. Ansco High Speed deviated somewhat from a straight line. The formulas for the graphs plotted in Figs. 9, 10, and 11 are shown in the Appendix. The graph of Kodak Industrial Type-K, the fastest film used, has a slope of 2.63 whereas the Blue Line has a

slope of 1.92. Ansco Non-Screen x-ray film was reported[7] to give a slope of 2 for spot diameter vs activity. The Ansco Non-Screen film is between the Kodak Type-K and the Blue Line in its film speed, thus verifying the value of the slopes obtained. Using these curves it is possible to select an exposure time which will give an optimum spot size if the specific activity of a particle is known.

2.1.3 Conclusions. Fall-out trays from each of the detonations in Nevada were re-examined to determine the individual particle activities. A number of tray radioautographs shown in Figs. 12 to 17 were reprocessed on Kodalith paper and the individual spots measured to obtain the activity of the particles. The activities distribution was plotted on logarithmic probability paper for these trays (Figs. 18 to 23). This confirmed the earlier assumption that the activities generally followed a normal logarithmic distribution and also showed that many of the particles exceeded the limit of 10^{-2} microcurie per particle.

A comparison of the particle activity from air drops and tower shots indicates a reason for the greater contamination from the latter. The data on two air drops (Figs. 18 and 19) show one with 91.5 per cent of the tray activity on particles exceeding the 10^{-2} microcurie limitation and the other 60 per cent above this limit. For the tower shots listed (Figs. 20 to 23), from 20 to 40 per cent of the tray activity was on particles above 100 microcuries at the time of fall-out. Particles of this activity were found as far as 140 miles from the detonation point.

The total activity on each tray, determined by counting the tray, is compared, in Table 2, to the total activity obtained by adding the activity of each particle. The results agree surprisingly well in spite of the inherent errors in determining the data for Operations Tumbler-Snapper and Upshot-Knothole. The results showing the greatest differences are from the areas of heaviest fall-out.

TABLE 2

COMPARISON OF TOTAL ACTIVITY MEASURED BY COUNTING AND BY SPOT SIZING ON KODALITH FILM

Series and location of particles	Activity measured by counting, μc	Activity measured by spot sizing, μc	Ratio
U-K 7, Mesquite	688	706	1.026
T-S 5, Lincoln Mine	3,760	4,080	1.085
T-S 2, Indian Spgs.	1.5	1.27	0.846
U-K 9, St. George	4,580	15,500	3.4
U-K 11, Glendale Jct.	8.64	13.44	1.555
U-K 2, Lincoln Mine	2,770	7,050	2.545

2.2 High-Volume Sampler

The high-volume sampler was first used, on Operations Ranger and Buster-Jangle, with a fluted filter paper (Fig. 24). The large surface area of the paper permitted a sampling rate of 85 cubic feet per minute. This high flow rate made it possible to collect a large amount

of airborne material, which seemed desirable on the basis of Ranger results. With the inclusion of more contaminating bursts in continental tests, the collection of such large samples was no longer required. Further, the fluted paper was not adaptable to direct counting but had to be put through the time-consuming process of ashing and plating on a planchet for counting with the Geiger-Mueller probe. In routine field operations at NPG, this placed a severe limitation on the number of samples which could be assayed properly.

For Operation Tumbler-Snapper a method was adopted which permitted direct counting. A flat 4 by 9 inch methane flow probe was used with the scaler as shown in Fig. 25 to count the filter, a 4-inch-diameter Mine Safety Appliances Company Comfo #2133 respirator filter. This system was continued in use during Operation Upshot-Knothole. Its efficiency has been reported as better than 99 per cent for particles greater than 0.3 micron in size.[8] A Fiberglas paper has been developed recently which reduces particle penetration in the filter surface. This paper may find application in future tests.

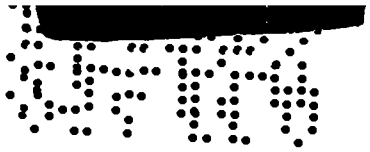
The high-volume sampler has been very reliable for intermittent periods of operation. The flow rate is nearly as constant as the supplied voltage. The equipment is not designed for continuous operation and should be checked frequently after 24 hours. Commutator brushes have to be changed, depending on the frequency of operation and length of sampling time. A standard pitot tube and inclined gauge were used to calibrate these samplers.

2.3 Cascade Impactor

The cascade impactor was not used extensively until Operation Upshot-Knothole. In previous tests on Operations Ranger, Buster-Jangle, and Tumbler-Snapper the impactor was used only to a limited extent because of lack of equipment. On Operation Buster-Jangle, a few samplers were placed in the expected fall-out pattern; on Tumbler-Snapper, impactors were used at selected stations in the communities in the path of the predicted fall-out. Although these data do not represent a complete pattern, the material collected was found to be largely in the respirable range. On Operation Upshot-Knothole, all the air sampling stations were furnished with impactors. These results confirmed the prevalence of particles smaller than 10 microns.

The slides of the impactors were covered with a 40 per cent solution of non-drying alkyd resin in toluene. This gave an adherent surface for the particles. If these particles are to be sized with a microscope, one must use some other collecting medium to avoid the large line of refraction caused by the resin coating on the particles. A liquid paraffin was recommended by the manufacturer of the impactor.[9] Stage median sizes of the particles in the impactor are dependent upon the density of the material to be sized. An average density of 2.5 was assumed on the basis of density measurements of firing site soil.

The last stage of the impactor was followed by a filter. On Operations Buster-Jangle and Tumbler-Snapper a 1-1/8-inch circle of Whatman #41 filter paper was used; before Upshot-Knothole it was found that a



great many of these had some pinholes. Hence, they were replaced with the newly developed membrane filters (Millipore Filters Type AA, Lovell Chemical Company, Lowell, Mass.). A flow rate of 17.5 liters per minute was maintained through the impactors.

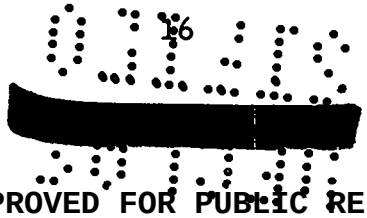
2.4 Comparison of Sampling Methods

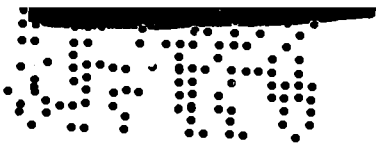
The results obtained with the impactors on Operation Upshot-Knothole were compared with those of the high-volume sampler (Table 3).

TABLE 3

COMPARISON OF THE CASCADE IMPACTOR AND HIGH-VOLUME SAMPLER
OPERATION UPSHOT-KNOTHOLE, 1953

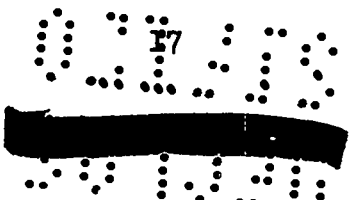
	Time sampled	Time counted	Count	Volume, m^3	$\mu c/m^3$
Shot 1 - St. George					
CI	0620-1400, 3/17	1830, 3/18			3.03×10^{-3}
HV	0820-1400, 3/17	1730, 3/18			6.08×10^{-3}
Shot 1 - Mesquite					
CI	1650-2000, 3/17	1430, 3/18	17000 d/m	3.34	1.16×10^{-3}
HV	1640-2000, 3/17	1200, 3/18	3.04×10^{-1} μc	238	1.28×10^{-3}
Shot 2 - Lincoln Mine					
CI	0550-0740, 3/24	1445, 3/25	2.478×10^{5} d/m	1.92	0.59×10^{-2}
HV	0550-0720, 3/24	1130, 3/25	4.1 μc	120	3.4×10^{-2}
Shot 2 - Lincoln Mine					
CI	0800-1000, 3/24	1515, 3/25	75160 d/m	2.1	1.63×10^{-2}
HV	0805-1035, 3/24	0900, 3/25	1.33 μc	216	0.6×10^{-2}





COMPARISON OF THE CASCADE IMPACTOR AND HIGH-VOLUME SAMPLER (Continued)

	Time sampled	Time counted	Count	Volume, m^3	$\mu c/m^3$
Shot 6 - C.P.					
CI	0535-0935, 4/18	1021, 4/18	22850 d/m	4.2	5 x 10^{-3}
HV	0535-0935, 4/18	1058, 4/18	0.622 μc	274	2.3 x 10^{-3}
Shot 6 - Indian Springs					
CI	0535-1435, 4/18	2345, 4/19	7.25 x 10^4 d/m	9.45	3.5 x 10^{-3}
HV	0535-1435, 4/18	2315, 4/19	2.06 μc	605	3.4 x 10^{-3}
Shot 6 - Indian Springs					
CI	2020-0920, 4/18	1522, 4/19	54080 d/m	13.91	1.76 x 10^{-3}
HV	2020-0920, 4/18	1135, 4/19	1.55 μc	981	1.6 x 10^{-3}
Shot 6 - Las Vegas					
CI	0910-1210, 4/18	1820, 4/19	60680 d/m	3.15	8.8 x 10^{-3}
HV	0840-1140, 4/18	1745, 4/19	1.05 μc	224	4.69 x 10^{-3}
Shot 6 - Las Vegas					
CI	1215-1815, 4/18	1840, 4/19	29460 d/m	6.3	2.12 x 10^{-3}
HV	1140-1755, 4/18	1750, 4/19	0.783 μc	475	2.31 x 10^{-3}
Shot 6 - Las Vegas					
CI	1815-0015, 4/18	1930, 4/19	42500 d/m	6.3	3.1 x 10^{-3}
HV	1755-2355, 4/18	1805, 4/19	0.898 μc	450	1.99 x 10^{-3}
Shot 6 - Las Vegas					
CI	0015-0435, 4/19	2040, 4/19	18400 d/m	4.55	1.8 x 10^{-3}
HV	0000-0435, 4/19	1808, 4/19	0.445 μc	340	1.31 x 10^{-3}



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COMPARISON OF THE CASCADE IMPACTOR AND HIGH-VOLUME SAMPLER (Continued)

	Time sampled	Time counted	Count	Volume, m^3	$\mu c/m^3$
Shot 7 - C.P.					
CI	0535-0935, 4/25	1030, 4/25	160000 d/m	4.2	1.73×10^{-2}
HV	0535-0930, 4/25	1030, 4/25	6.84 μc	289	2.37×10^{-2}
Shot 7 - C.P.					
CI	0935-1335, 4/25	1345, 4/26	53000 d/m	4.2	5.7×10^{-3}
HV	0930-1330, 4/25	1130, 4/26	1.65 μc	290	5.7×10^{-3}
Shot 7 - Mercury					
CI	0630-1130, 4/25	2305, 4/25	216360 d/m	5.25	1.9×10^{-2}
HV	0630-1130, 4/25	2230, 4/25	10.88 μc	370	2.9×10^{-2}
Shot 7 - Mercury					
CI	1145-1530, 4/25	1625, 4/25	21900 d/m	3.94	2.5×10^{-3}
HV	1130-1530, 4/25	1600, 4/25	0.68 μc	323	2.1×10^{-3}
Shot 7 - St. George					
CI	1052-2125, 4/25	0920, 4/27	1.6×10^5 d/m	11	6.6×10^{-3}
HV	1040-2120, 4/25	1420, 4/27	2.59 μc	836	3.1×10^{-3}
Shot 9 - Caliente					
CI	0605-0935, 5/19	1910, 5/20	40712 d/m	3.7	4.9×10^{-3}
HV	0605-0935, 5/19	1818, 5/20	0.585 μc	204	2.8×10^{-3}
Shot 9 - St. George					
CI	0610-1130, 5/19	0355, 5/21	2.73×10^6 d/m	5.94	2.1×10^{-1}
HV	0610-1130, 5/19	0045, 5/21	88.5 μc	397	2.23×10^{-1}

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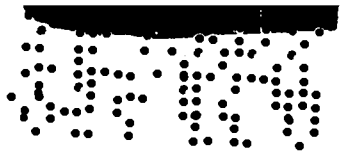
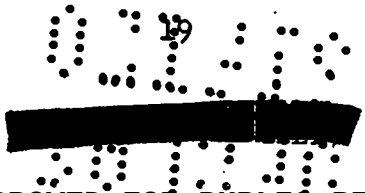


COMPARISON OF THE CASCADE IMPACTOR AND HIGH-VOLUME SAMPLER (Continued)

	Time sampled	Time counted	Count	Volume, m^3	$\mu c/m^3$
Shot 9 - St. George					
CI	1140-1445, 5/19	0400, 5/21	1.7×10^6 d/m	3.15	2.44×10^{-1}
HV	1130-1445, 5/19	0120, 5/21	75.1 μc	243	3.19×10^{-1}
Shot 9 - St. George					
CI	1450-2300, 5/19	0415, 5/21	1.2×10^6 d/m	8.57	0.6×10^{-1}
HV	1450-2300, 5/19	0230, 5/21	40.6 μc	608	1.4×10^{-1}
Shot 9 - St. George					
CI	2305-0635, 5/19	0425, 5/21	65280 d/m	7.87	3.7×10^{-3}
HV	2305-0635, 5/19	0340, 5/21	3.12 μc	558	6.34×10^{-3}
Shot 10 - Lincoln Mine					
CI	0900-1140, 5/25	1530, 5/26	1.8×10^4 d/m	2.79	2.9×10^{-3}
HV	0930-1130, 5/25	1540, 5/26	3.63×10^{-1} μc	132	2.75×10^{-3}
Shot 11 - Overton					
CI	1210-1400, 6/4	2313, 6/4	3.4×10^5 d/m	2	7.7×10^{-2}
HV	1250-1350, 6/4	0200, 6/5	1.97 μc	59	2.8×10^{-2}

By adding the activity found on each of the impactor stages, the resulting concentration corresponds to that from a low-volume sampler. In Fig. 26 a regression line is shown between the net results of the two samplers. Because the slope of the line is almost unity, the material collected by the two samplers is apparently the same. In this plot the impactor is given the value of unity because its calibration is more



accurately known and its collecting efficiency is higher than that of the high-volume sampler. This information indicates that the respirator filter collected the airborne radioactive material with adequate efficiency.

