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PROJECT BUGGY GAMMA FALLOUT FIELD

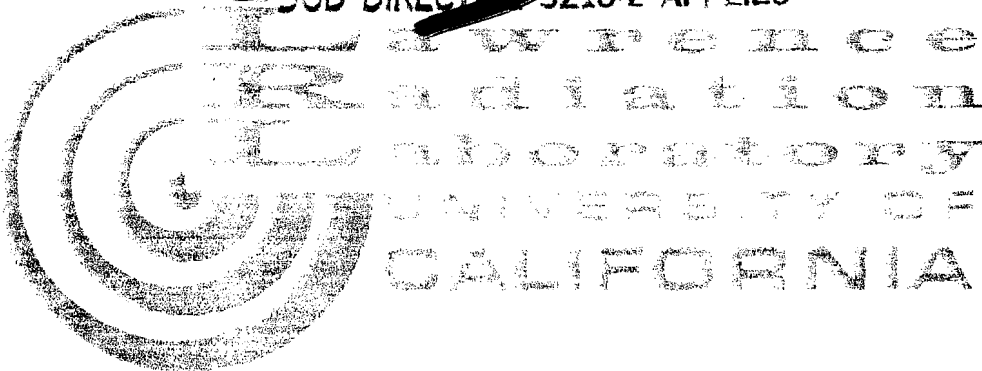
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John P. Clement, III
Thomas A. Gibson, Jr.

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Lawrence Radiation Laboratory
UNIVERSITY OF CALIFORNIA
LIVERMORE

UCRL-50832

PROJECT BUGGY GAMMA FALLOUT FIELD

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John P. Clement, III
Thomas A. Gibson, Jr.

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PROJECT BUGGY GAMMA FALLOUT FIELD

Abstract

The gamma radiation early fallout field of the Buggy Event was measured and documented. The radioactive decay of the field with time was also followed. Isoexposure rate contour maps of the fallout field are presented. Analysis of the information collected shows that approximately 3.3% of the gamma-emitting radioactive material produced was deposited beyond the area of continuous ejecta in the fallout field.

Introduction

OBJECTIVES

The objectives of this phase of the Buggy Event were: (1) to provide ground level gamma fallout field measurements for estimating the total gamma radioactivity vented and deposited in early fallout; (2) to provide fallout field contours from this test event for use in normalizing fallout prediction models; and (3) to determine whether the amount of radioactivity deposited in early fallout from a nuclear row charge is significantly different from that resulting from a single cratering detonation.

BACKGROUND

Ground surface gamma fallout exposure rates have been measured following almost every uncontained test shot since Trinity. The resulting fallout contours are summarized in Ref. 1 and subsequent publications by the Army Nuclear Defense Laboratory. Prior to Buggy, only four nuclear cratering events had been conducted by the USA which were useful as fallout experiments for cratering. These were Teapot-ESS, Danny Boy, Sedan, and Cabriolet. We eliminated the Jangle Underground Event because it was buried at too shallow a depth, and the Palanquin Event because of its abnormal venting. Thus, Buggy is a significant addition to our small number of experiments. Also, Buggy is unique in being the first nuclear row charge experiment.

For the Buggy Event, a number of different agencies and laboratories measured gamma radiation. All the known pertinent information available from these sources is included in this report. The authors served as field coordinates, collected the available data from the various participants, reduced the raw data, and formulated the results presented in this report.

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Experimental Procedure

SHOT PARTICIPATION

Project Buggy was the first nuclear row cratering detonation executed as part of the Plowshare Program for developing nuclear excavation techniques. Five nuclear explosives, each with a yield of 1.1 kt, were detonated simultaneously at 0904:00.111 PST, 12 March 1968. The explosives were detonated at depths of 135 ft, and were spaced 150 ft apart. The experiment took place on Chukar Mesa, Area 30, Nevada Test Site, in a dry, complex basalt formation. Surface ground zero (SGZ) coordinates of the end emplacement holes designated as U30a and U30e were:

	U30a	U30e
NTS grid coordinates:	N 821,828.24 E 586,630.95	N 822,039.76 E 586,069.54
Latitude:	N 37° 0' 26.9695"	N 37° 0' 29.0784"
Longitude:	W 116° 22' 11.8817"	W 116° 22' 18.7955"

The line of charges was on a bearing of N 69° 21' 05" W. Ground elevations at each hole were:

	Hole U30				
	A	B	C	D	E
Elevation, MSL (ft)	5208.28	5210.04	5210.52	5209.47	5208.42

The principal objectives of the experiment were: (1) to determine nuclear row crater parameters through level terrain in a hard, dry rock; and (2) to determine the fraction of radioactivity which escapes the immediate cratered area.

The dimensions of the resultant crater are:

Apparent crater width, average (W_a)	254 ft
Apparent crater depth, maximum (D_a)	69.8 ft
Lip crest width, average (W_{al})	355 ft
Apparent crater length (L_a)	865 ft
Apparent lip height, average (H_{al}) sides	41 ft
Apparent lip height, average (H_{al}) ends	14 ft
Apparent crater volume	262,456 yd ³
Apparent lip volume	422,205 yd ³

The approximate dimensions of the cloud at +72 sec, the time of maximum initial growth, were:

Base surge diameter	4,500 ft
Base surge height	780 ft
Plume height	2,200 ft
Plume diameter	900 ft

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GENERAL DESCRIPTION OF STATIONS

Gamma radiation exposure rate measurements in the Buggy fallout field were made by several organizations using different detection equipment.

The Reynolds Electrical and Engineering Company (REECo) remote area monitoring system (RAMS) consisted of 17 units connected by wire to a central trailer at the Command Post (CP). The individual stations were Neher-White ionization chambers mounted on stakes 3 ft above ground level.

REECo also deployed 22 gamma intensity time recorders (GITR) throughout the fallout field. Each of these stations was self-contained and consisted of a Neher-White ionization chamber mounted on a stake 3 ft above ground level, an Esterline-Angus recorder, and a portable gasoline generator. Each recorder semi-logarithmically plotted exposure rate versus time within a preset range of three decades.

Lawrence Radiation Laboratory, Livermore placed 45 units of its gamma telemetry system² at fixed locations. This system consisted of individual stations connected to a trailer at the CP via VHF radio. Each unit consisted of an ionization chamber mounted on a tripod 4 to 5 ft above ground level and the associated electronics, battery, and radio transmitter-receiver.

REECo mobile radiological safety monitoring teams measured exposure rates with hand-held Victoreen Radector AGB-500-B-SR instruments. U. S. Public Health Service mobile monitoring teams also made measurements, using primarily E-500B instruments; these were outside the Nevada Test Site boundary and at a considerable distance from ground zero (GZ).

STATION LOCATIONS

Figures 1, 2 and 3 show locations of the REECo stations, the gamma telemetry stations of LRL K-Division, the fallout trays of LRL Radiochemistry Div., the mobile monitoring team stakes, and all other pertinent positions where exposure-rate measurements were recorded.

The locations of all remote monitoring stations, with the exception of the LRL gamma telemetry system, are controlled by the requirements of reentry and radiological safety, and were positioned by the Health and Safety Office, LRL-Nevada. The authors were responsible for the location of the LRL gamma telemetry units.

The technique used to position the gamma telemetry units depended on the predicted fallout pattern, fallout sector, throwout or ejecta range and base surge radius; and also on terrain adaptability, the number of units available, location of other remote monitoring systems, and a reasonable minimum exposure rate value to be detected. Reference 3 contains a detailed discussion of the technical and practical techniques used in placing the LRL gamma telemetry units.

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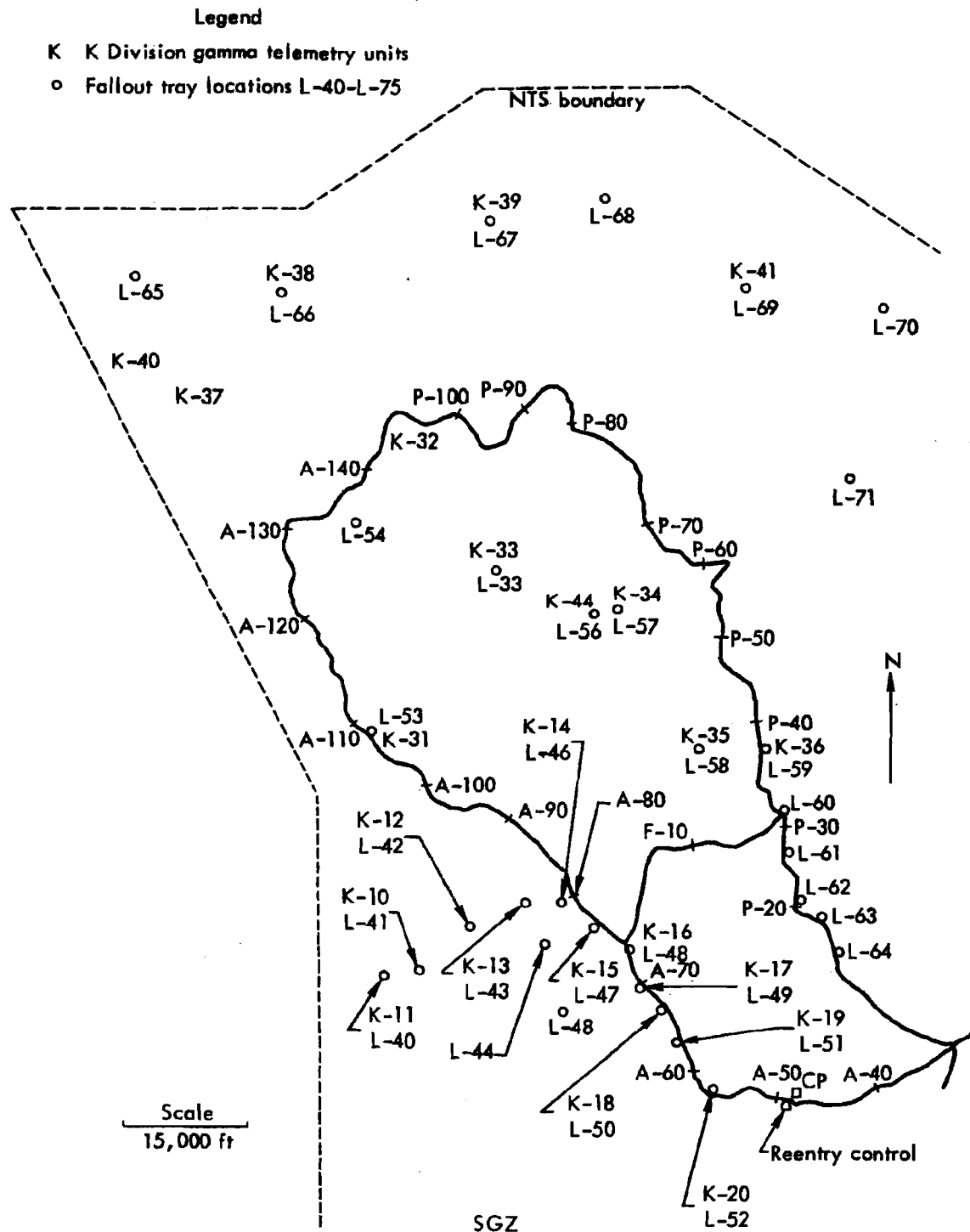


Fig. 1. Buggy far-out experimental station locations.