A few impactor slides collected at St. George, Utah, on the ninth shot of the Upshot-Knothole series were radioautographed. Figure 27 gives an activity distribution graph for the particles on first-stage impactor slides from the first three impactor samples collected. The activities of these particles do not approach those of the particles found on the fall-out tray (Fig. 28) for the same period. Virtually all the particles are below 10^6 disintegrations per minute on the first stages of the impactor whereas 86 per cent of the fall-out tray activities are above 10^6. Obviously, the fall-out tray collects those particles which contribute most of the radioactivity to contaminated areas. The impactor, and consequently the high-volume sampler, collect particles of minor significance in surface contamination, but which are presumably representative of airborne material. Unfortunately, no more radioautographs of slides are available from other heavy fall-out areas. However, the radioassay information is available from all impactors and high-volume samples from all the test series. None of these slides or filters display activities which indicate the collection of even a single particle of activity comparable to those found on fall-out trays from the same sampling locations. The fall-out tray has particles in the microcurie range, whereas the total activity of its compan-

ion impactor shows only a few thousand disintegrations or at the most a few hundred thousand disintegrations as is the unique case shown in Fig. 27. Thus it may be stated that the total activity found on any stage or on an entire impactor sample does not approach that activity which would be demonstrated by a single particle of median activity of the companion fall-out tray. The same reasoning applies to high-volume samples since previous data indicated that identical material was collected. It appears that there are particles falling to the ground which are not collected in the air samples. The only possible explanation is that these particles are of such large size that they escape capture. The theoretical considerations on which such a supposition might be based have not been investigated.

3. Discussion of Results

An examination of the sampling program which has been presented serves as a basis for certain conclusions and as a guide for future programs.

The agreement of impactor and high-volume sampler air concentrations (Sec. 2.4) indicates that further duplication is unnecessary for a radiological safety unit. One or the other of these methods would be sufficient. For field operations the high-volume sampler is the more practical. In this case the entire sample would be considered respirable and representative of the inhalation exposure. Any error involved in this assumption probably would not be more than a factor of five. Such an error is inherent in any tolerance value now that the limita-

tions of the Jangle Feasibility Committee have been abandoned (January 1954).

The median particle size of impactor samples has been generally less than 50 microns.[2-5] For example, the three impactor samples whose radioautographs have been discussed (Sec. 2.4), showed median particle sizes of 42, 18, and 26 microns. This fraction has been found to contribute but a few per cent to the total fall-out intensity. Thus it may be inferred that primary concern should be given to particles in excess of 50 microns, and probably in excess of 100 microns, when attempting to predict fall-out location and intensity.

The hazard from beta burns to the skin probably results from exposures to the particles represented by fall-out tray collection, i.e., the most active particles (Sec. 2.1.3). Although air concentrations are known to increase and decrease with time for several hours following the arrival of fall-out at a particular location, the ground level of radioactivity usually becomes equilibrated to the normal decay law ($t^{-1.2}$) in less than 1 hour and more often in less than 30 minutes.[3-5] Thus, protection against most external contamination by such a measure as remaining indoors need be in effect for only a relatively short time after fall-out has begun.

No complete size distribution was performed on a gross sample of fall-out particles. The continuous distribution of activities (Sec. 2.1.3) indicates a continuous spectrum of sizes might be expected rather than that the particles might be divided into two distinct

types represented by the different collectors. The air samplers merely "see" but a small fraction of the whole.

4. Summary

1. The field equipment employed in the collection of fall-out is adequate for the measurement of air concentration and particle size distribution in the respirable range. Similarly, the fall-out tray represents a convenient method of collecting the more radioactive surface contamination in a form which is readily adaptable to radioassay and radioautographic procedures.

2. A technique of radioautography for fall-out trays has been developed which yields information about the activities of individual fall-out particles.

3. Individual particles of very high activity have been found at distances out to 140 miles from the point of detonation.

4. Particles of higher individual activity are produced by tower shots than by air drops.

5. Good correlation is obtained between air concentrations measured by the impactor and the high-volume sampler.

6. Air sampling does not appear to capture the most active fall-out particles. Such particles are presumably too large to be respirable or captured.

7. The implications of past results and techniques have been considered for their practical importance in future test operations.

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1. U. S. Atomic Energy Commission, Report on Sheep Losses Adjacent to the Nevada Proving Grounds, January 6, 1954.
2. T. L. Shipman, Operation Buster-Jangle Report WT-425, Classified.
3. P. S. Gwynn, Operation Tumbler-Snapper Report WT-558, Classified.
4. W. S. Johnson, H. F. Schulte, and E. C. Hyatt, Operation Tumbler-Snapper Report WT-566, Classified.
5. T. D. Collison, Operation Upshot-Knothole Report WT-702 (Ref.), Classified.
6. W. S. Johnson *et al.*, Rad-Safe Off-Site Summaries, unpublished data.
7. H. T. Dybvig, Ansco Film Company, private communication.
8. K. H. Larson, UCLA-AECP, private communication.
9. C. F. Casella and Co. Ltd., Instructions for Use of the Cascade Impactor.

[redacted]

Appendix

The equation of the line for Kodak Type-K x-ray film is given by the expression

$$\log d = \log a + b \log s$$

or

$$d = as^b$$

where

d = total disintegrations

s = spot diameter

a = intercept on the d axis where s = 1

b = slope of line

Putting in values of a and b from the curve

$$\log d = 6.03 + 2.63 \log s$$

For Kodak Blue Line x-ray film the corresponding expression is

$$\log d = 6.07 + 1.92 \log s$$

For Ansco High Speed film a quadratic expression is necessary

$$\log d = \log a + b \log s + c (\log s)^2$$

Putting in pairs of values of d and s from the curve and solving

$a = 1.9 \times 10^6$

$b = 1.67$

$c = 0.48$

And the equation is

$$\log d = 6.25 + 1.67 \log s + 0.48 (\log s)^2$$

[redacted]

The value of "a" is a measure of the minimum exposure capable of producing a measurable spot and is affected by the characteristics of the Kodalith as well as the x-ray film. The value of the slope "b" might be predicted to be 2.0 on a basis of the inverse square law; Kodak Blue Line film actually had a slope of 1.92. The relative sensitivities of the films to beta and gamma radiation might cause deviations from this value.

Fig. 1. Fall-out tray.

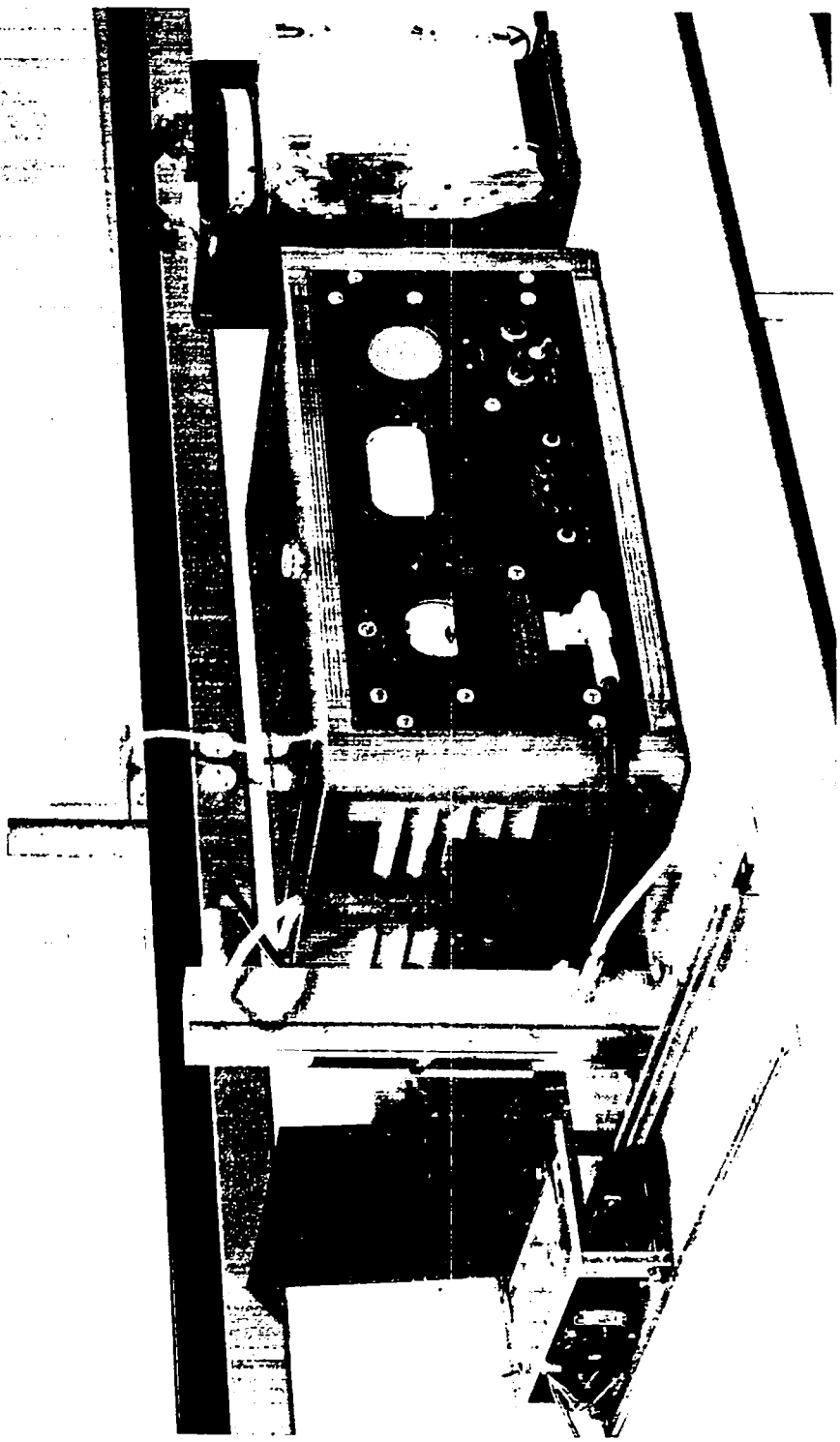


Fig. 2. Tray scanning device.

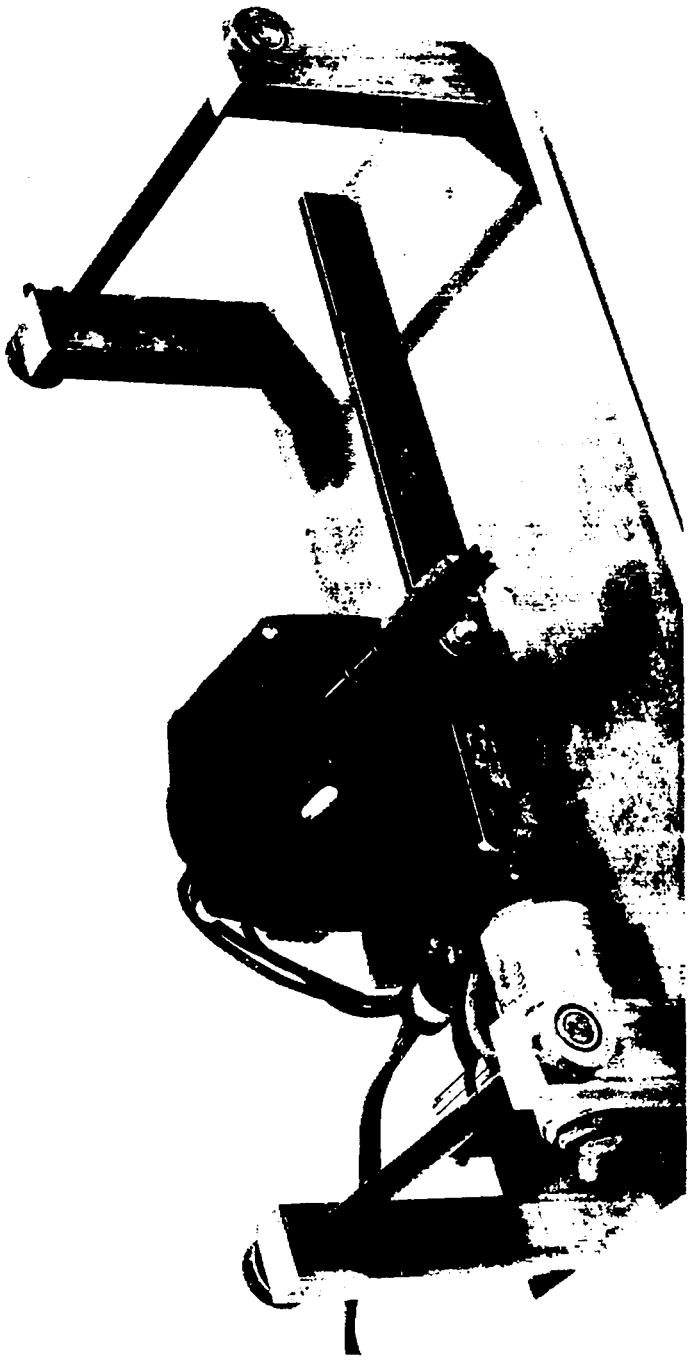
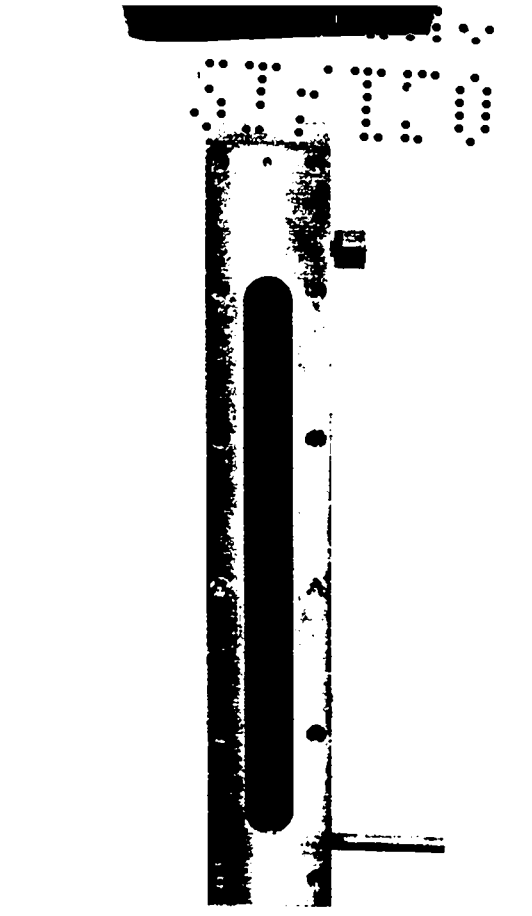


Fig. 3. Motor-driven carriage



PROBE WITH SLITS
(1/8" & 1/16")

Fig. 4. Probe with slits (1/8 and 1/16 inches).

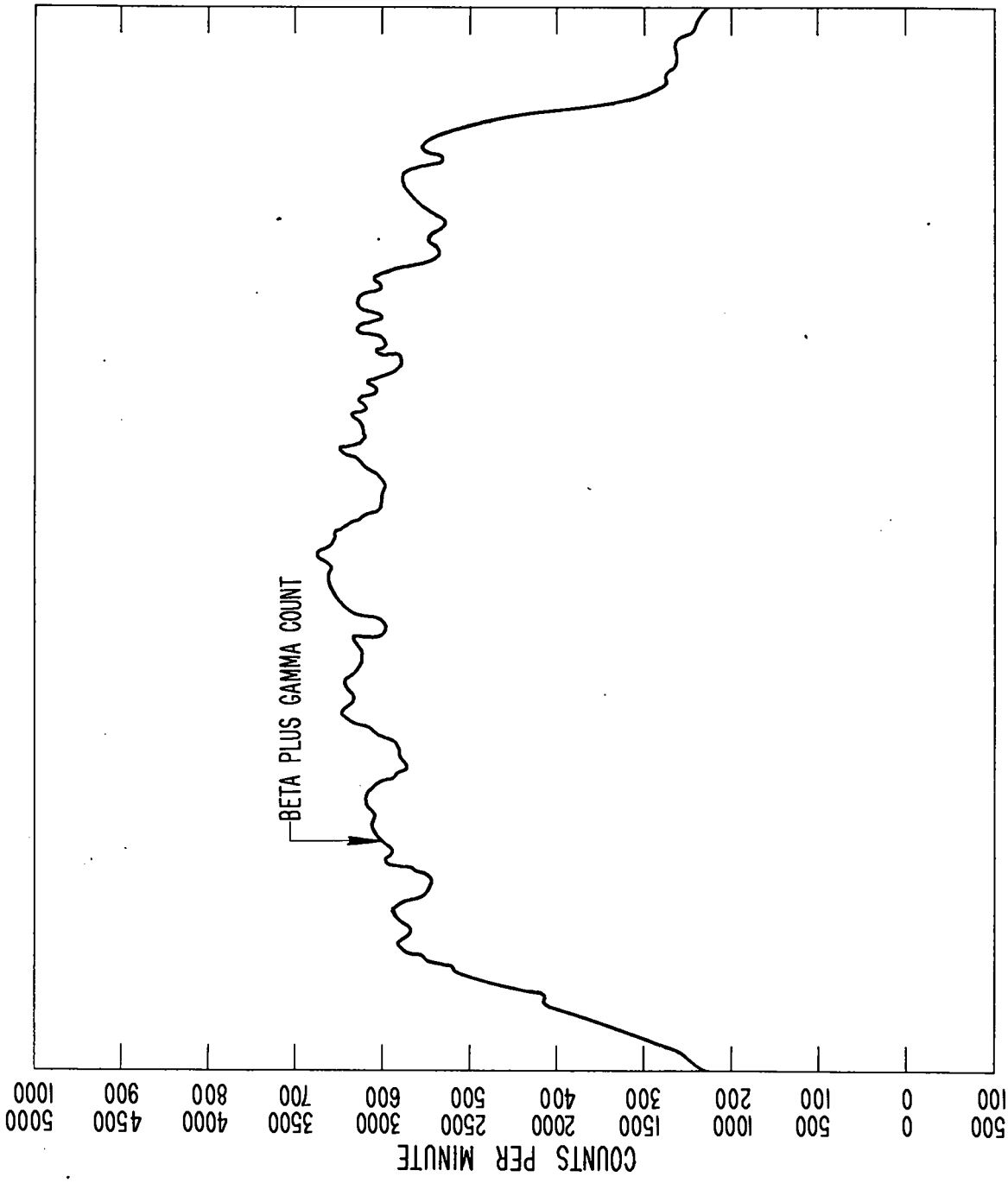


Fig. 5. Graph showing the integrated beta plus gamma count.

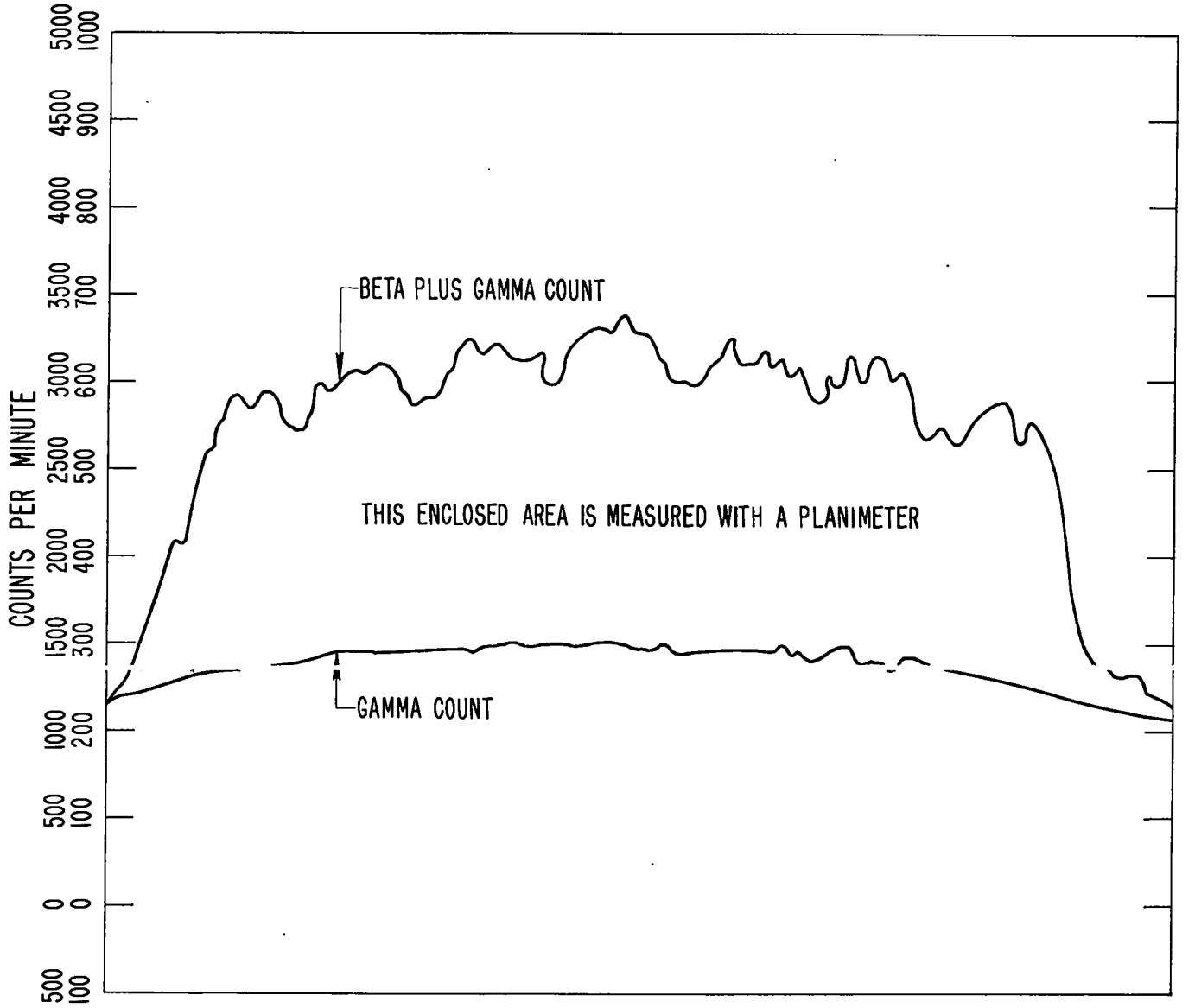


Fig. 6. Graph showing the integrated beta count with the gamma background subtracted.

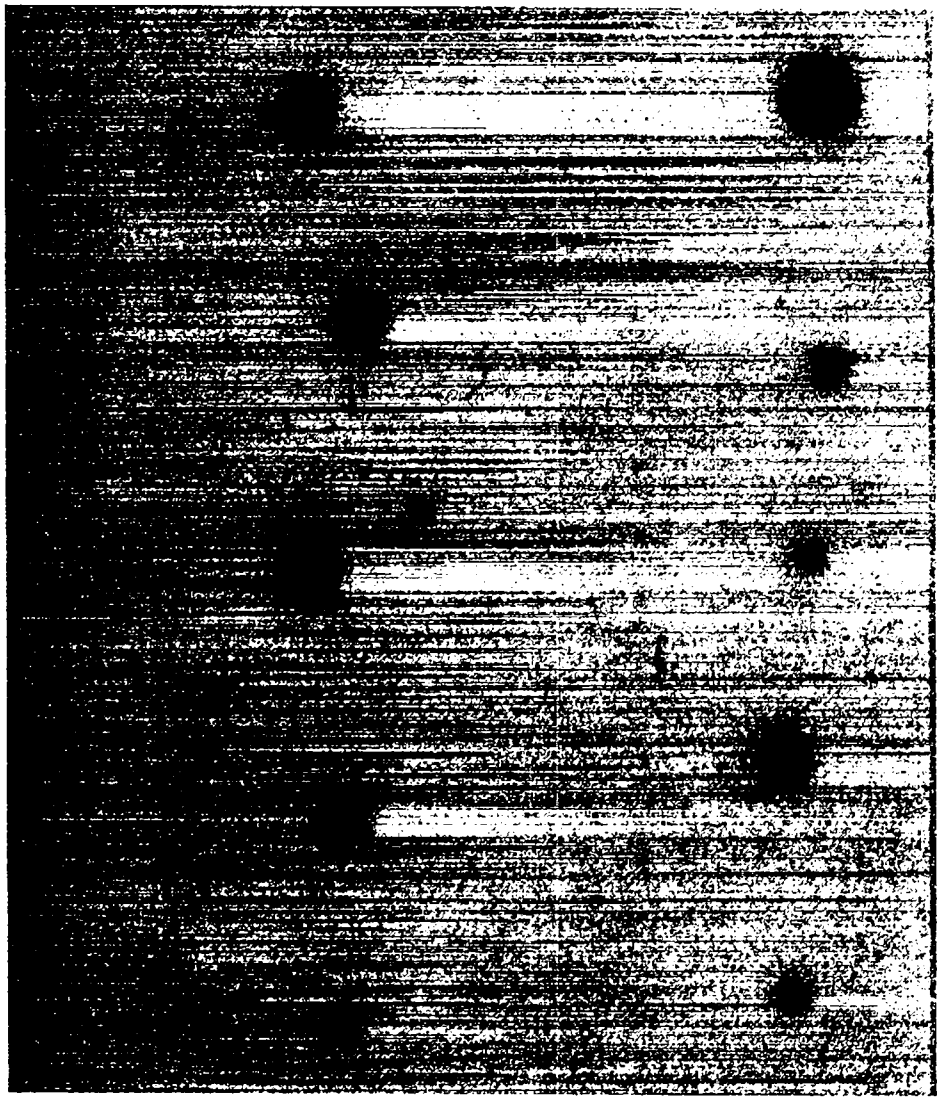


Fig. 7. Two-hour exposure of particles with various activities on Type-K x-ray film.

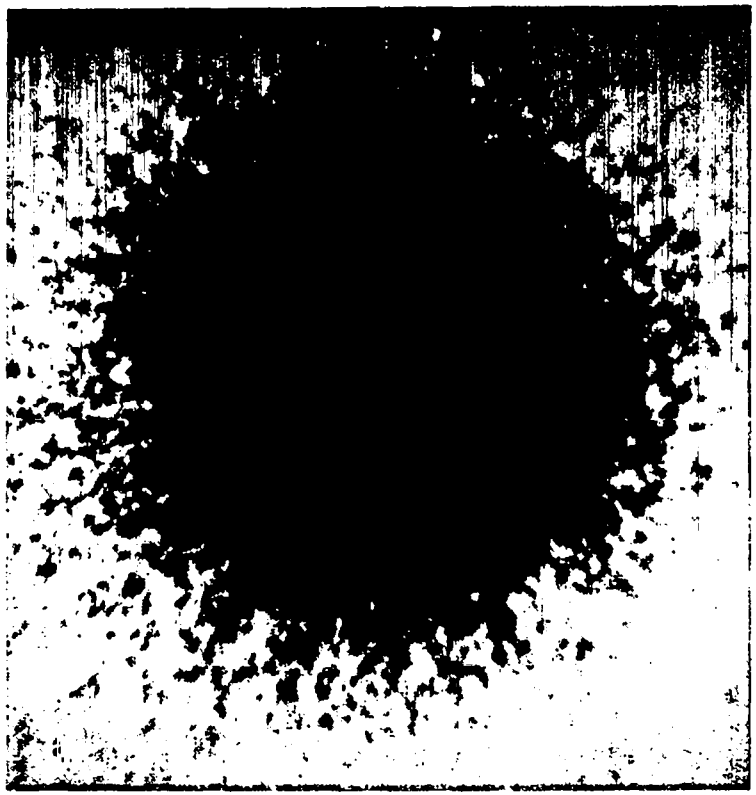


Fig. 8a. Photomicrographic enlargement of radioautograph on Type-K x-ray film. 75x

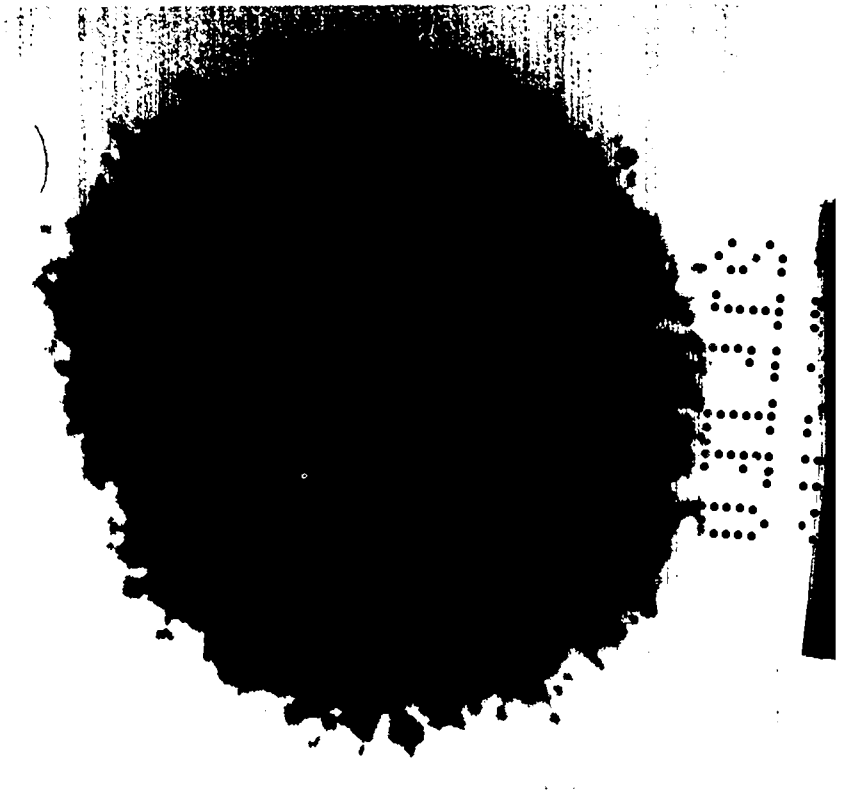


Fig. 8b. Kodalith copy of the radioautograph in fig. 8a.