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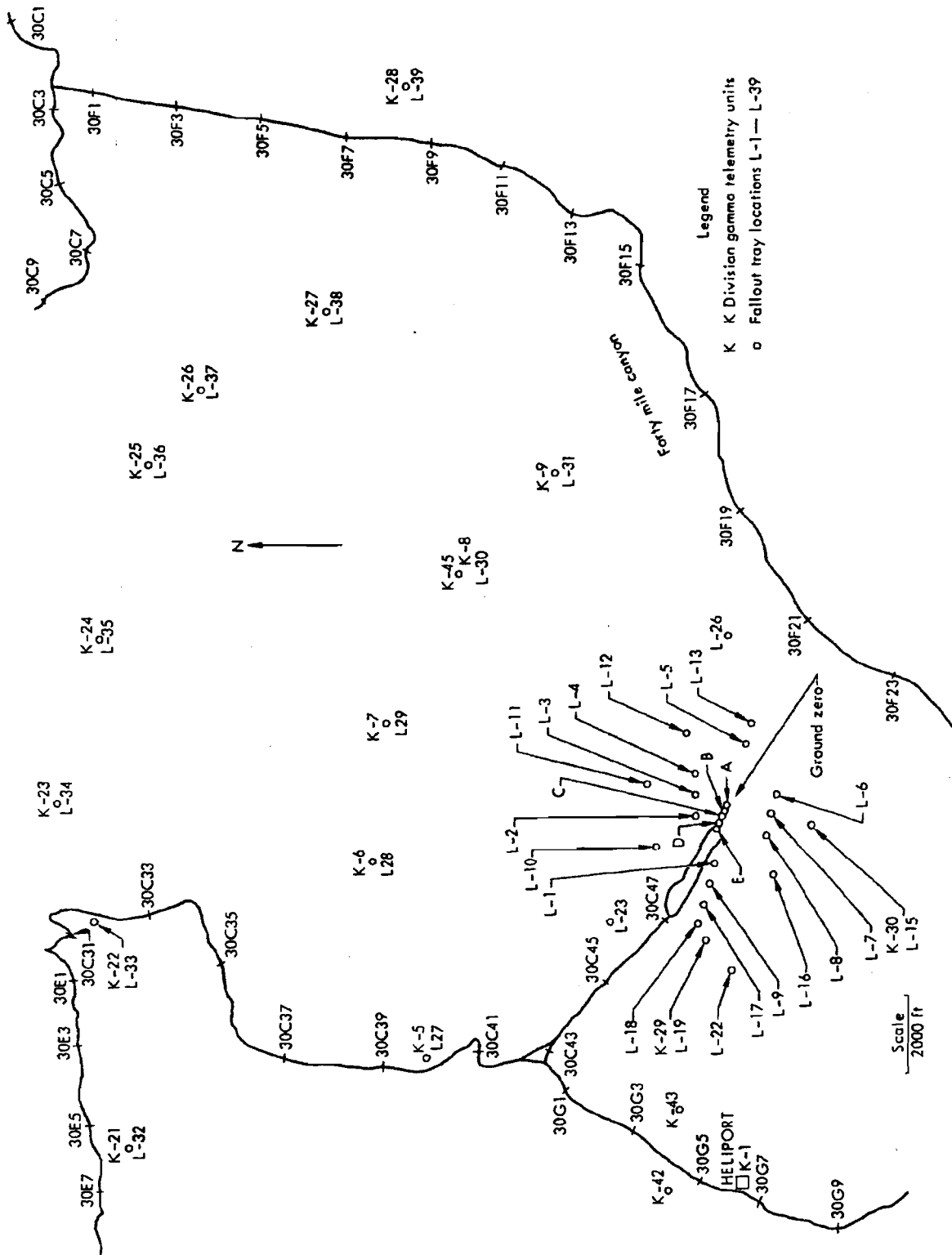


Fig. 2. Buggy intermediate experimental station location.

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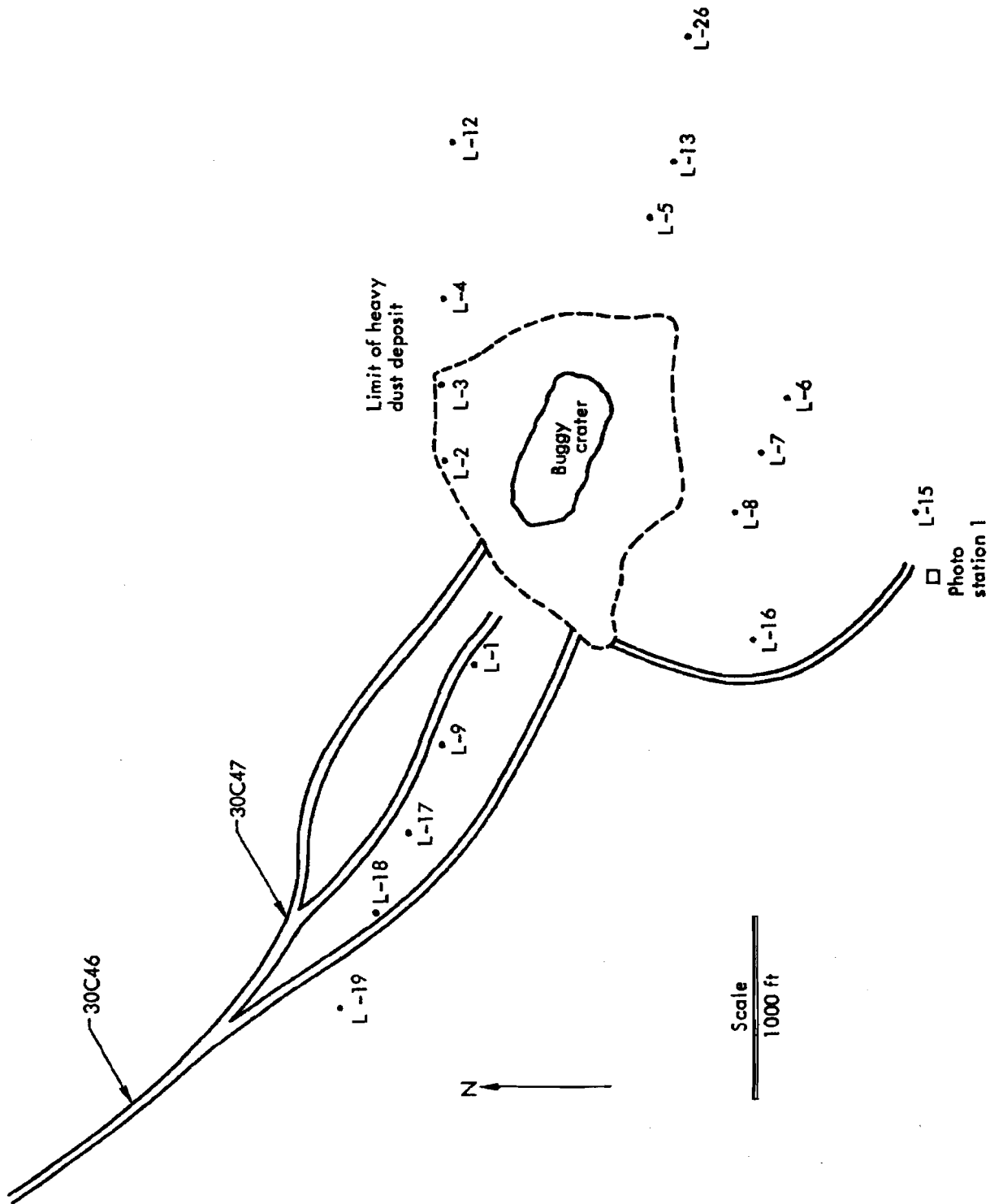


Fig. 3. Buggy GZ vicinity postshot, from aerial photograph.

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Results

DECAY CURVES

The LRL gamma telemetry system followed the course of the radioactive decay of the gamma radiation field for slightly more than 100 hours. The REECO system was expected to augment these decay measurements; however, the RAMS detectors did not function since all the wires to RAMS units passed too close to GZ and were cut by falling rock within a few seconds after shot time.

Only one GITR station of the 22 deployed produced a trace which was at all believable. Even this was not used because the GITR system measurements failed to correlate with other measurements obtained during the Cabriole Event.

The Buggy early time decay curve, Fig. 4, is the nonweighted, arithmetic average of the log-log normalized decay curves produced by LRL telemetry units 4, 12, 23, 30 and 31. These five stations were selected because they operated uninterrupted for more than 100 hours and their readings did not fall below the lowest level for which the units were calibrated. Each of the five decay curves can be contained within the shaded envelope graphically represented by Fig. 5.

The long-term decay was recorded by repeated hand-held instrument readings taken at stakes around the crater lip. The average slope for the log-log straight line plot of the ten lip stations was -0.9. Figure 6 is a time decay plot of one lip stake location with this average slope.

Appendix A contains the time decay curves from all LRL telemetry stations and the time decay plots for the ten crater lip stake locations.

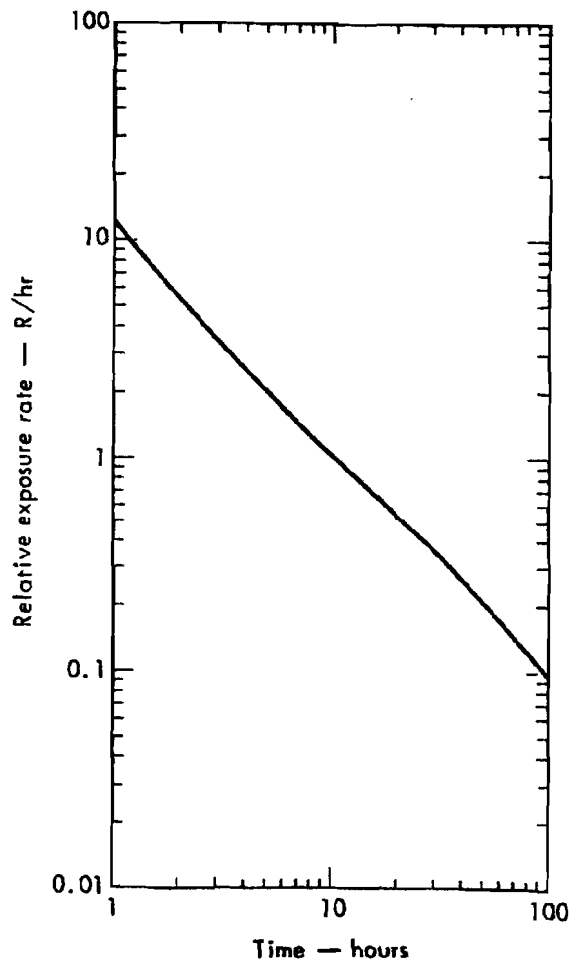


Fig. 4. Average normalized LRL gamma decay curve.

MONITOR TEAM DATA AND DATA REDUCTION

Monitoring teams conducted radiological surveys following the event. The technique employed was the standard

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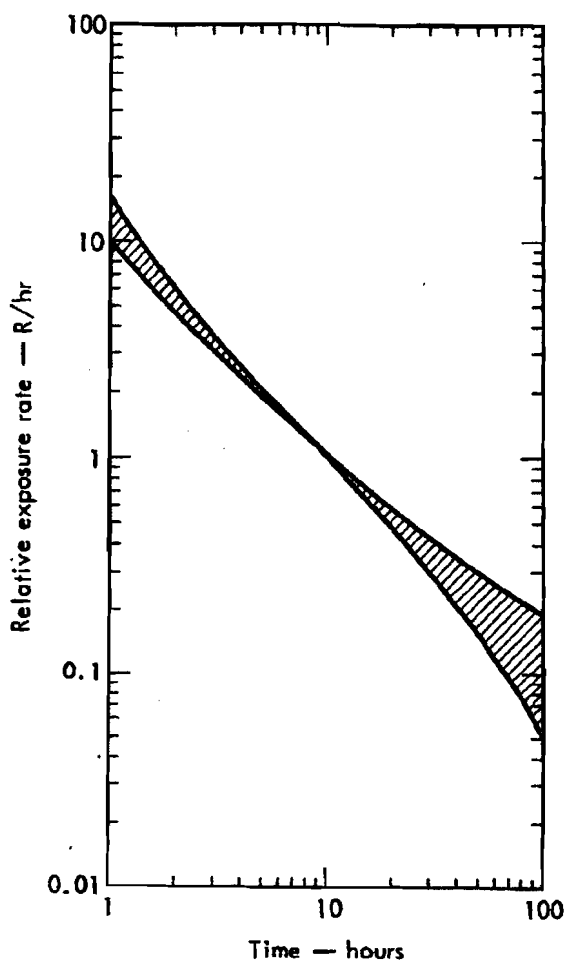


Fig. 5. Normalized decay envelope.

each geographical location was made. The monitor team readings and reduced data are tabulated in Appendix B.

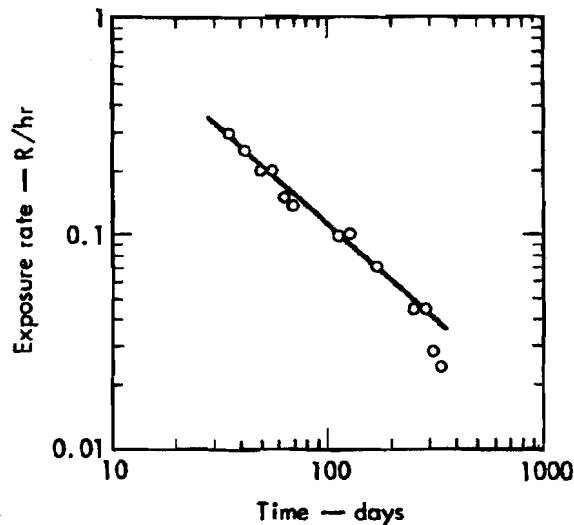


Fig. 6. Decay at crater lip—Station 3.

procedure of marking the various roads and trails with rad-safe survey monitor stakes. Other locations were identified by the location of sampling trays, RAMS units, GITR units, LRL telemetry units, or distinguishable man-made features.

We have converted each monitor team exposure rate measurement to a common time of H+1 hour postshot by use of the early time decay curve, Fig. 4. From these numbers, a best estimate of H+1 hour exposure rate for

FALLOUT EXPOSURE RATE CONTOURS

The fallout pattern contours shown in Figs. 7 and 8 represent isoexposure rate levels at a reference time of H+1 hour. This representation follows a convention well established in the literature; it does not mean that fallout was complete at all locations one hour after detonation. These figures were drawn using the reduced monitor team data presented in Appendix B, and where appropriate, LRL telemetry data. We used plots of log exposure rate versus log distance to interpolate between measured data point locations to establish contour locations. Figure 9 is a plot of exposure rate versus distance downwind along the pattern "hot line."

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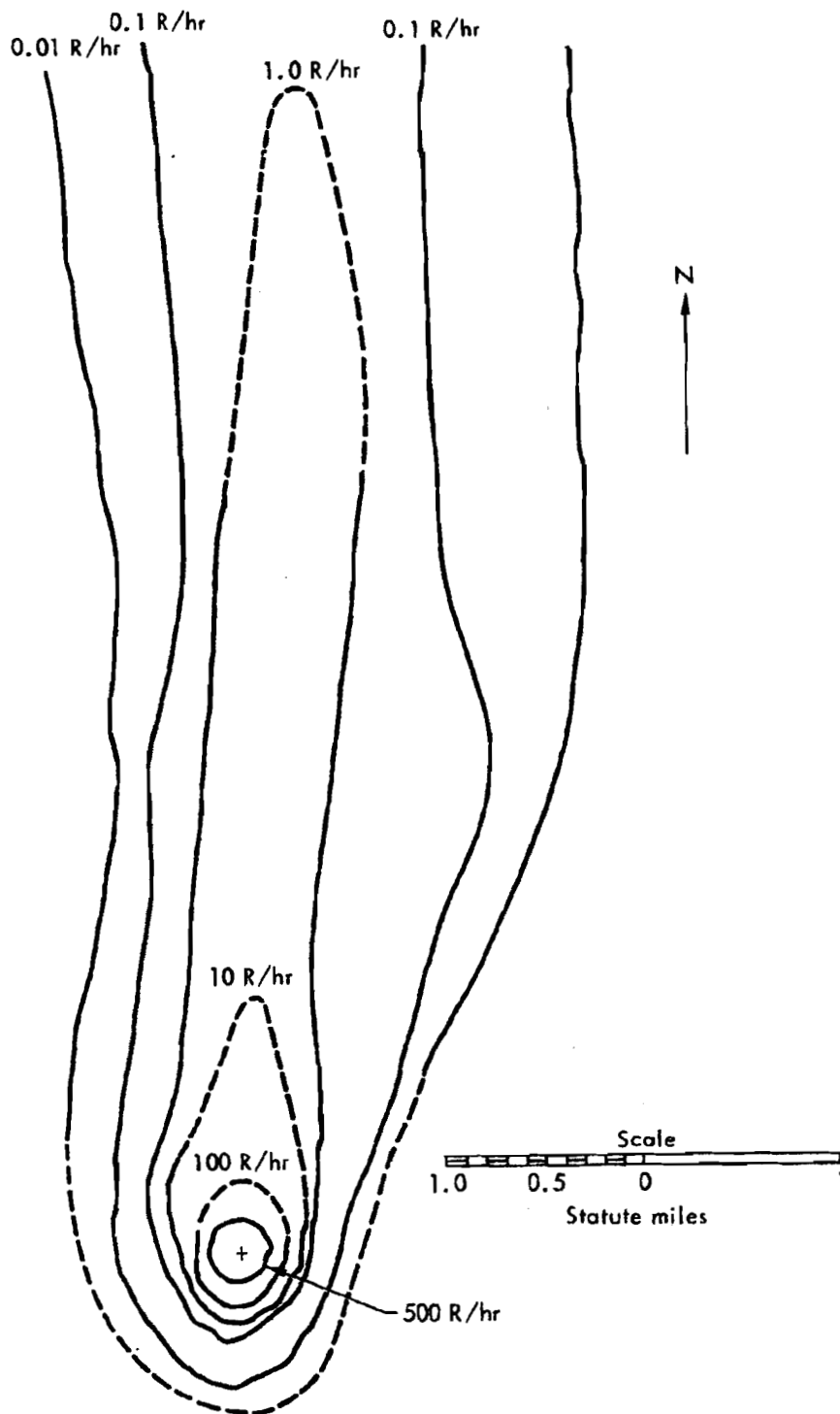


Fig. 7. Exposure rate contours at H+1 hour, in R/hr.

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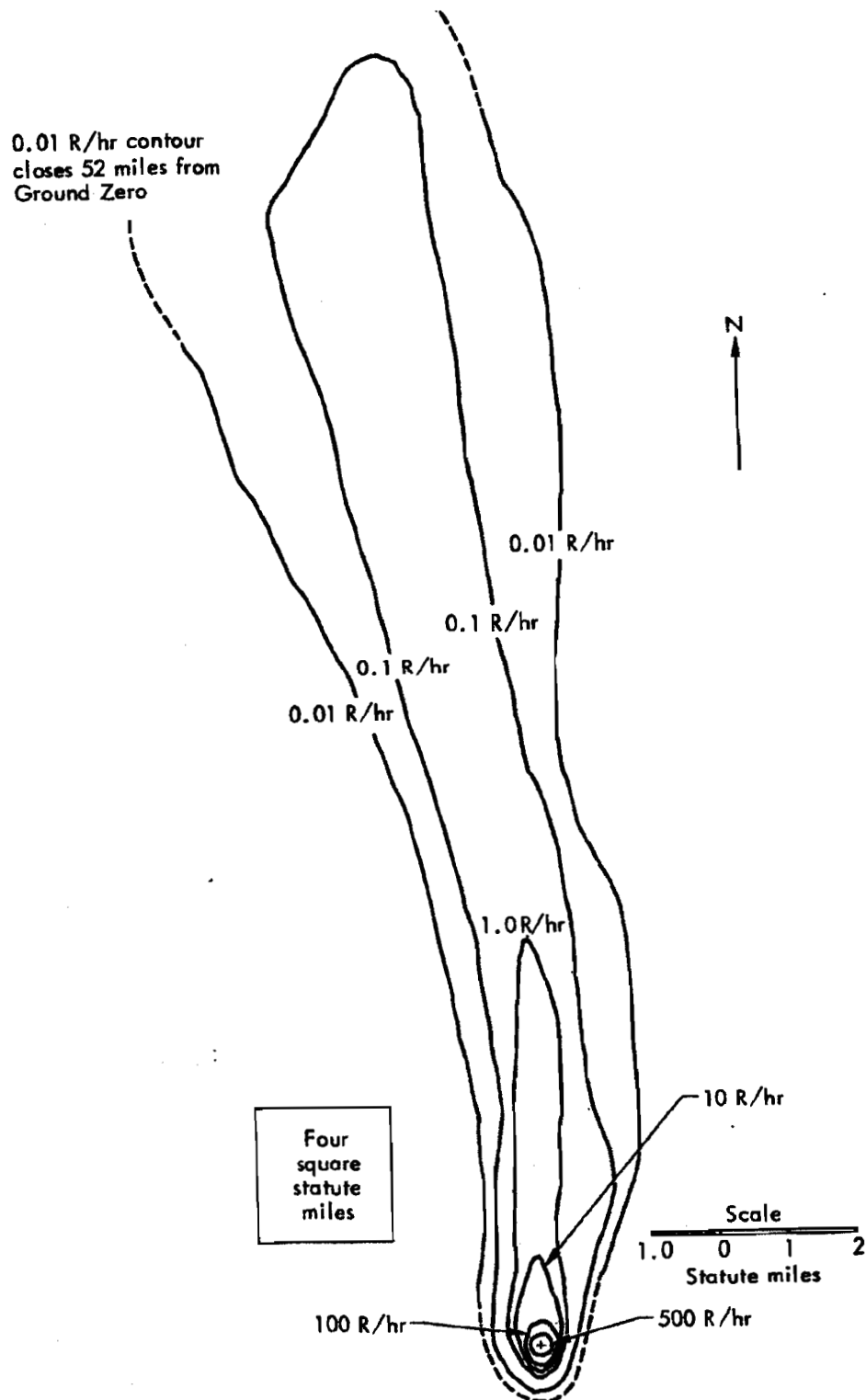


Fig. 8. Exposure rates at H+1 hour, in R/hr.

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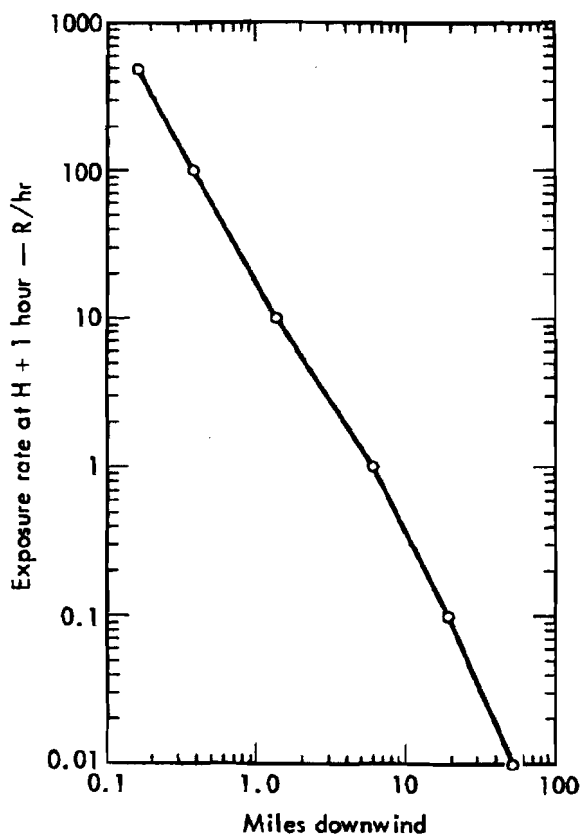


Fig. 9. Exposure rate versus distance.