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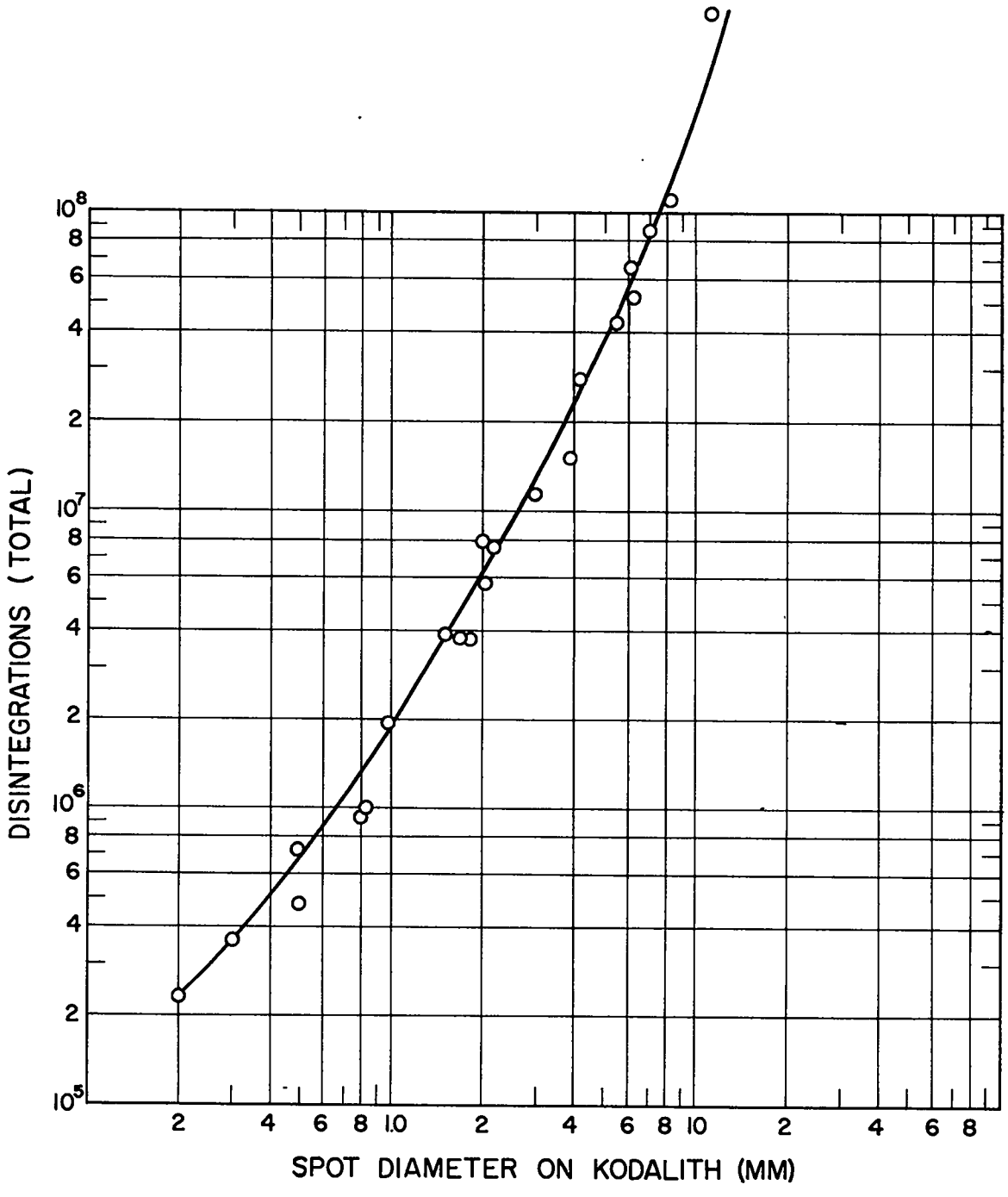

Fig. 9. Spot size on Kodalith film as a function of beta activity. (Ansco High Speed x-ray film).

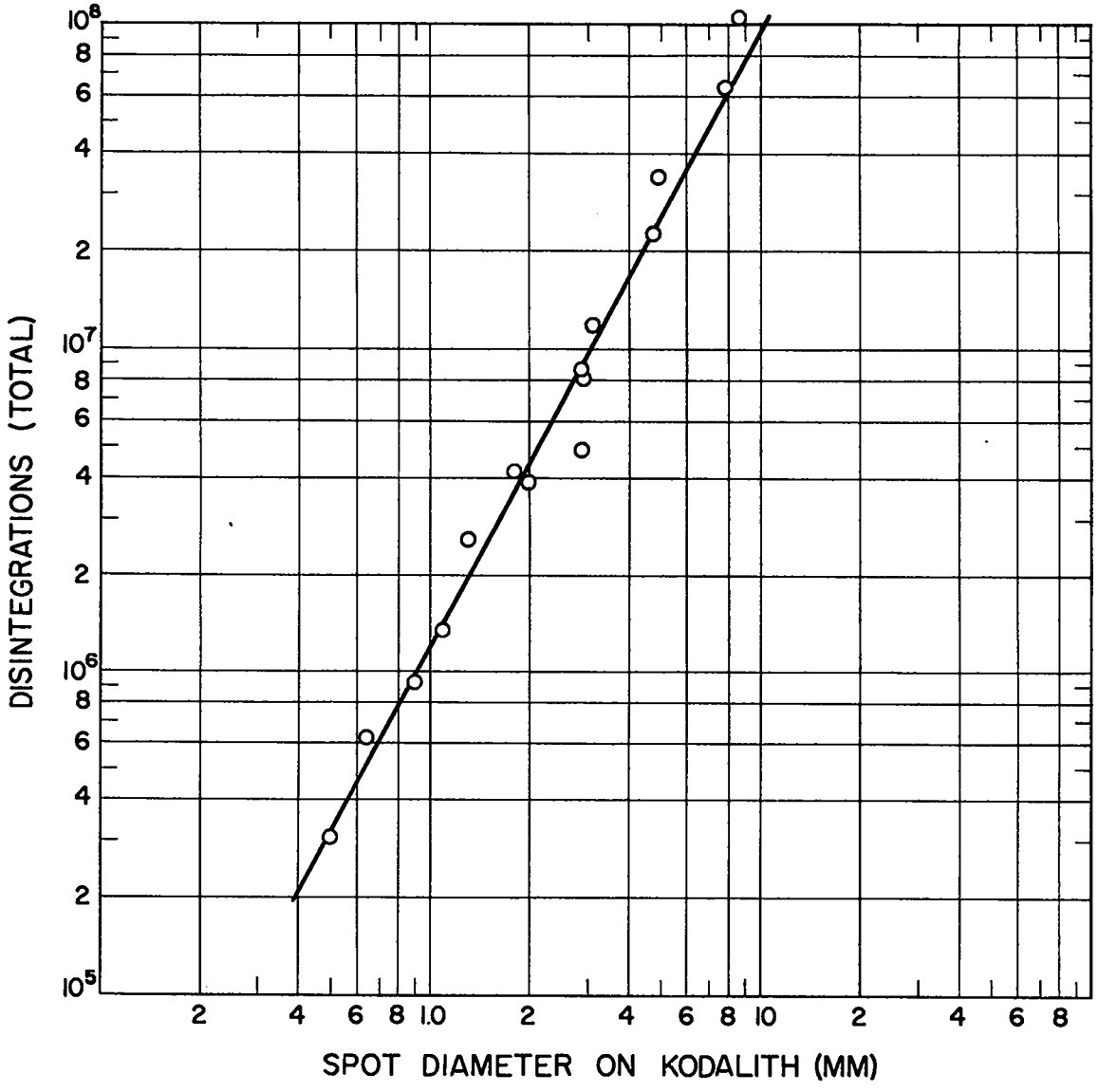

Fig. 10. Spot size on Kodalith film as a function of beta activity (Kodak Blue-Line x-ray film).

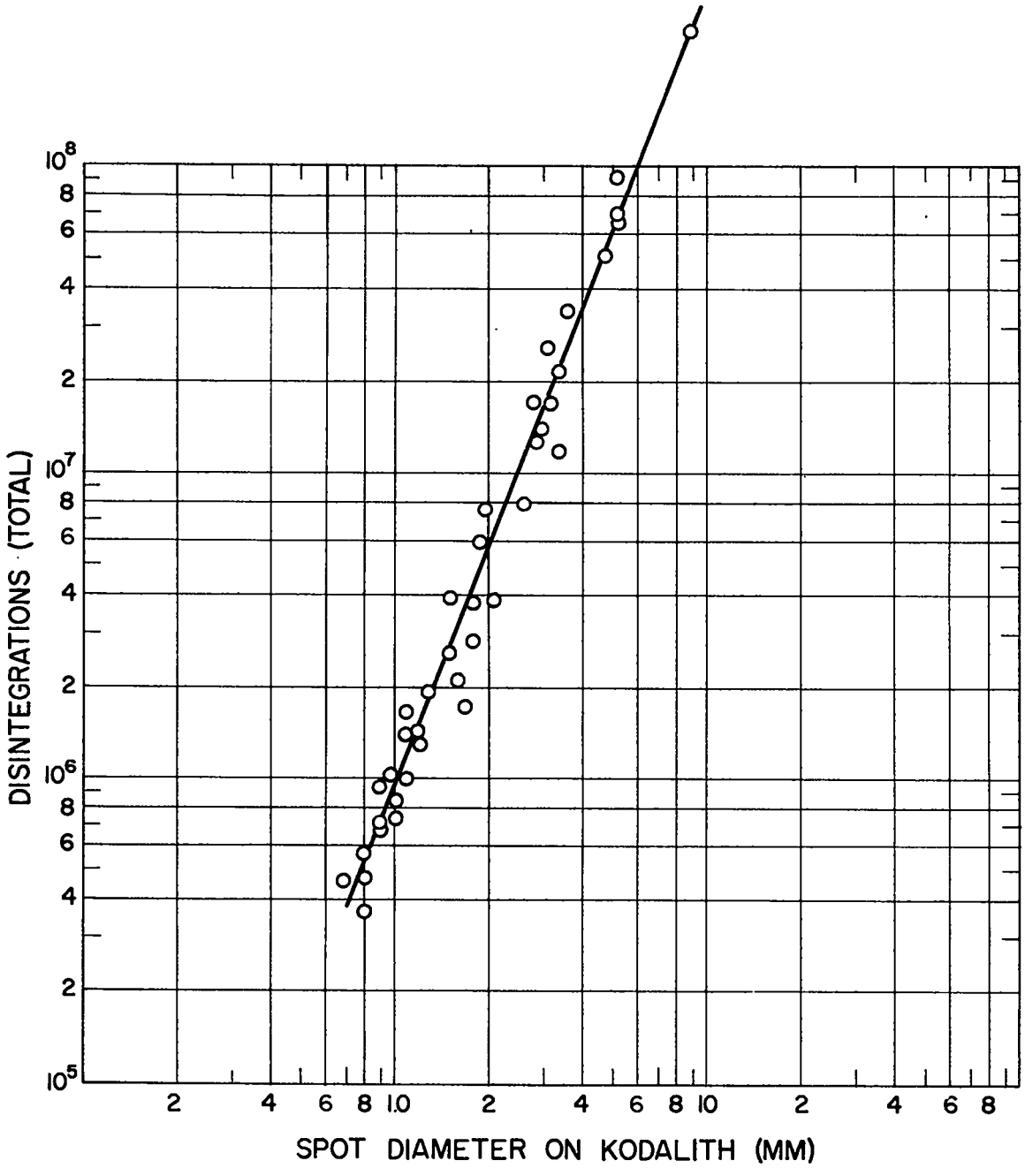

Fig. 11. Spot size on Kodalith film as a function of beta activity (Type-K x-ray film).

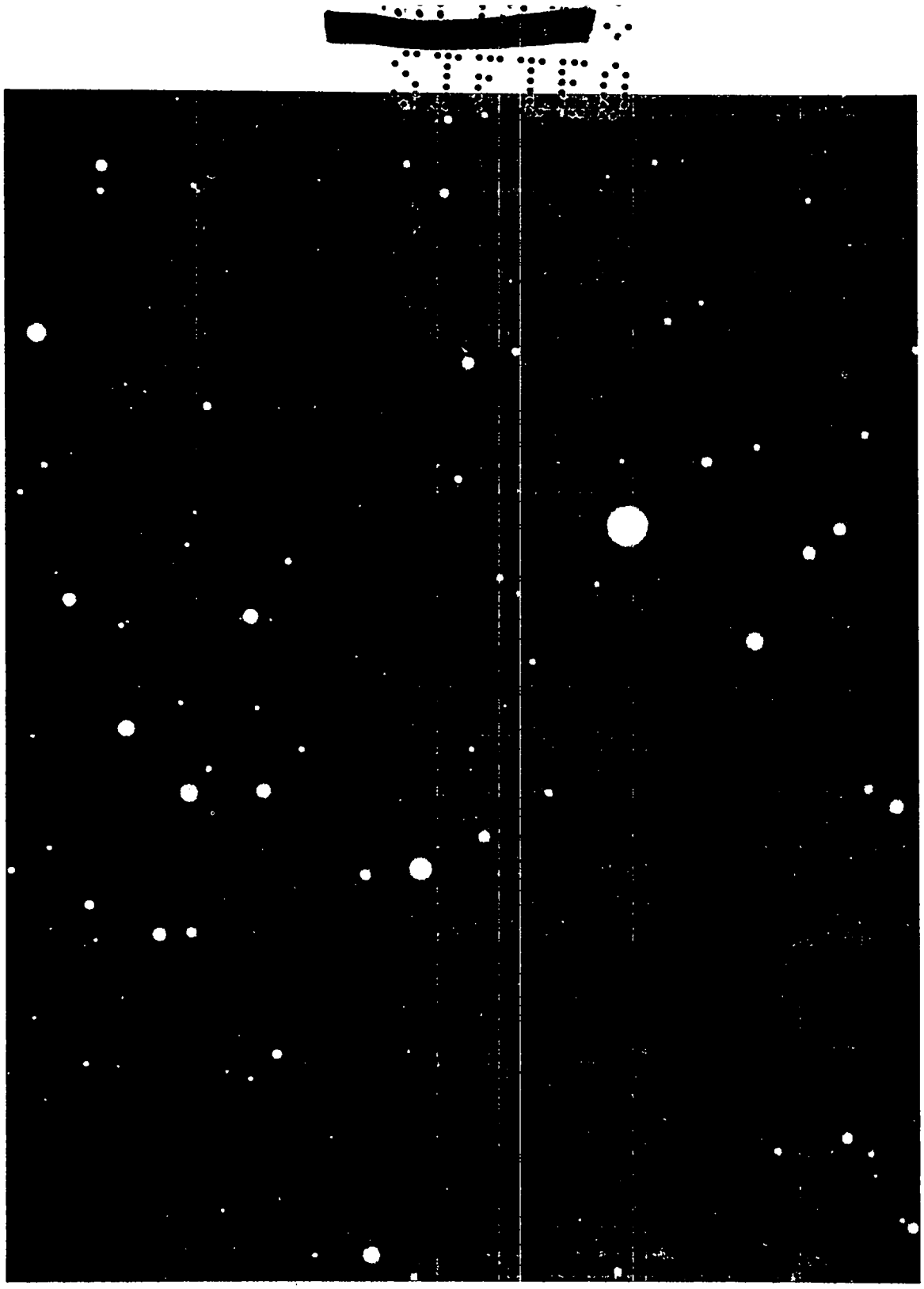

Fig. 12. Kodalith print of a fall-out tray radioautograph (film exposure time 120 hours). Tray collected after an air drop at 40 miles from ground zero, Tumbler-Snapper series.

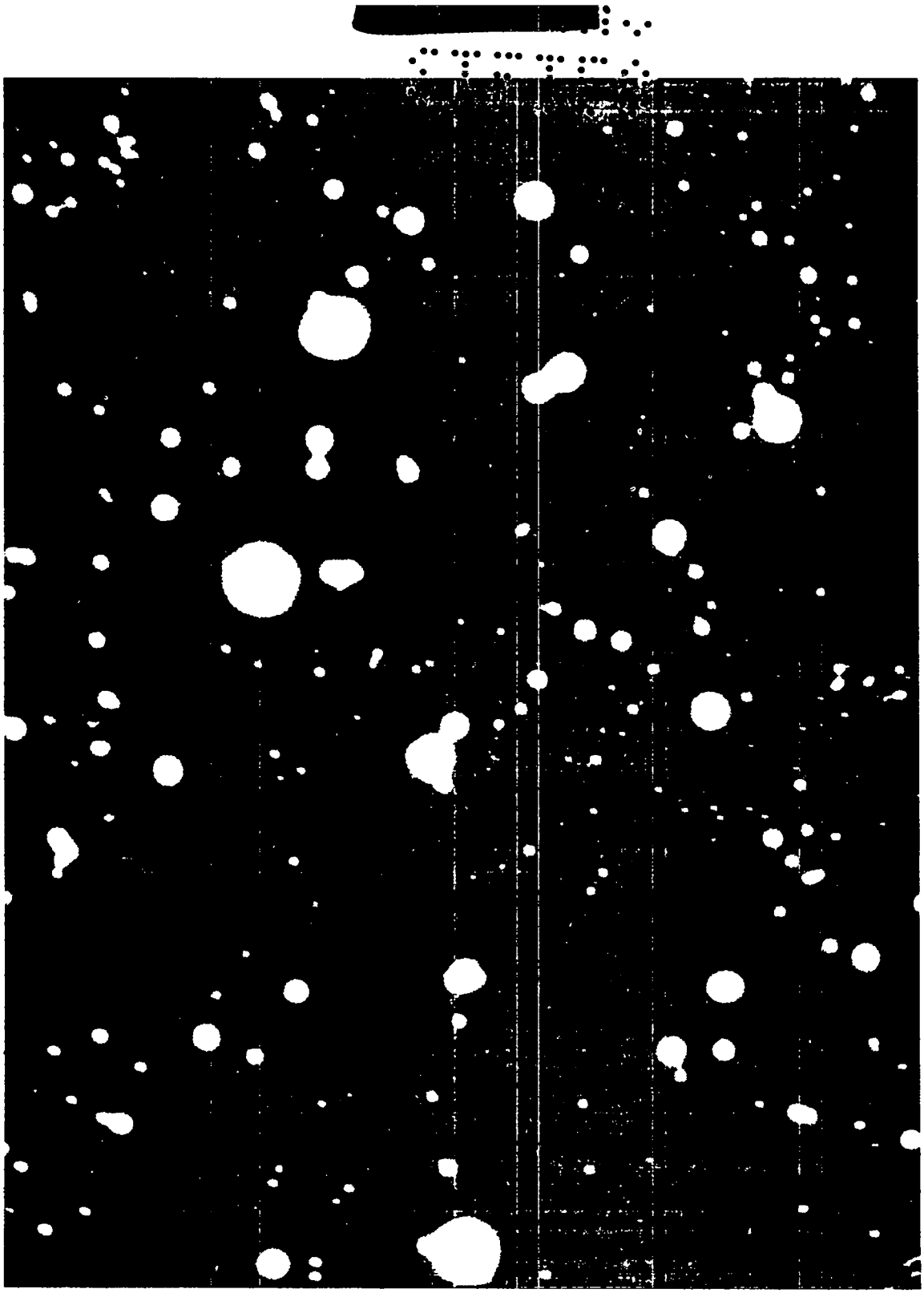

Fig. 13. Kodalith print of a fall-out tray radioautograph (film exposure time 36 hours). Tray collected after an air drop at 85 miles from ground zero, Upshot-Knothole series.

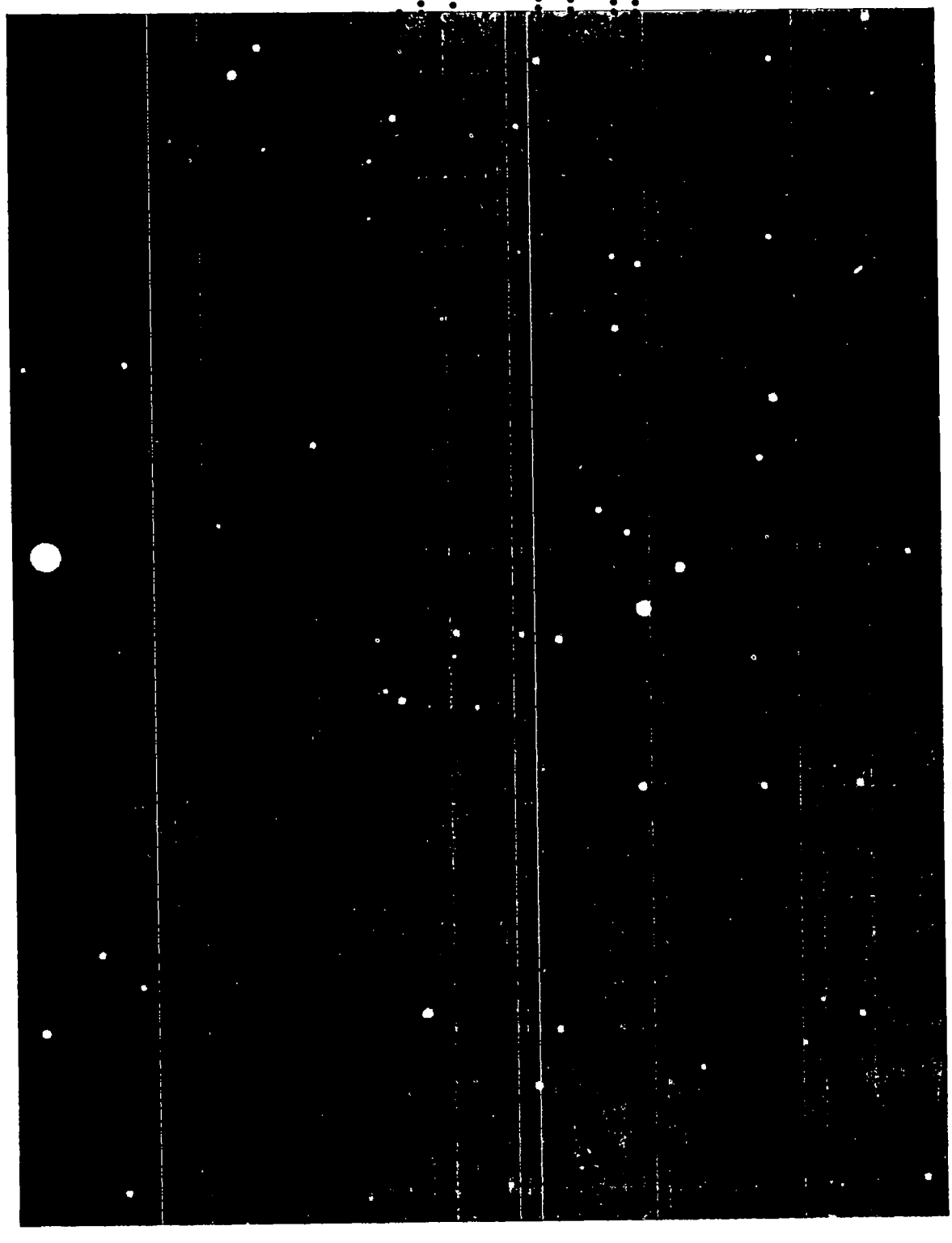

Fig. 14. Kodalith print of a fall-out tray radioautograph (film exposure time 1 minute). Tray collected after a tower shot at 50 miles from ground zero, Upshot-Knothole series.

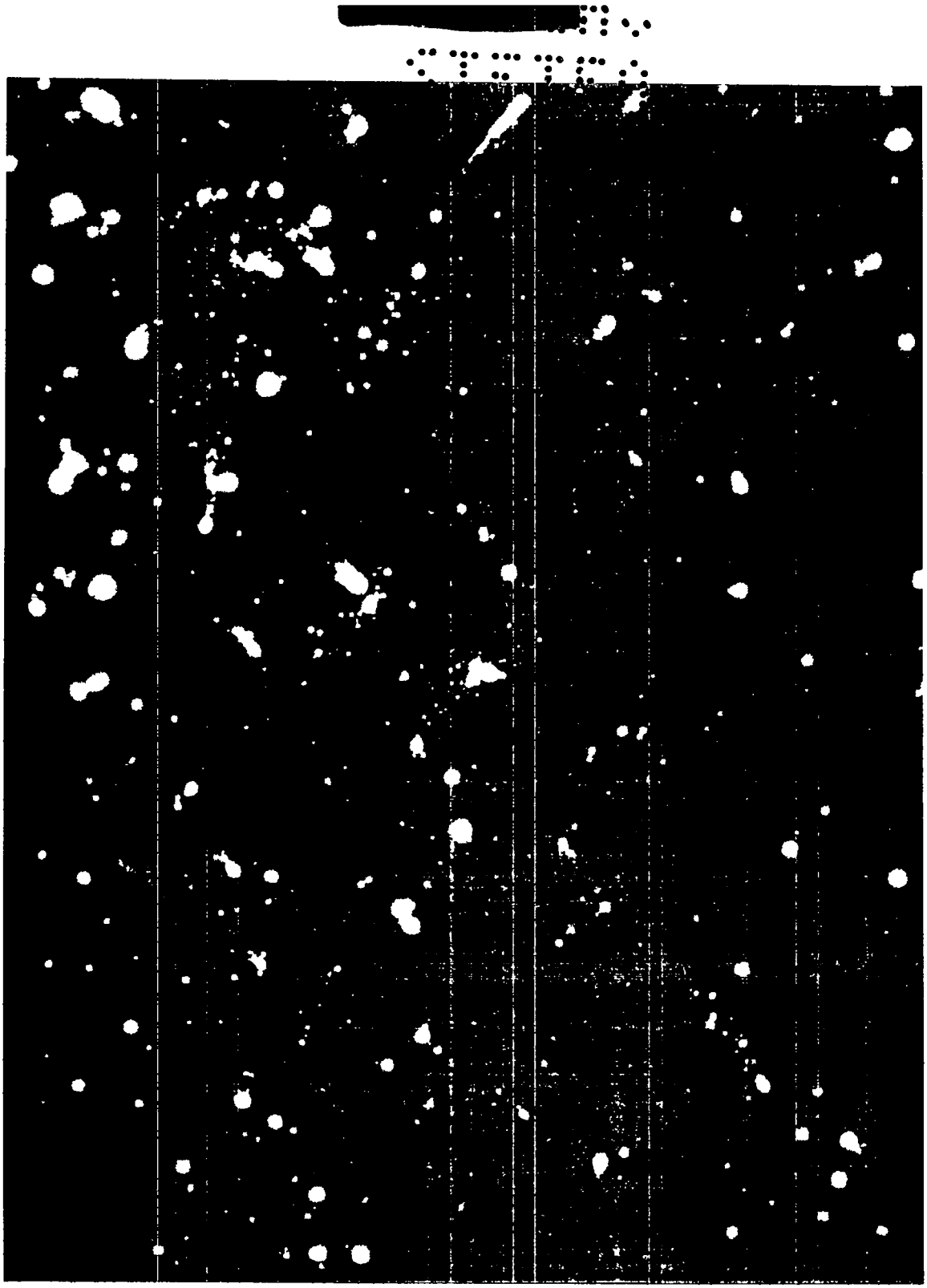

Fig. 15. Kodalith print of a fall-out tray radioautograph (film exposure time 3 minutes). Tray collected after a tower shot at 140 miles from ground zero, Upshot-Knothole series.