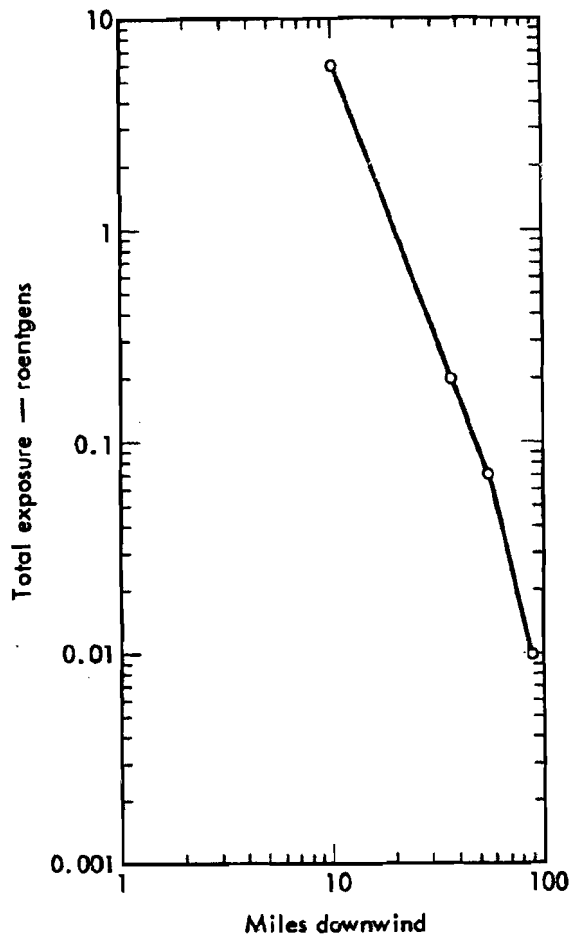


Fig. 10. Total exposure versus distance.

TOTAL EXPOSURE VERSUS DISTANCE

The U. S. Public Health Service placed thermoluminescent dosimeters along arcs at various distances downwind. Figure 10 is a plot of total exposure versus distance along the "hot line" taken from their measurements. The dosimeters were recovered from a few days up to seven days after the event. Thus the exposure represents cloud passage radiation and radiation from fallout deposited on the ground.

Discussion

OBSERVED DECAY OF GAMMA FIELD COMPARED TO THEORETICAL DECAY

The total production of fission products and other gamma-emitting radionuclides which made a significant contribution to the gamma radiation field are listed in Table 1.

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Table 1. Principal radioactive species available to produce gamma radiation field.^a

Nuclide	Atoms at zero time	Fission tons ^b equivalent at H+1 hour
Na ²⁴	1.1×10^{22}	34
Mn ⁵⁶	4.4×10^{22}	324
W ¹⁸⁷	1.7×10^{23}	58
Pb ^{204m}	1.0×10^{21}	14
Total fission products		800
	Total:	1230

^aRef. 4.

^bOne fission ton equivalent is that amount of radioactive material which produces the same gamma exposure rate in air as the fission products from one ton of fission.

of fission products alone. And in Fig. 13, the observed average decay is contrasted to the expected decay of the mixture of fission products plus neutron-induced radioactive nuclides. The observed decay is seen to follow the decay of the total mixture the most closely. At H+100 hours, the observed decay is not as great as anticipated. This is probably due to the preferential increase in the relative amount of W¹⁸⁷ present in the mixture and measured by radiochemical analysis. That is, fractionation caused an enrichment in the amount of W¹⁸⁷ in the fallout field.

CALCULATION OF GAMMA ACTIVITY IN EARLY FALLOUT

The areas contained within the isoexposure rate contours previously presented in Figs. 7 and 8 were measured with a planimeter to yield values of gamma radiation exposure rate versus area in square statute miles. This information is plotted in Fig. 14; the integration of these data yields the "exposure rate integral." For Buggy, the value of this integral was $99 \text{ R/hr} \times \text{mi}^2$ for the area from 0.054 mi^2 (continuous ejecta area) to infinity (see Table 2):

$$\int_{0.054 \text{ mi}^2}^{\infty \text{ mi}^2} R(A) dA = 99(R/\text{hr})_{H+1} \times \text{mi}^2.$$

An expected (quasi-theoretical) time decay curve for the fallout field can be constructed from the information in Table 1; such a curve is given in Fig. 11. When doing this, one assumes a relatively small amount of fractionation in the early fallout pattern. For this Buggy mixture of radionuclides, one would expect the observed gamma field decay to be different from fission products until around H+200 hours. The slope of the observed curve should depart from the fission product line and approximate the line labeled "total" in Fig. 11.

That this was in fact observed to a reasonable degree can be seen from Figs. 12 and 13. In Fig. 12, the observed average decay is contrasted to the decay

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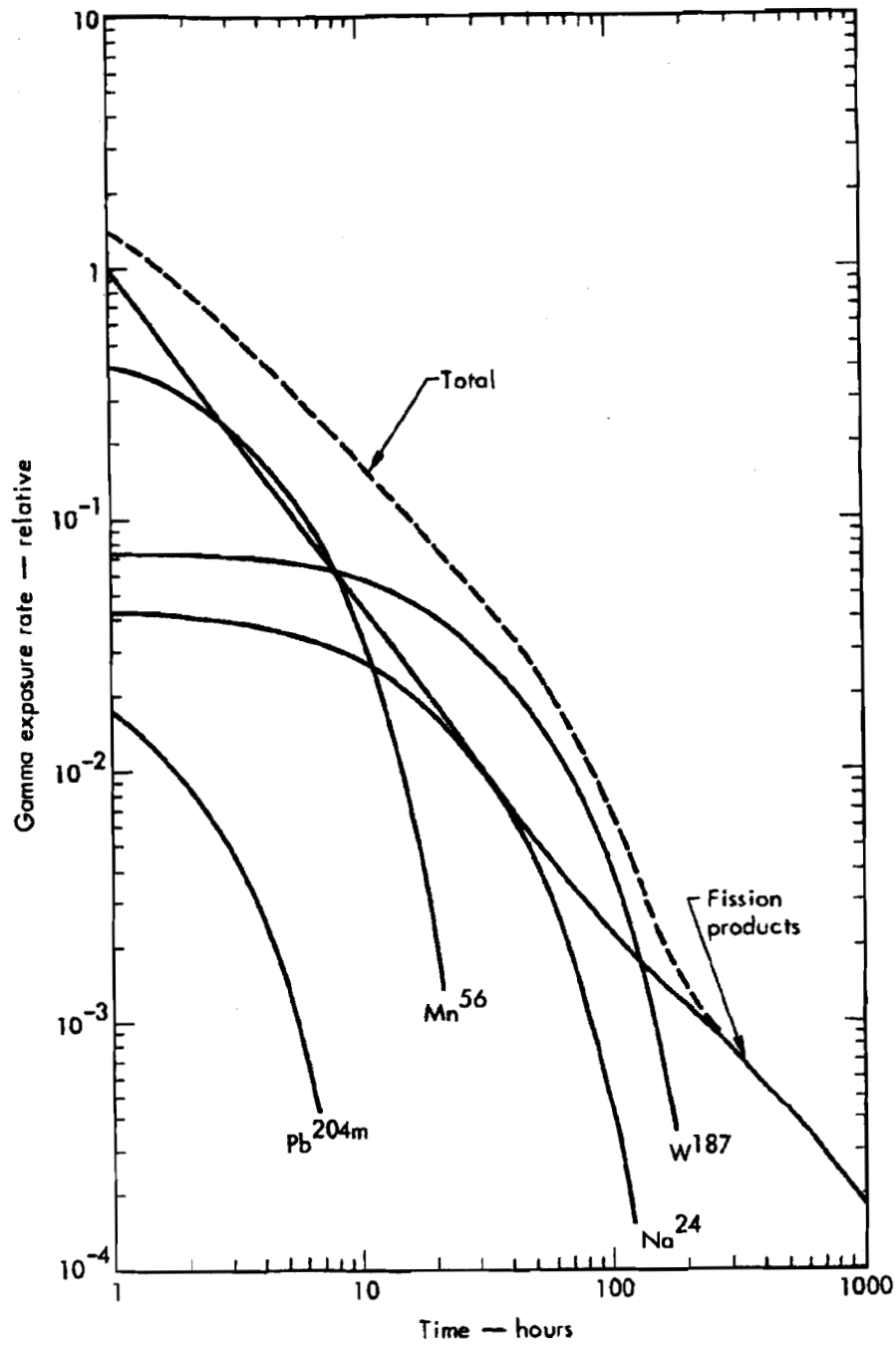


Fig. 11. Expected decay of exposure rate in gamma fallout yield.

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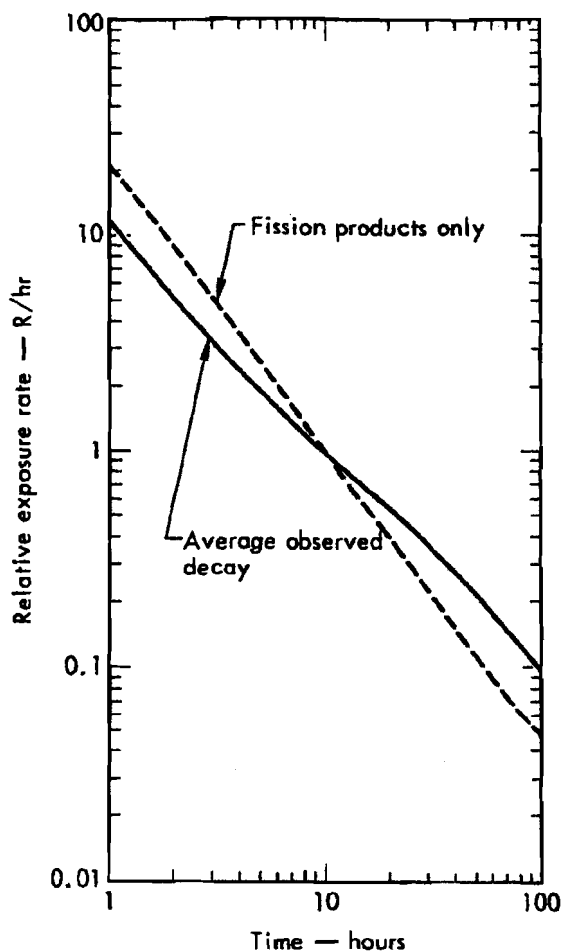


Fig. 12. Observed radioactive decay versus decay of fission products alone.

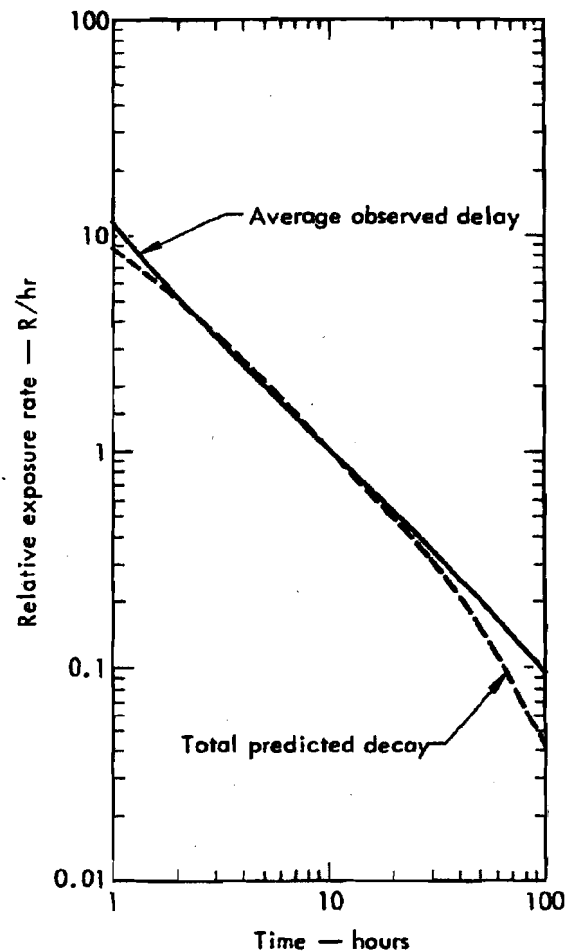


Fig. 13. Observed radioactive decay versus expected decay of fission products plus induced radioactive nuclides.

Table 2. Values of exposure rate integral.

Exposure rate (R/hr)	Area (mi ²)	Exposure rate integral (R/hr × mi ²)
800 to 100	0.054 to 0.234	46.9
100 to 10	0.234 to 0.803	17.1
10 to 1	0.803 to 4.00	9.6
1 to 0.1	4.00 to 32.2	7.6
0.1 to 0	32.2 to ∞	17.9
Total:		99.0

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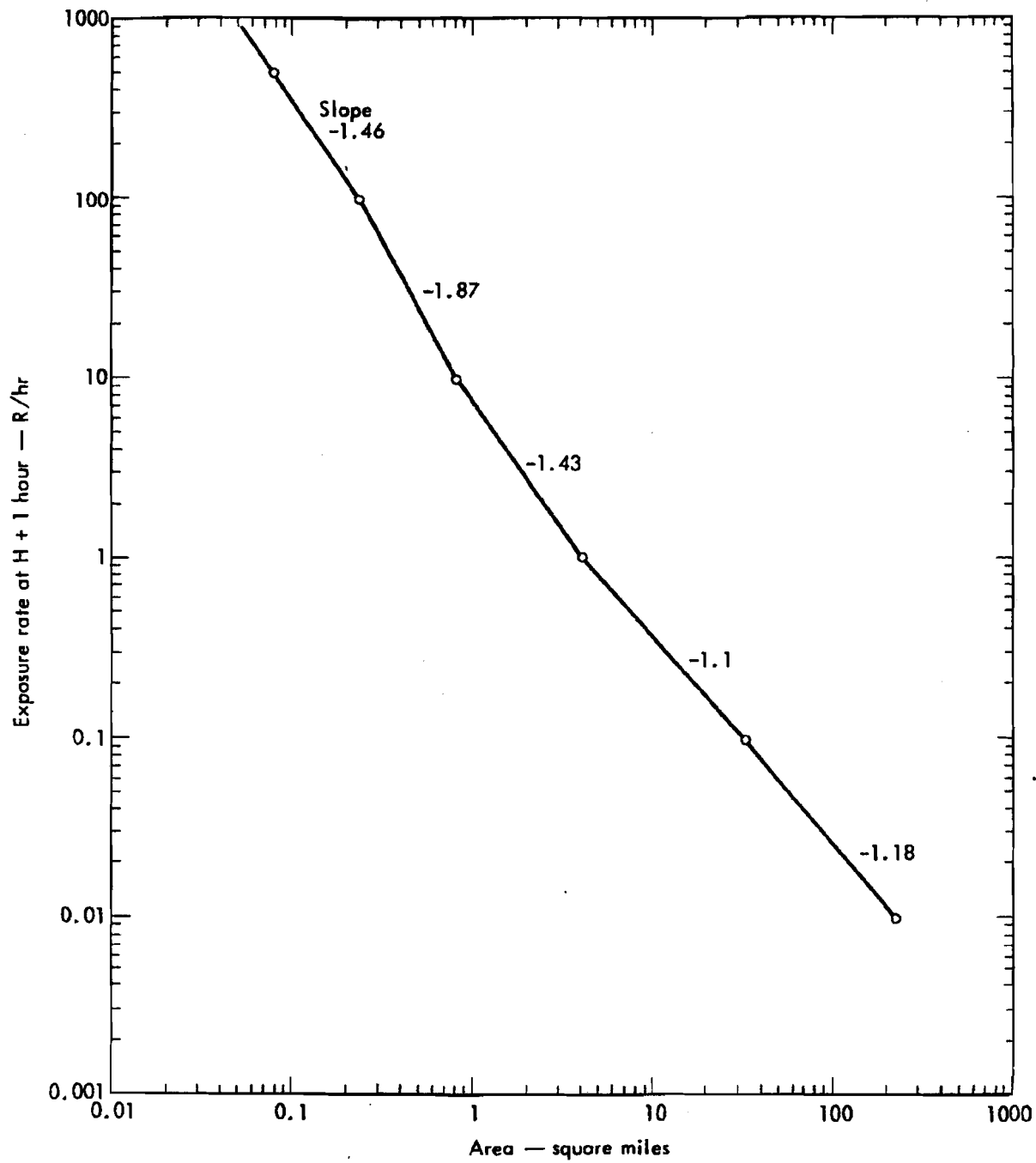


Fig. 14. Exposure rate at H+1 hour versus area in mi².

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Conclusions

FRACTION OF TOTAL GAMMA ACTIVITY DEPOSITED

In the Buggy Event, within the early fallout field an amount of gamma radiation activity equivalent to approximately 40 tons of fission products was deposited. This amount is based on the value of 1 kt of fission products, evenly distributed over 1 mi² (statute) of Nevada Test Site terrain, producing an H+1 hour gamma radiation field of 2500 R/hr. Since the total gamma radioactivity produced by Buggy was equivalent to 1230 tons of fission products at H+1 hour, the fraction deposited in fallout was some 3.3%. The standard deviation of this value is estimated as roughly $\pm 60\%$ of the value. Thus, the deposited fraction has a probability of 0.68 of being between 1.1% and 5.3%, with the most likely value being 3.3%.

This deposited fraction for the Buggy row charge detonation is very similar to the fraction for single charge detonations under comparable conditions. Both Danny Boy and Cabriolet were fired in hard, dry rock at roughly the Buggy scaled depth of burst. In their early fallout patterns, 4% and 2.5% fractions were deposited respectively.

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1. M. Morgenthau, et al., Local Fallout from Nuclear Test Detonations (U), Vol. II, Part 1, Trinity through Redwing, and Part 2, Plumbob through Hardtack, U. S. Army Nuclear Defense Laboratory, Edgewood Arsenal, Md., DASA-1251, August 1963 (SRD).
2. W. T. Onaka, A Telemetry System for Monitoring Gamma Radiation in Plowshare Experiments, Lawrence Radiation Laboratory, Livermore, Rept. UCRL-50633, April 1969 (U).
3. J. P. Clement, and T. A. Gibson, Cabriolet Gamma Fallout Field (U), Lawrence Radiation Laboratory, Livermore, Rept. UCRL-50515, Dec. 1968 (SRD).
4. L. L. Schwartz, Lawrence Radiation Laboratory, Livermore, private communication; data to be published as UCRL.

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Appendix A

Exposure Rate Versus Time Plots for All Stations

This appendix contains the individual gamma radiation decay curves from the LRL gamma telemetry units and the gamma decay curves deduced from monitoring team readings taken in the vicinity of GZ (Figs. A-1 through A-26). The geographical locations of the telemetry units are shown in Figs. 7 and 8; the unit number designations were related to location as given in Table A-1.

Table A-1. Location of LRL telemetry units.

Telemetry unit number	Location	Telemetry unit number	Location
1	Heliport	24	L-35
2	Photo 2	25	L-36
3	Bunker (inside)	26	L-37
4	Bunker (outside)	27	L-38
5	L-27	28	L-39
6	L-28	29	L-19
7	L-29	30	L-13
8	L-30	31	L-53
9	L-31	32	L-54
10	L-41	33	L-55
11	L-40	34	L-57
12	L-42	35	L-58
13	L-43	36	L-59
14	L-46	37	L-65
15	L-47	38	L-66
16	L-48	39	L-67
17	L-49	40	L-68
18	L-50	41	L-69
19	L-51	42	REEC Co No. 12
20	L-52	43	REEC Co No. 11
21	L-32	44	CP
22	L-33	45	L-30
23	L-34		

Three and four days after Buggy D-Day, ten monitor stakes were placed around the crater (see sketch map, Fig. A-1). Hand-held instruments were used to take monitor readings at these locations during the next year to provide long-time gamma decay information.

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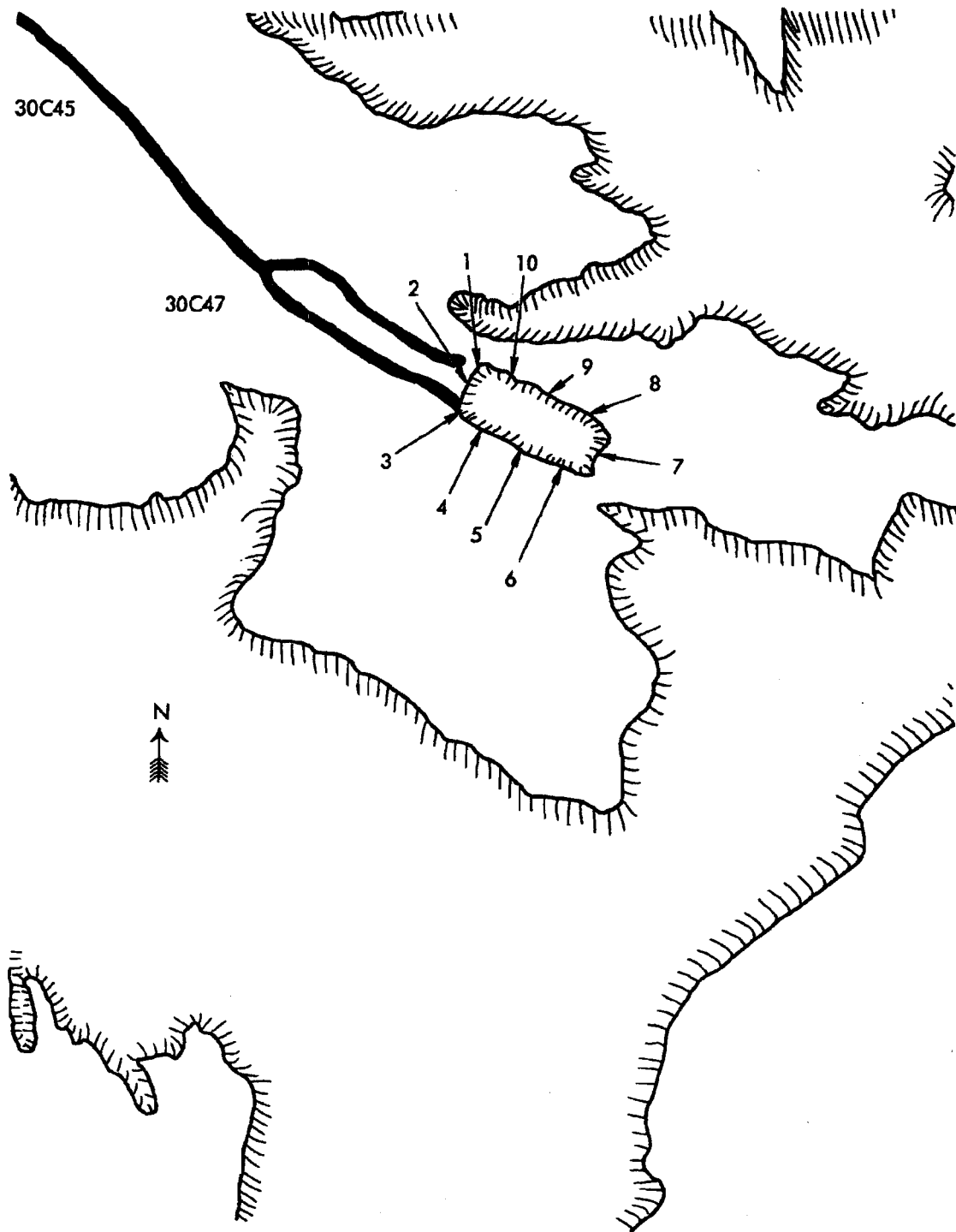


Fig. A-1. Buggy crater lip survey stations.