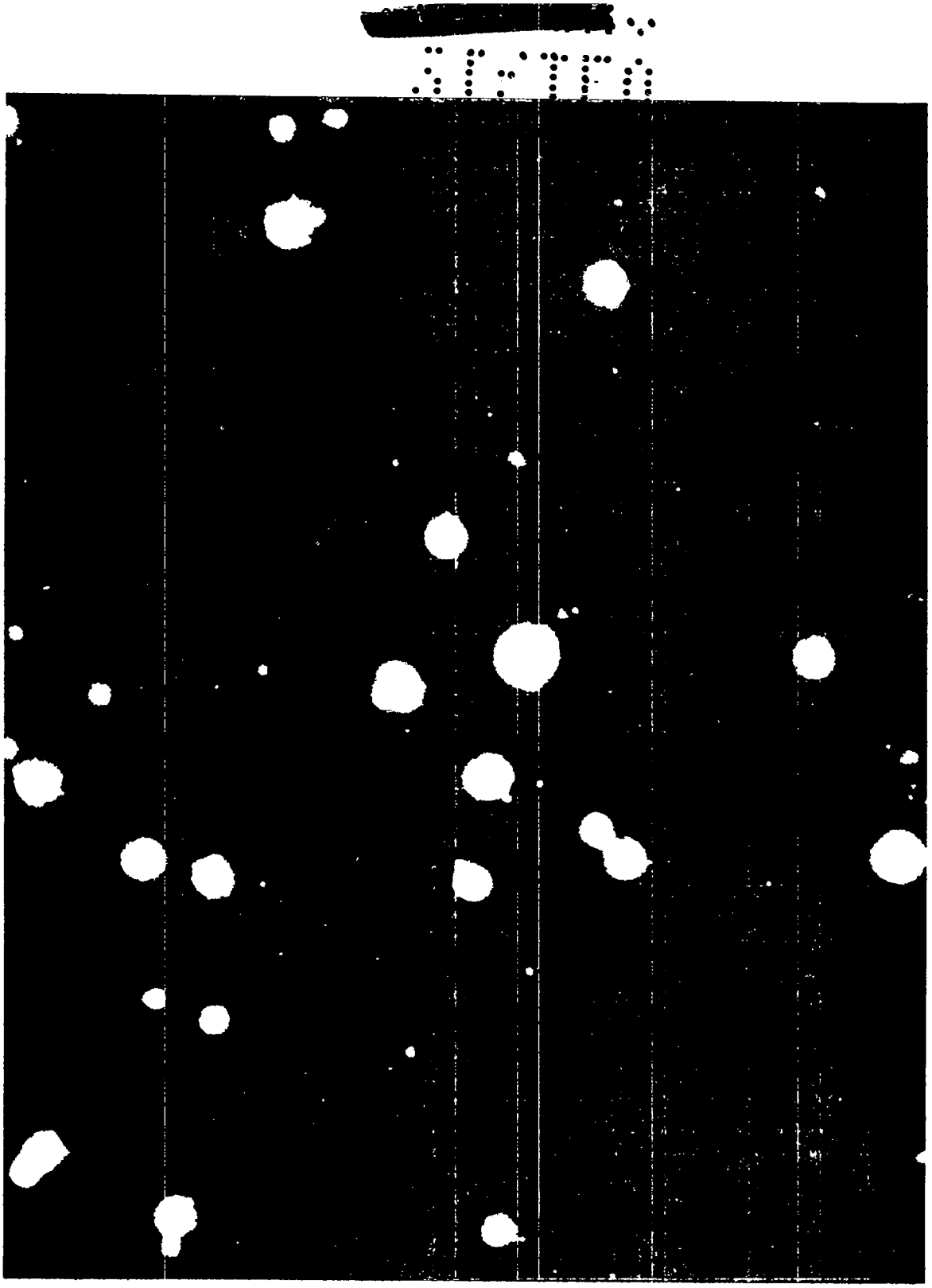

Fig. 16. Kodalith print of a fall-out tray radioautograph (film exposure time 30 minutes). Tray collected after a tower shot at 50 miles from ground zero, Upshot-Knothole series.

[redacted]

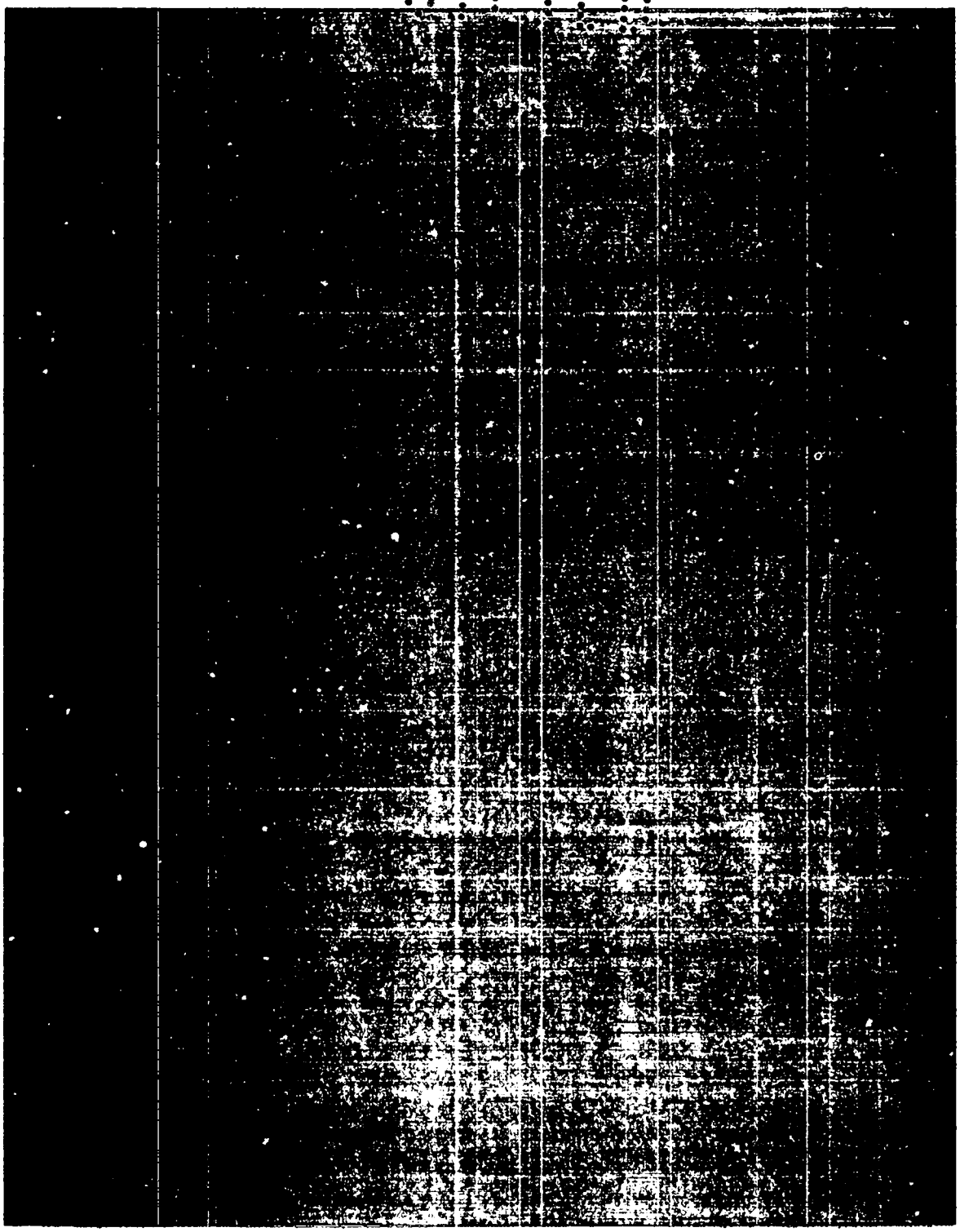

Fig. 17. Kodalith print of a fall-out tray radioautograph (film exposure time 5 minutes). Tray collected after a tower shot at 100 miles from ground zero, Upshot-Knothole series.

[redacted]

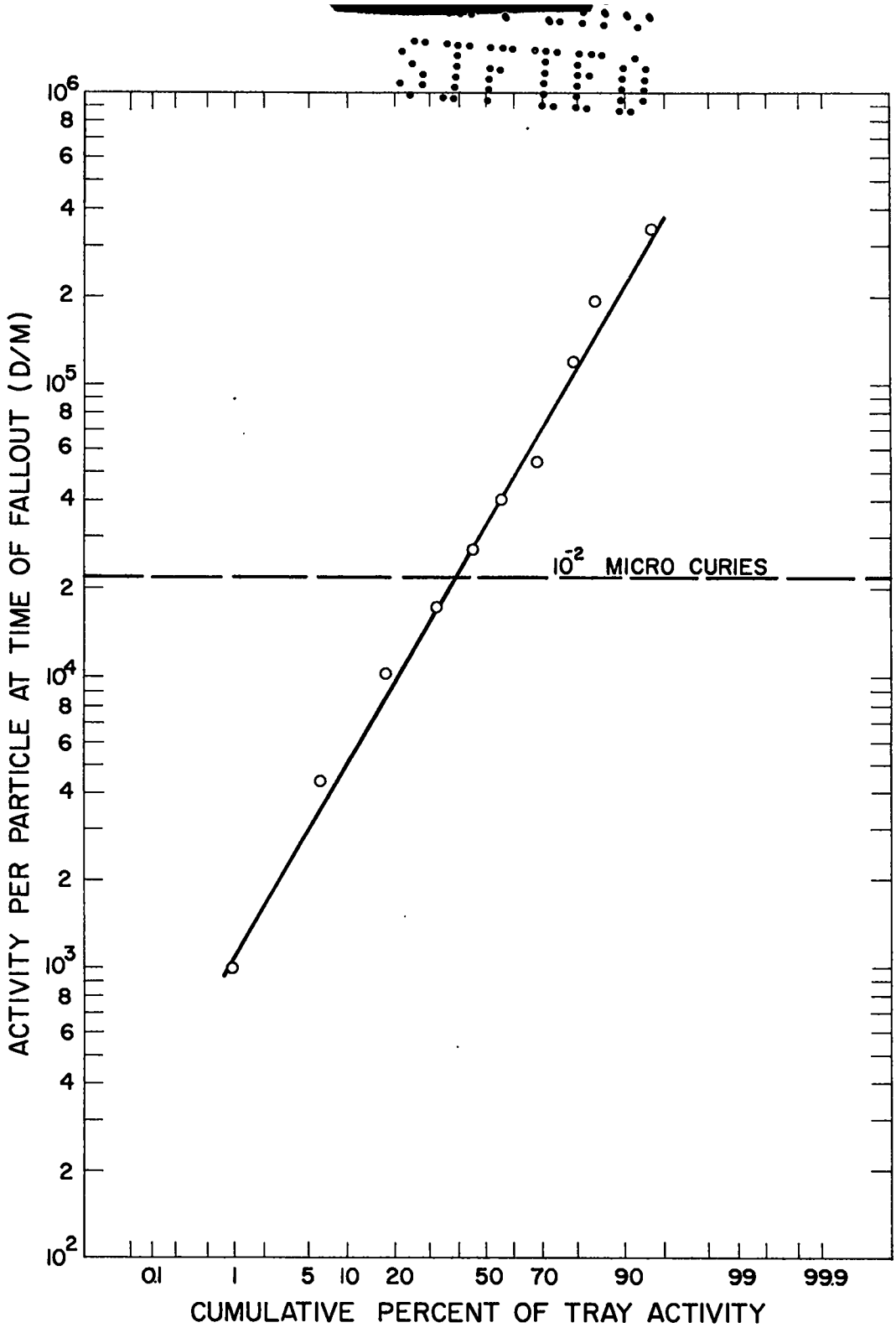

Fig. 18. Activities distribution from a fall-out tray. Sample collected after an air drop at 40 miles from ground zero, Tumbler-Snapper series.

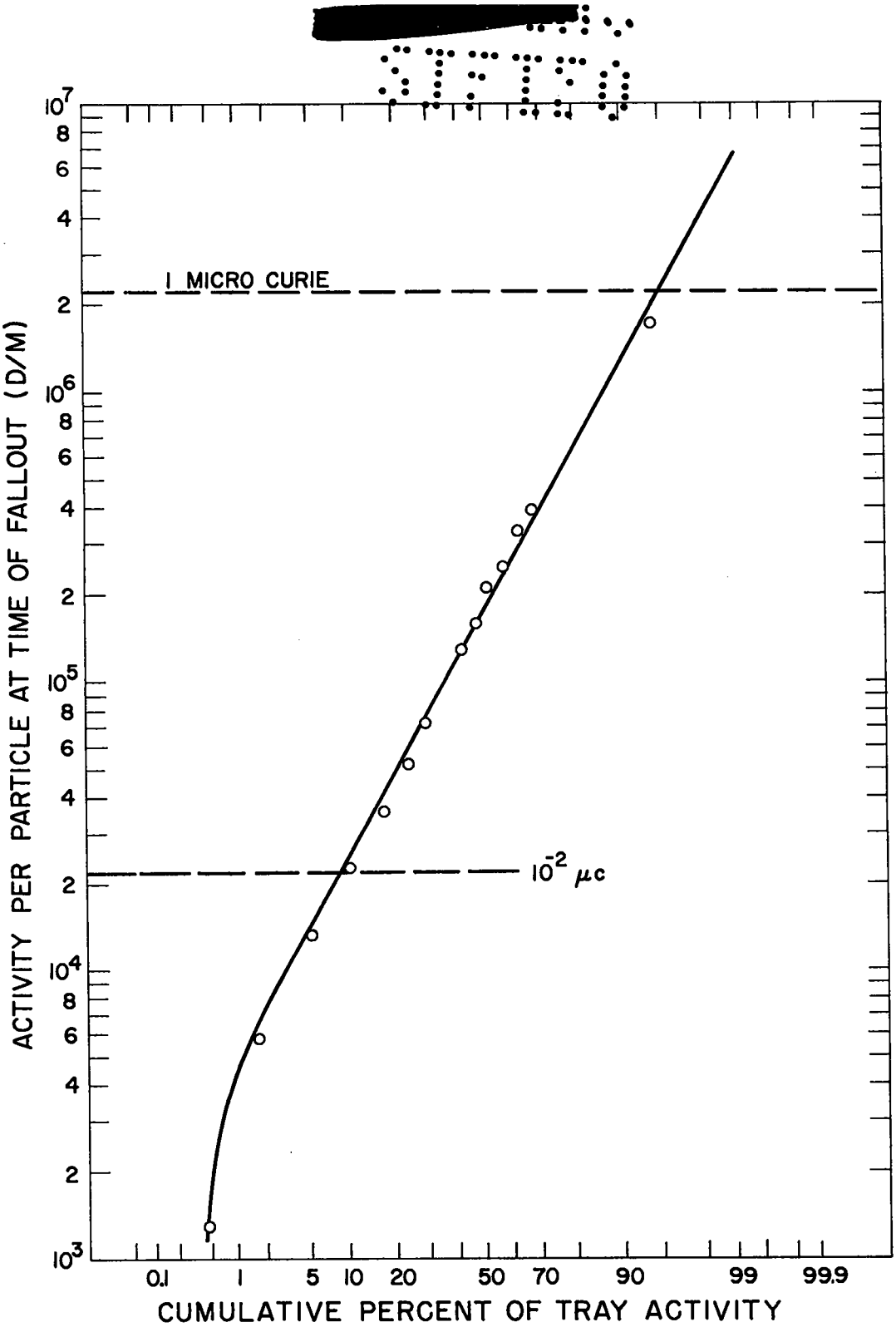

Fig. 19. Activities distribution from a fall-out tray. Sample collected after an air drop at 85 miles from ground zero, Upshot-Knothole series.