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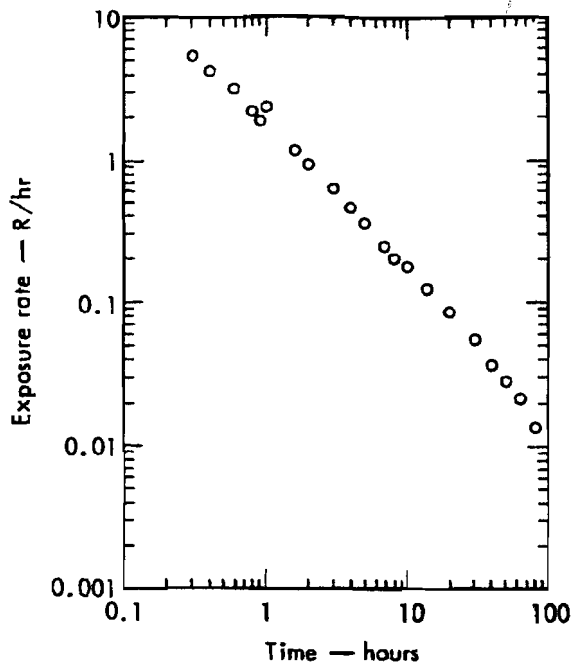


Fig. A-2. LRL gamma telemetry station 4.

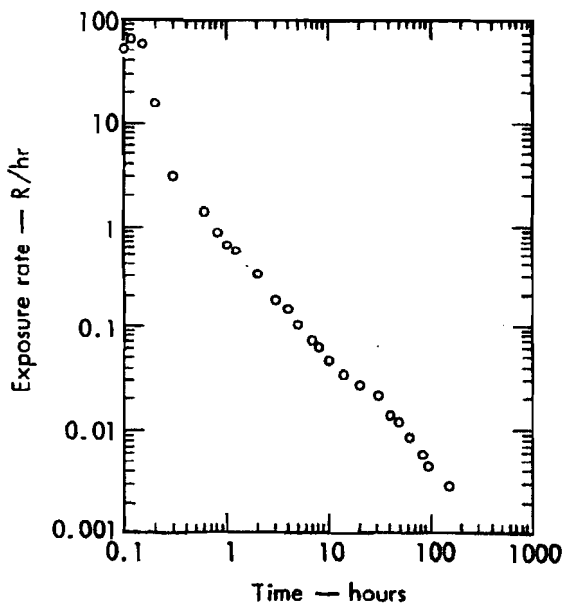


Fig. A-4. LRL gamma telemetry station 6.

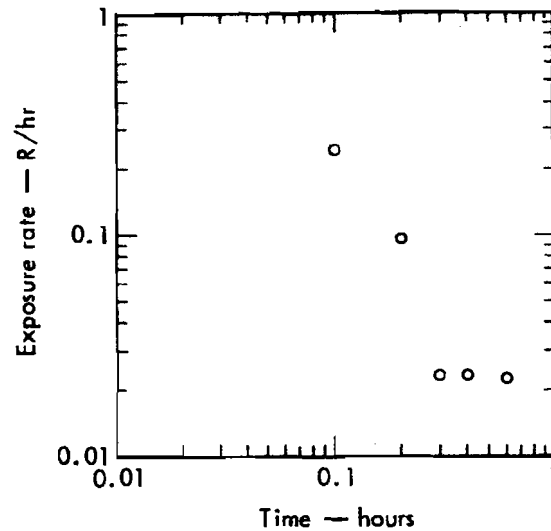


Fig. A-3. LRL gamma telemetry station 5.

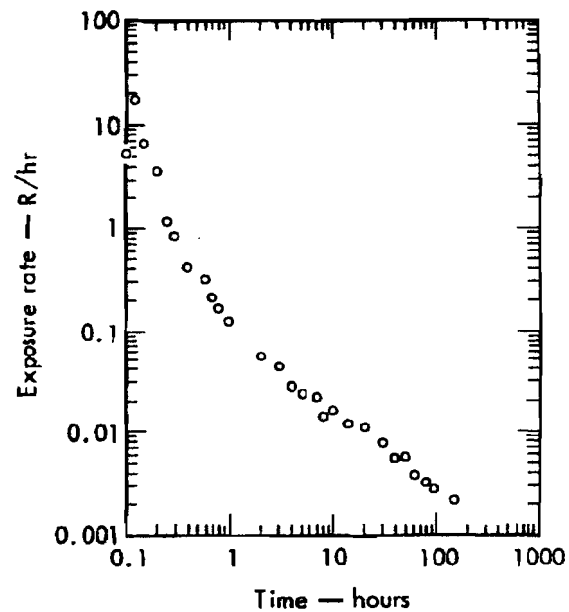


Fig. A-5. LRL gamma telemetry station 7.

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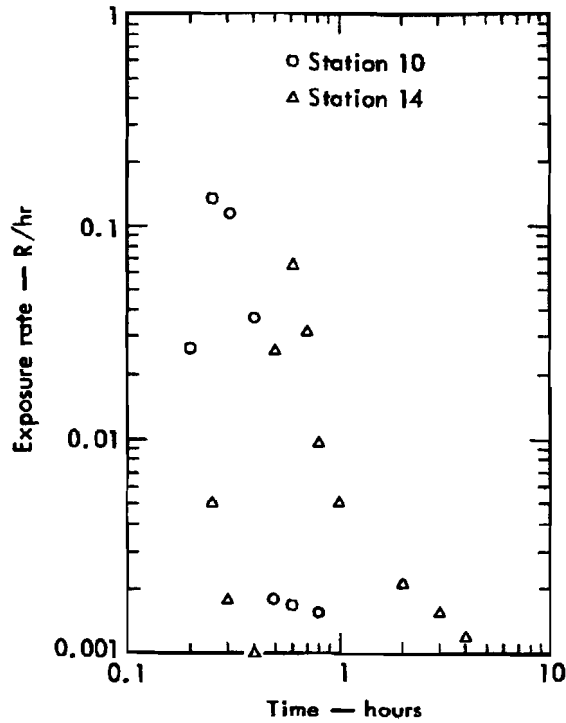


Fig. A-6. LRL gamma telemetry stations 10, 14.

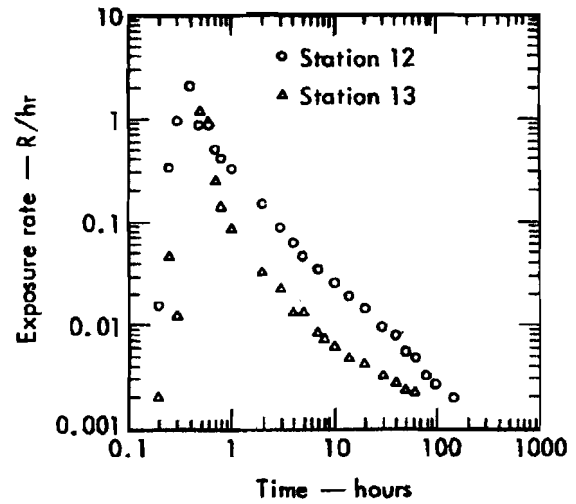


Fig. A-7. LRL gamma telemetry stations 12, 13.

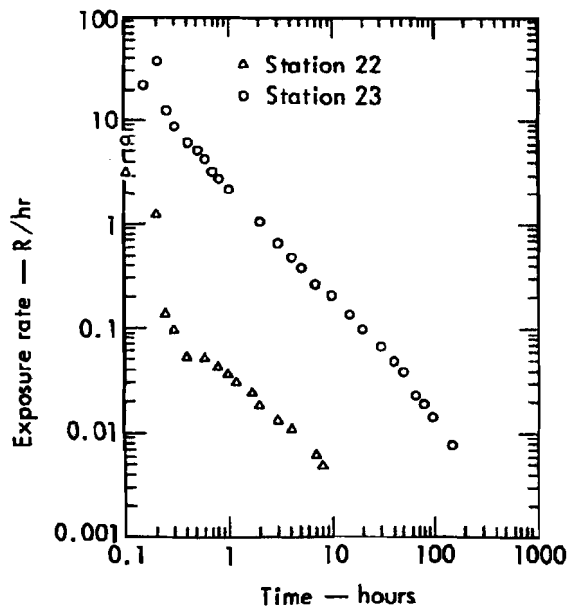


Fig. A-8. LRL gamma telemetry stations 22, 23.

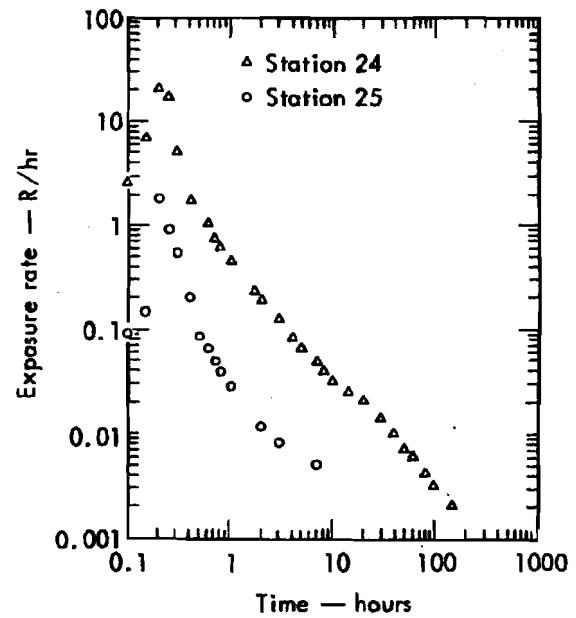


Fig. A-9. LRL gamma telemetry stations 24, 25.

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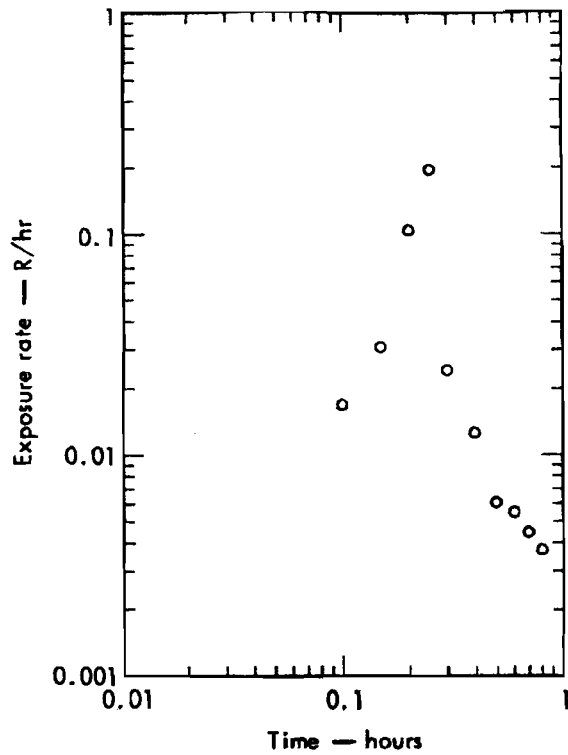


Fig. A-10. LRL gamma telemetry station 26.

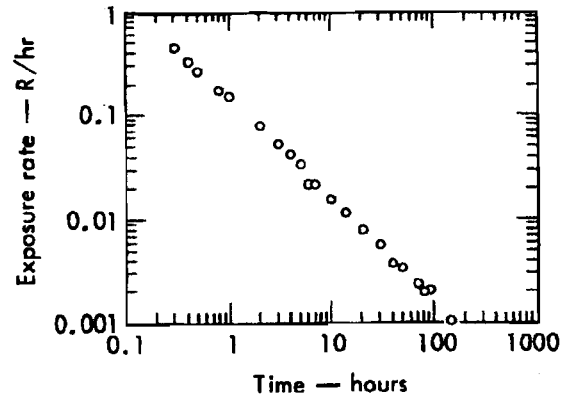


Fig. A-11. LRL gamma telemetry station 29.

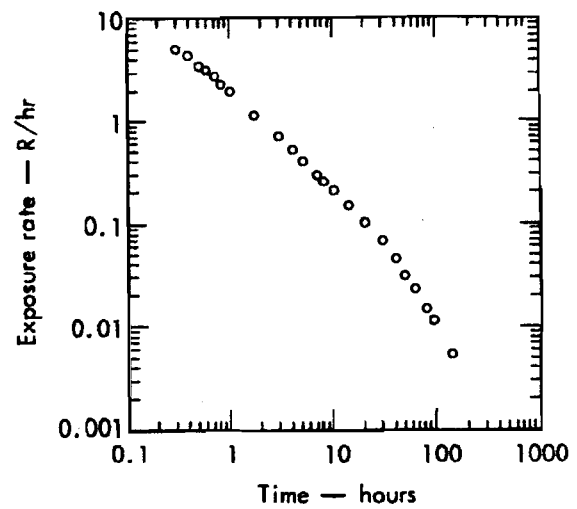


Fig. A-12. LRL gamma telemetry station 30.

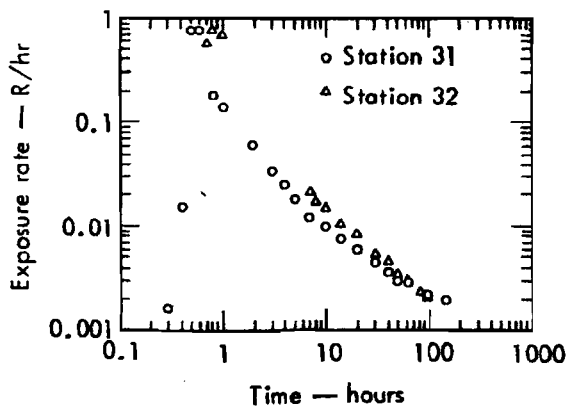


Fig. A-13. LRL gamma telemetry stations 31,32.

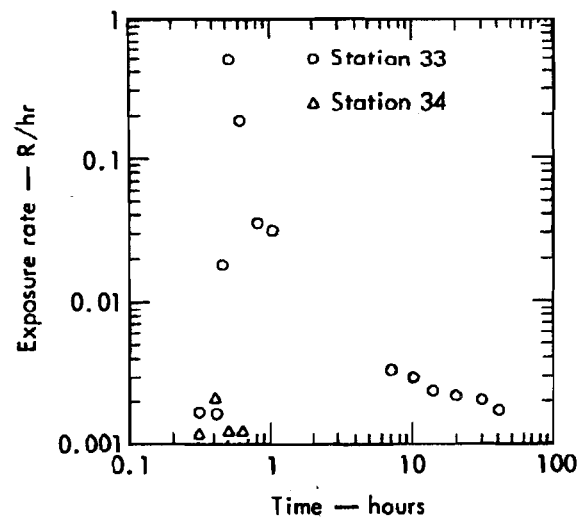


Fig. A-14. LRL gamma telemetry stations 33, 34.

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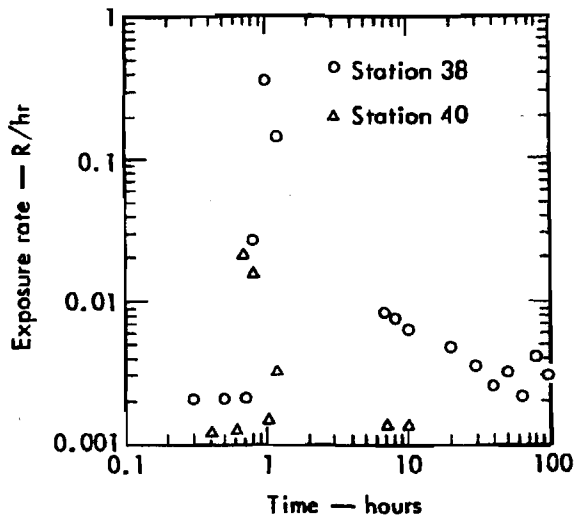


Fig. A-15. LRL gamma telemetry stations 38, 40.

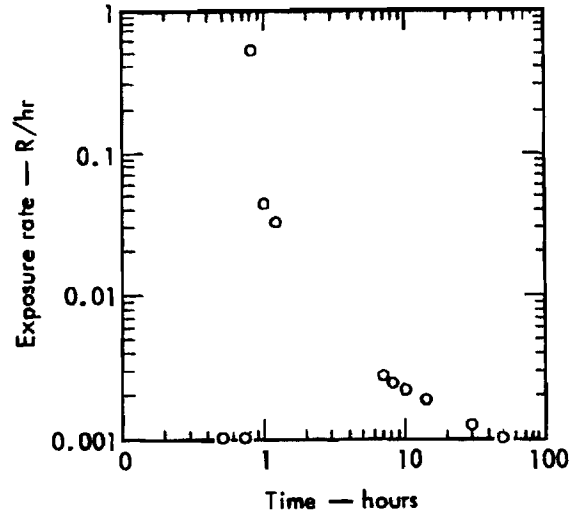


Fig. A-16. LRL gamma telemetry station 39.

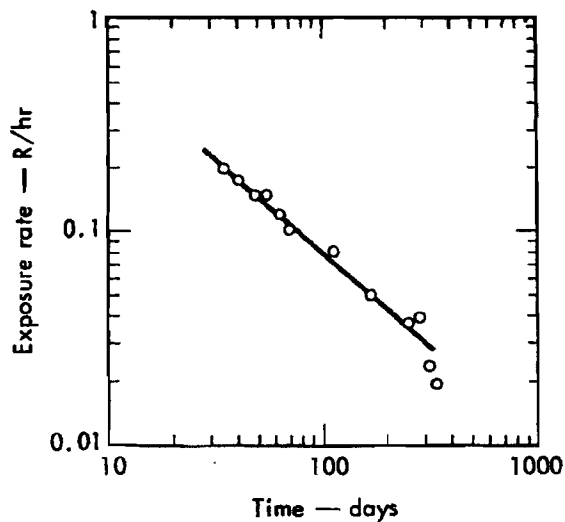


Fig. A-17. Crater lip station 1.

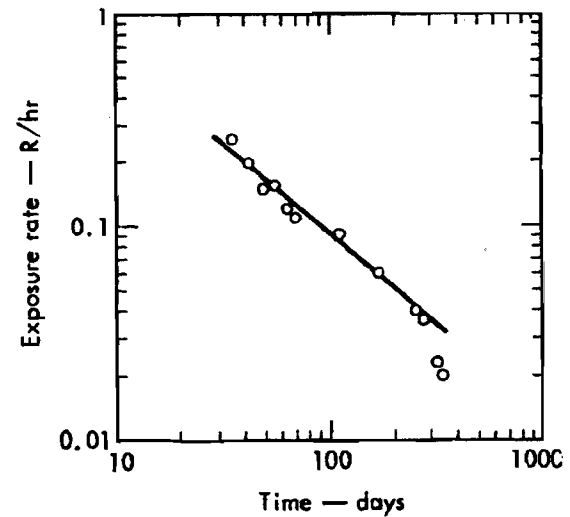


Fig. A-18. Crater lip station 2.

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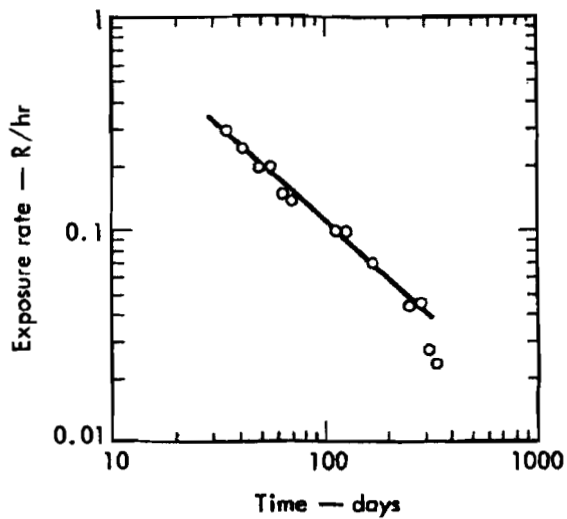


Fig. A-19. Crater lip station 3.

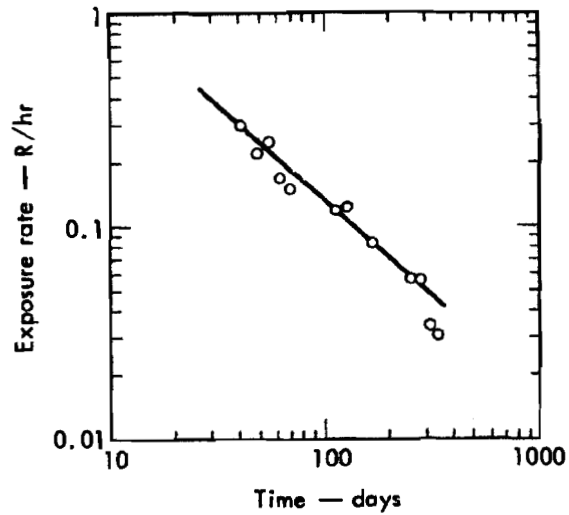


Fig. A-20. Crater lip station 4.

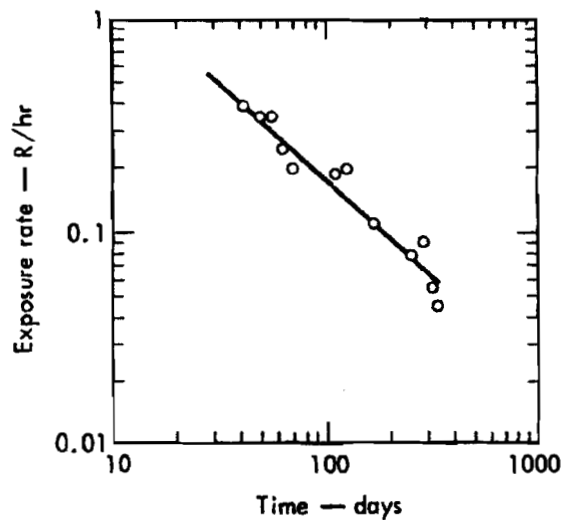


Fig. A-21. Crater lip station 5.