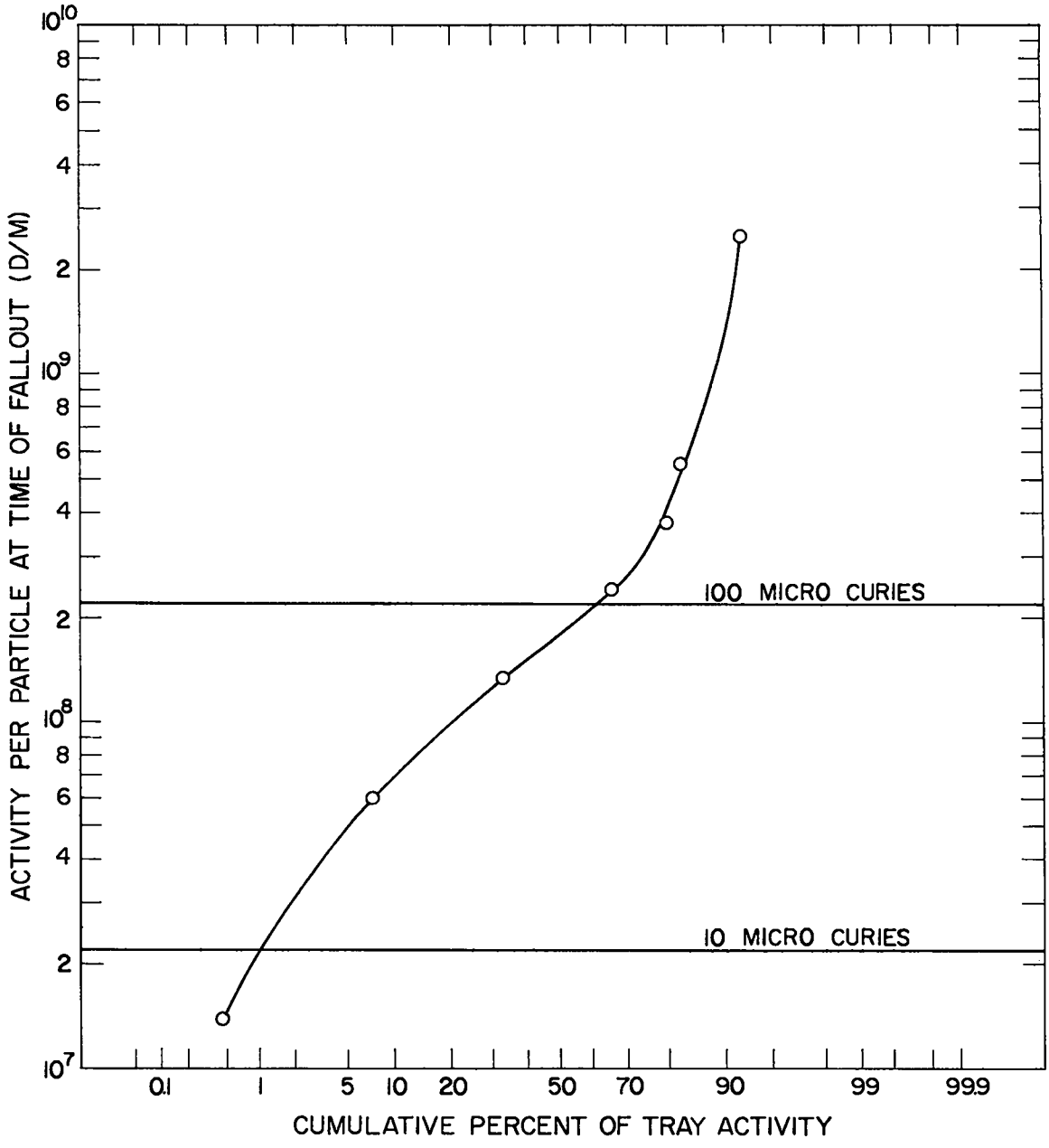

Fig. 20. Activities distribution from a fall-out tray. Sample collected after a tower shot at 50 miles from ground zero, Upshot-Knothole series.

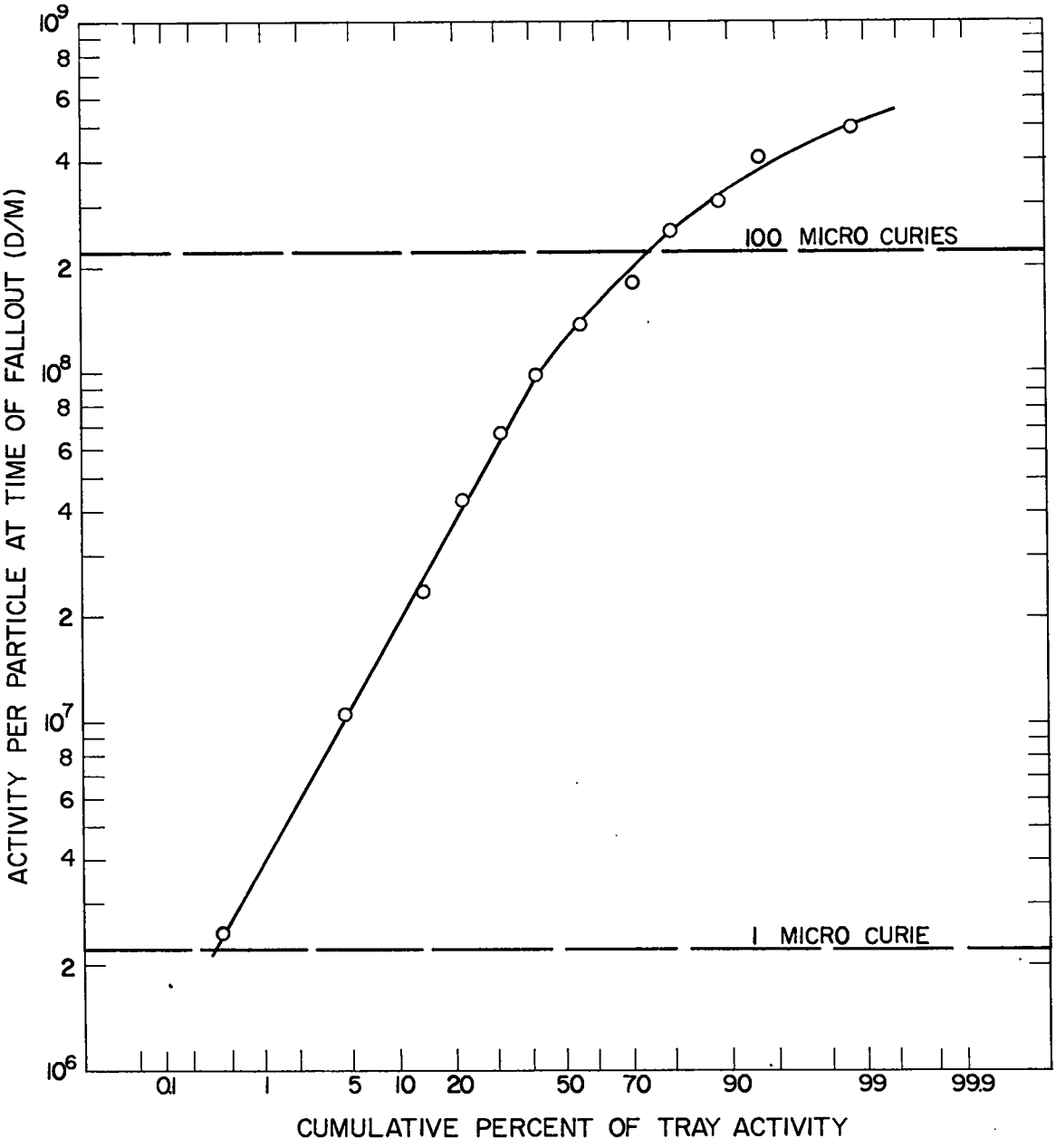

Fig. 21. Activities distribution from a fall-out tray. Sample collected after a tower shot at 140 miles from ground zero, Upshot-Knothole series.

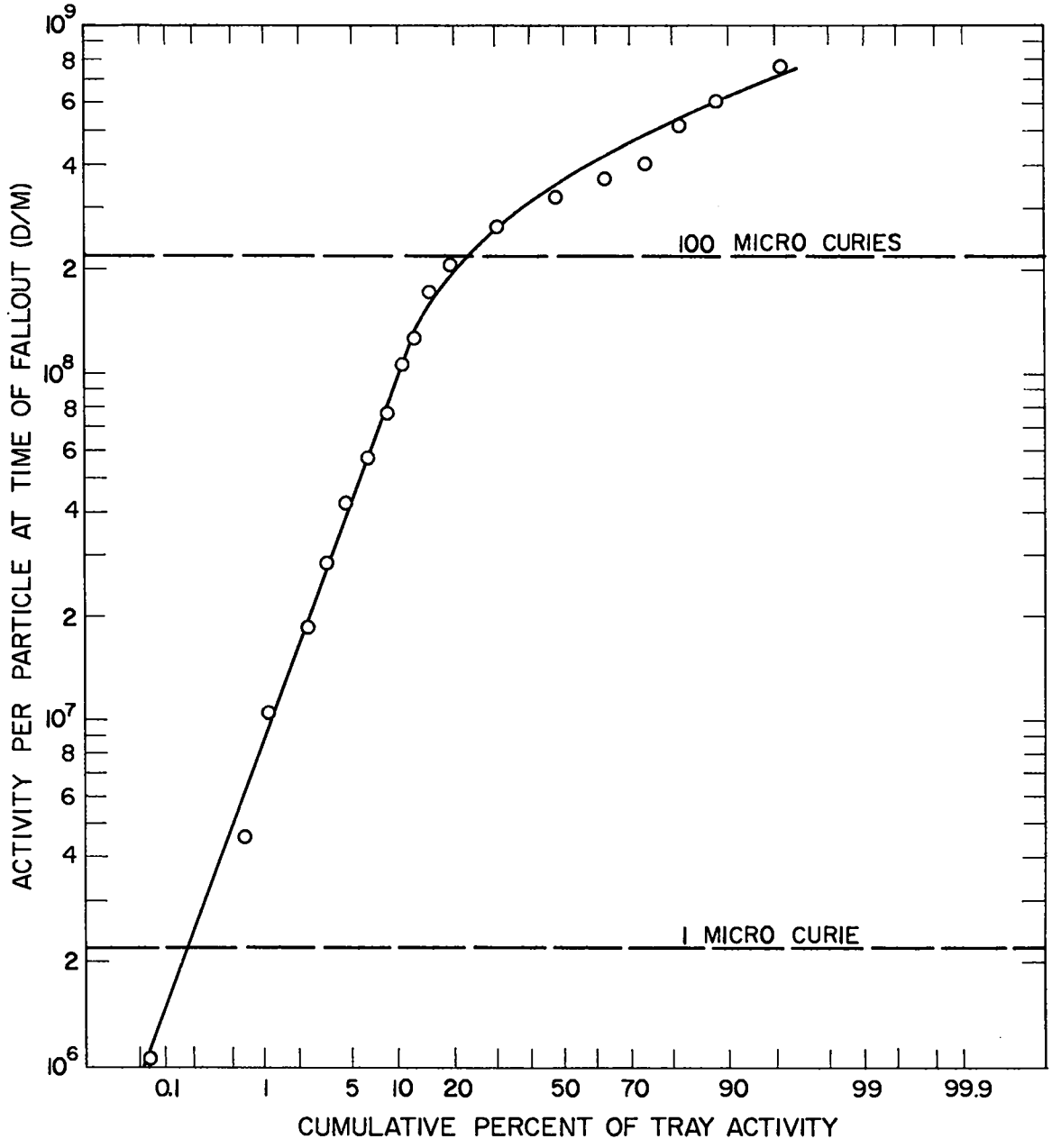

Fig. 22. Activities distribution from a fall-out tray. Sample collected after a tower shot at 50 miles from ground zero, Tumbler-Snapper series.

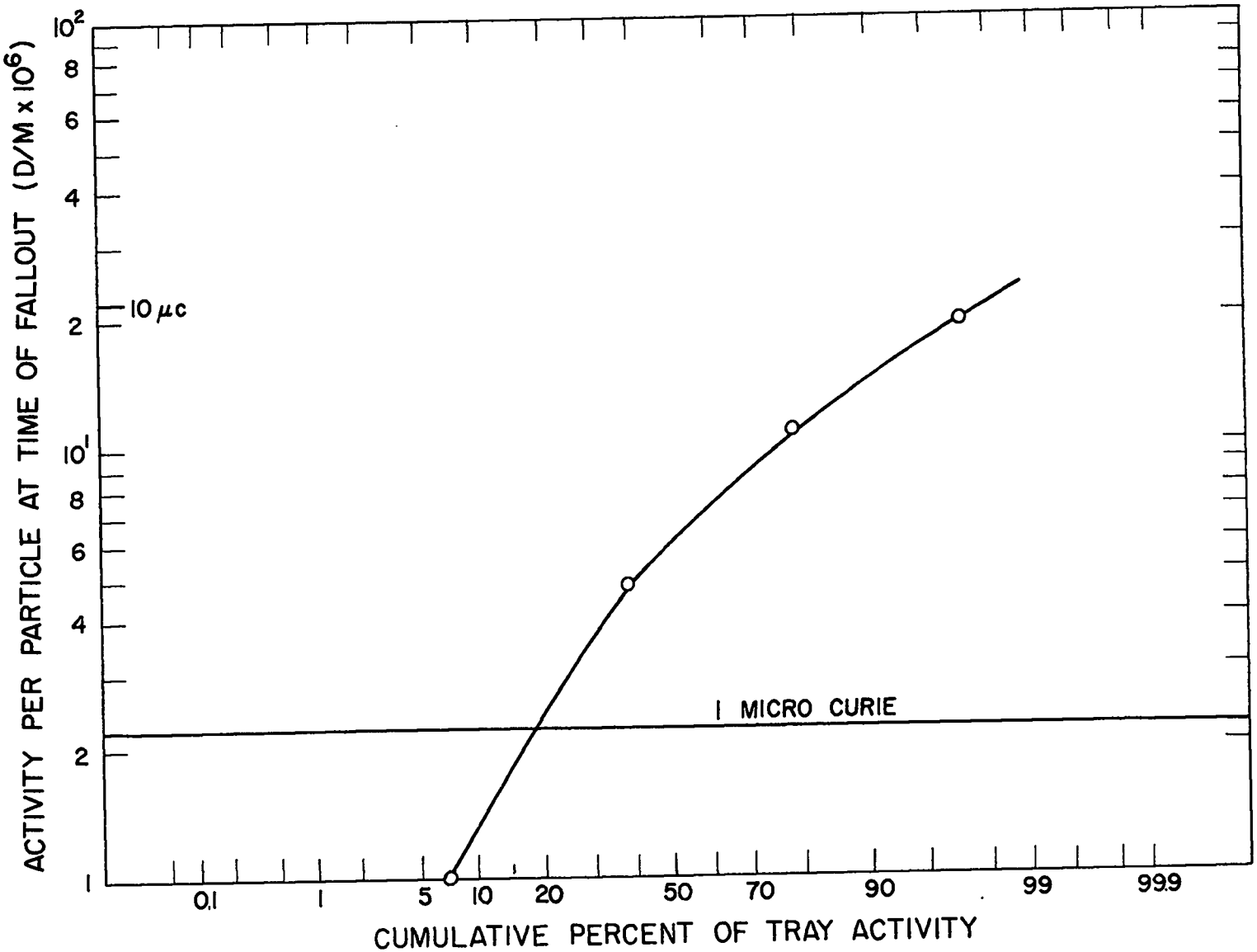

Fig. 23. Activities distribution from a fall-out tray. Sample collected after a tower shot at 100 miles from ground zero, Upshot-Knothole series.

Fig. 24. Fluted filter paper.

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Fig. 25. Flat 4 by 9 inch methane flow chamber.

[redacted]

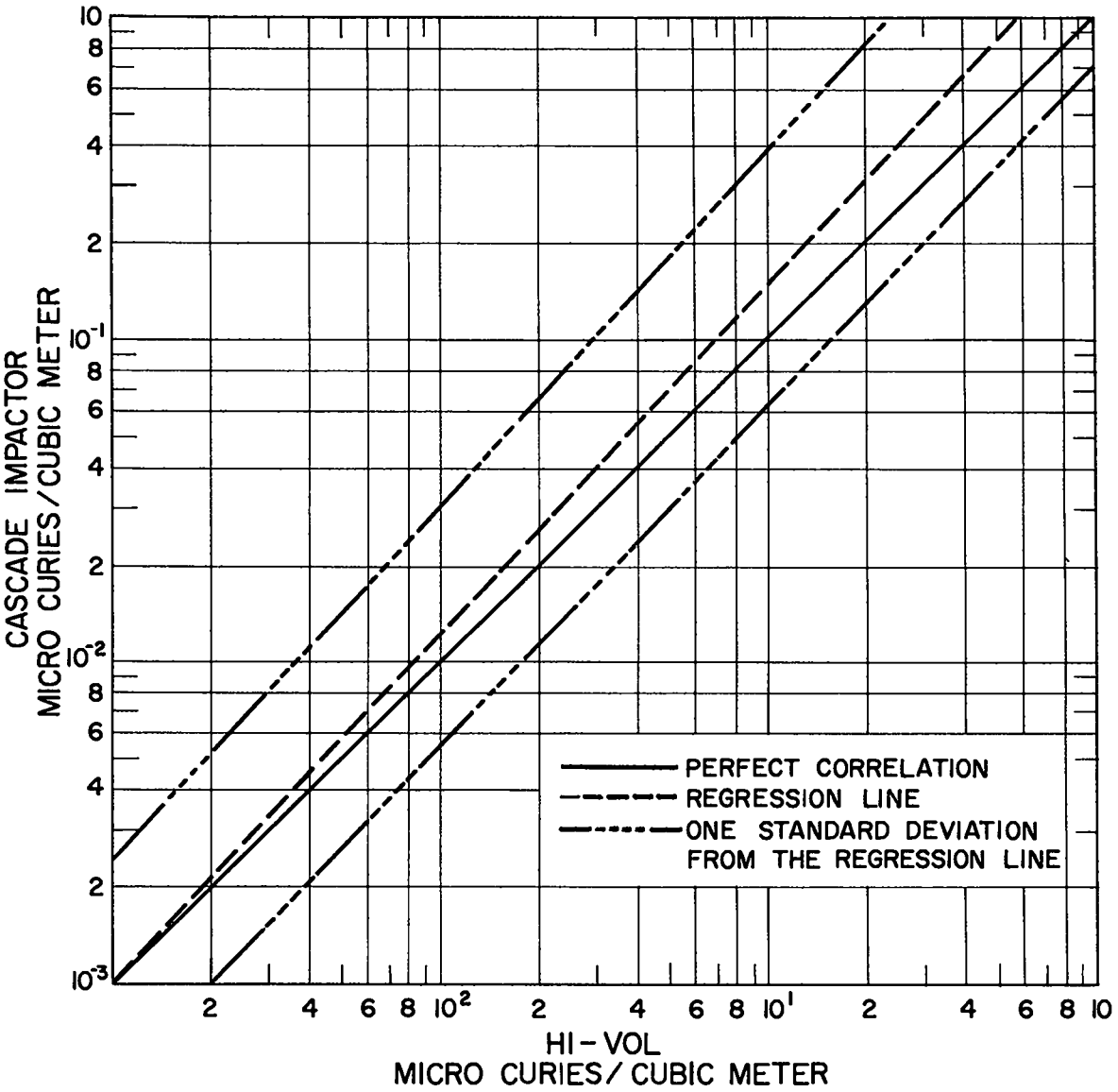

Fig. 26. Air concentration. Comparison of the High-Volume sampler and the cascade impactor.

[redacted]

[redacted]

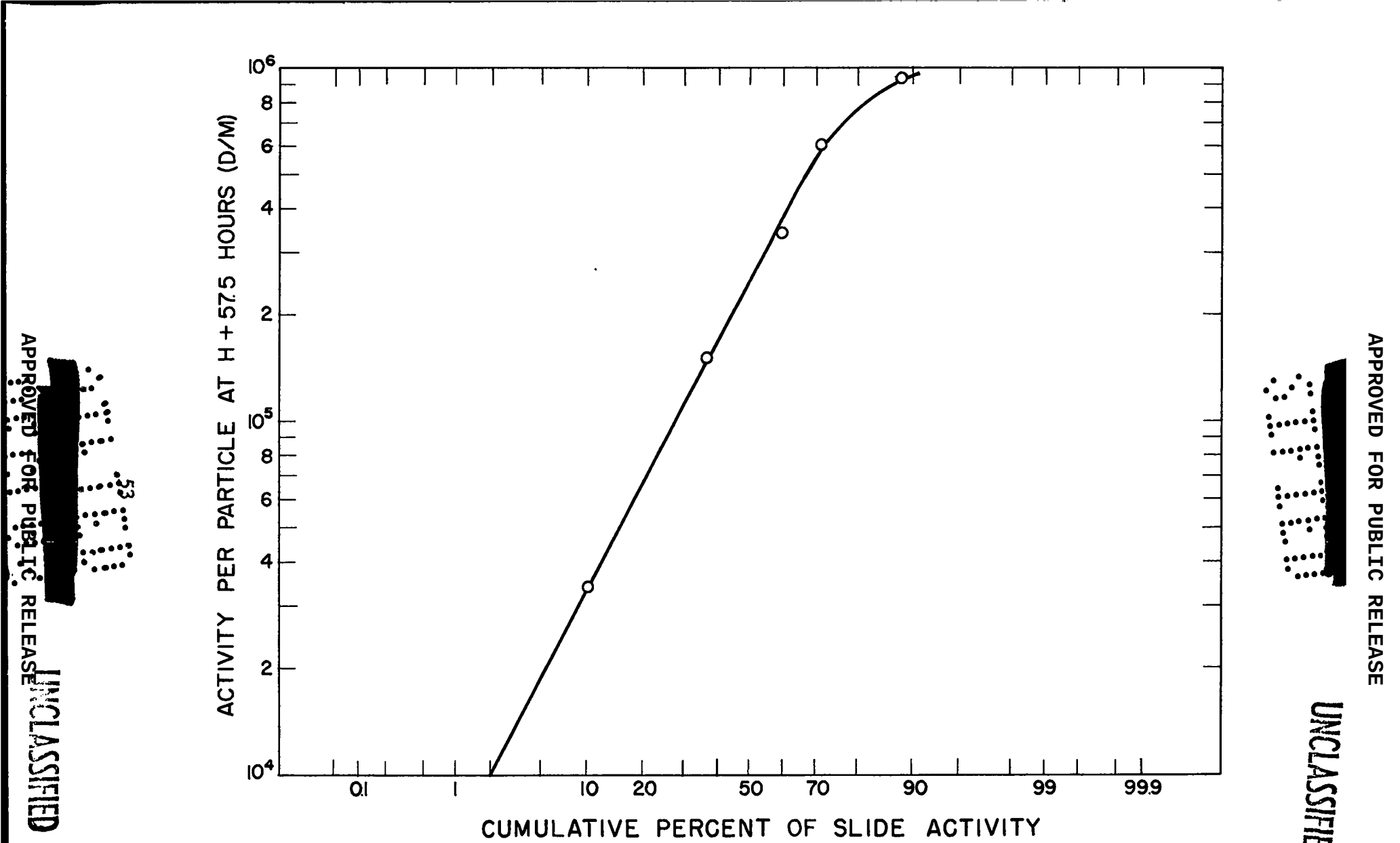

Fig. 27. Activities distribution from a radioautograph of the first stage of a cascade impactor. Sample collected after a tower shot at 140 miles from ground zero, Upshot-Knothole series.

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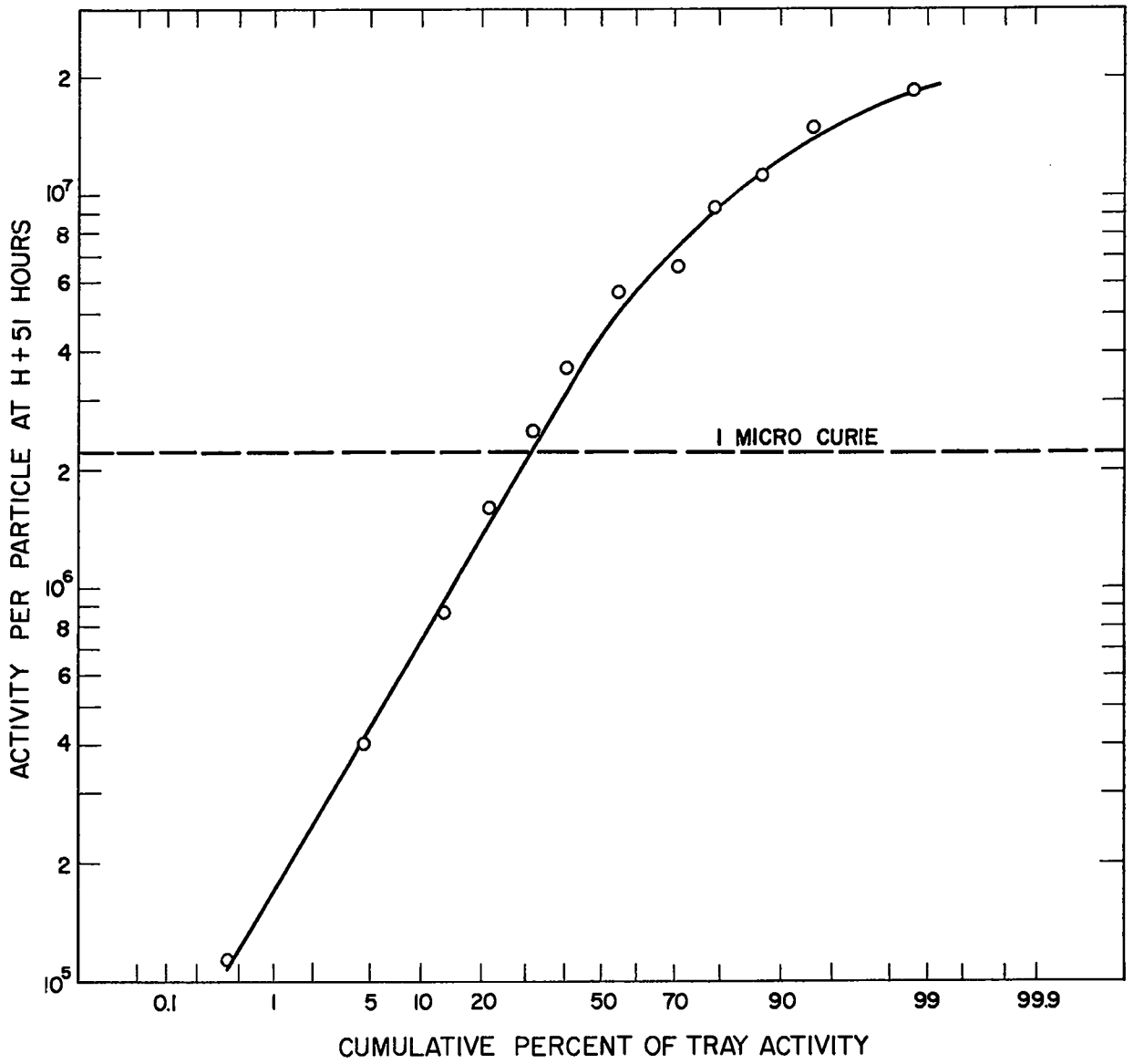

Fig. 28. Activities distribution from a radioautograph of a fall-out tray. Sample collected after a tower shot at 140 miles from ground zero, Upshot-Knothole series.