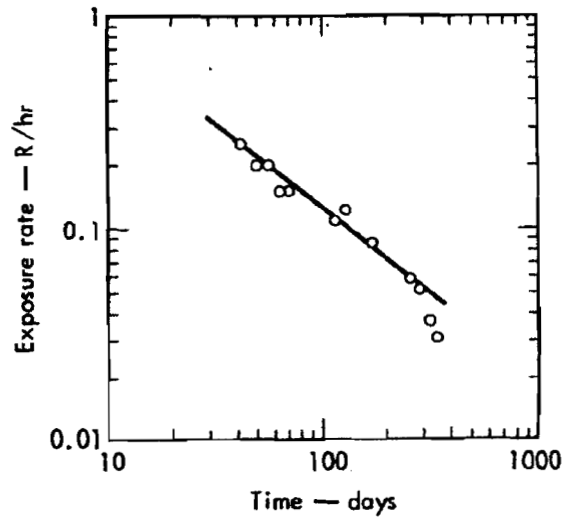


Fig. A-22. Crater lip station 6.

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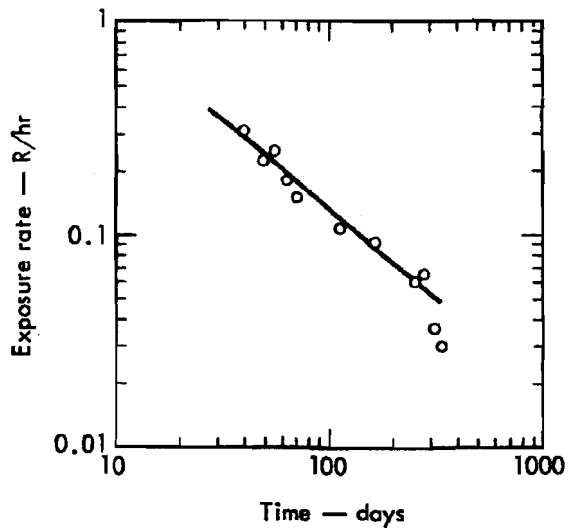


Fig. A-23. Crater lip station 7.

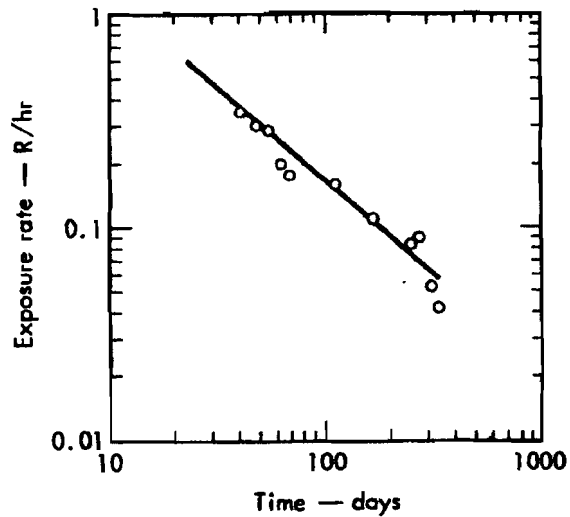


Fig. A-24. Crater lip station 8.

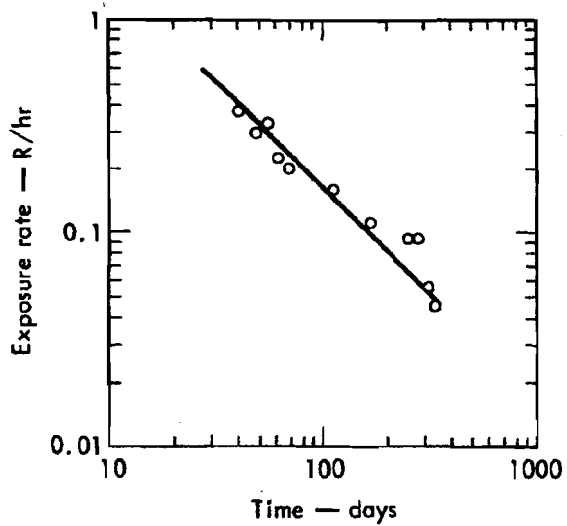


Fig. A-25. Crater lip station 9.

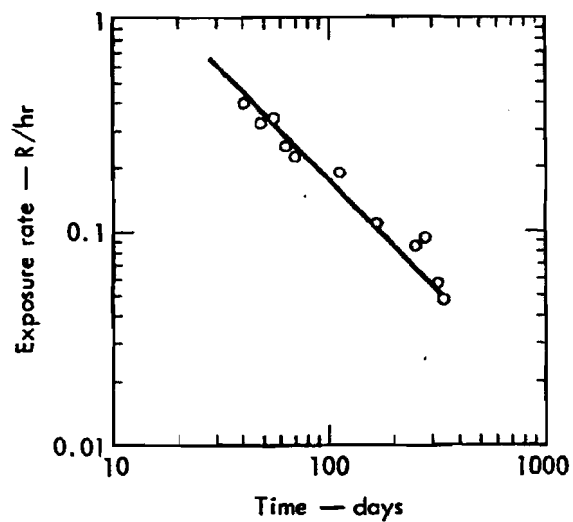


Fig. A-26. Crater lip station 10.

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Appendix B

Monitor Team Readings and Reduced Monitor Team Data

Tables B-1, B-2 and B-3 consist of monitor team readings and reduced data taken at three locations. In each table the exposure rates as determined by the monitor teams and the location and time of the readings are given. Also listed are the exposure rates time-corrected to H+1 hour, using the average decay curve for Buggy. Where several readings were made at the same location, the best estimate is given.

Table B-1. Monitor readings at rad-safe road stakes.

Stake location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)	Stake location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)
18A51 to 18A58	1.4 1.5	0.05	0.00007	0.00007	18A94	2.8 5.7 24.5 49.4 72	150 65 20 7 4	0.48 0.43 0.53 0.40 0.34	
18A79	2.1 6.1	10 <0.5	0.024 <0.003	0.013	18A95	2.8 5.6 24.5 49.4 72	200 95 25 9 5	0.64 0.63 0.66 0.50 0.42	0.44
18A80	2.4 6.0	Bkg ^a <0.5	Bkg <0.003	<0.003	18A96	2.9 5.6 24.5 49.4 72	250 95 25 10 5	0.85 0.63 0.66 0.56 0.42	
18A81	6.0	<0.5	<0.003	<0.003	18A97	2.9 5.6 24.6 49.4 72.3	200 85 20 9 4.5	0.68 0.56 0.53 0.50 0.38	0.57
18A82	6.0	0.5	0.003	0.003	18A98	3.0 5.6 24.5 49.5 72	150 55 15 5 3	0.53 0.36 0.40 0.28 0.25	
18A83	6.0	0.6	0.004	0.004	18A99	4.0 5.6 27.2 49.5 72	100 45 10 5 2	0.46 0.30 0.29 0.28 0.17	0.62
18A84	2.5 5.9	1 0.6	0.003 0.004	0.004	18A100	3.1 5.6 27.2 49.5 72.4	90 43 8 4 2	0.33 0.28 0.23 0.22 0.17	
18A85	5.9	0.7	0.005	0.005	18A101	3.1 5.6 27.2 72	80 33 7 1.8	0.29 0.22 0.21 0.15	0.36
18A86	2.5 5.9	Bkg 1.1	Bkg 0.008	0.008	18A102	3.1 5.5 27.2 49.6 72.5	50 20 4 2 1.4	0.18 0.135 0.117 0.112 0.119	
18A87	2.5 5.9	2.5 1.3	0.007 0.009	0.008					
18A88	2.6 5.9	3.0 1.1	0.009 0.008	0.0085					
18A89	2.6 5.8 24.4	5.0 4.0 1.0	0.015 0.029 0.026	0.023					
18A90	2.6 5.8 24.4	8.0 5.0 1.0	0.024 0.038 0.026	0.029					
18A91	2.6 5.7 24.5	20 7 1.5	0.060 0.046 0.040	0.049					
18A92	2.6 5.7 24.5 49.4 72	50 23 5 1.0 1.4	0.15 0.15 0.13 0.055 0.12	0.14					
18A93	2.7 5.7 24.5 49.4 72	100 34 10 3.5 2.0	0.30 0.22 0.264 0.196 0.17	0.23					

^aBkg = background.

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Table B-1 (continued)

Stake location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)	Stake location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)
18A103	3.1 5.5 27.1 49.6 72.5	20 14 1.0 1.0 1.2	0.072 0.087 0.020 0.056 0.102	0.07	19P93	3.5	1.5	0.006	0.006
18A104	3.2 5.4 72.5	15 8 0.7	0.056 0.052 0.059	0.056	19P94	3.5 26.4	1.5 Bkg	0.006 Bkg	0.006
18C1	1.6	Bkg		Bkg	19P95	3.6	2	0.008	0.008
18C2	1.6	Bkg		Bkg	19P96	3.6 26.4	10 1	0.042 0.029	0.035
18C3	1.7	Bkg		Bkg	19P97	3.6 26.4	10 1	0.042 0.029	0.035
18C4	1.8	1.0	0.002	0.002	19P98	3.67	10	0.043	0.043
18C5	1.8 4.7	3.5 1.0	0.007 0.006	0.006	19P99	3.7	10	0.043	0.043
18C6	1.8 4.7	15 5	0.030 0.028	0.029	19P100	3.7 26.3	10.2 1	0.044 0.028	0.036
Junction 18C and 18D	1.0	20	0.042	0.042	20A105	3.4 5.4 72.5	10 5.5 0.5	0.040 0.035 0.042	0.039
18C7	1.9	30	0.063	0.063	20A106	3.4 5.4 72.6	8 4 0.5	0.032 0.024 0.043	0.033
18C9	4.8	50	0.29	0.29	20A107	3.5 5.3	6 3	0.025 0.019	0.022
18C10	4.8	45	0.26	0.26	20A108	5.3	1.6	0.010	0.010
18C11	4.9	45	0.26	0.26	20A109	3.6 5.3	3.5 1.5	0.015 0.009	0.012
18D1	4.7	5	0.028	0.028	20A110	3.6 5.3	2.5 1.6	0.010 0.010	0.010
18D2	4.9	6	0.035	0.035	20A111	3.6 5.3	2.5 1.9	0.011 0.012	0.012
18D3	5.0	7	0.042	0.042	20A112	3.7 5.2	2.5 2.0	0.011 0.012	0.012
18D4	5.1	7	0.043	0.043	20A113	3.7 5.2	2.0 2.0	0.009 0.012	0.010
18D5	5.2	4	0.024	0.024	20A114	3.7 5.2	2.5 1.7	0.011 0.010	0.010
18D6	5.2	2	0.012	0.012	20A115	3.7 5.2	3.0 2.5	0.013 0.014	0.014
18D7	5.2	2	0.012	0.012	20A116	3.7 5.1	3.5 2.2	0.015 0.013	0.014
18D8	5.3	1	0.006	0.006	20A117	3.8 5.1	3.5 2.7	0.016 0.017	0.017
18D9	5.3	1.5	0.009	0.009	20A118	3.8 5.1	4.0 3.0	0.018 0.018	0.018
18D10	5.3	1.0	0.006	0.006	20A119	3.8 5.05	5.0 2.5	0.022 0.015	0.019
18D11	5.4	1.0	0.006	0.006	20A120	3.9 5.0	1.0 2.3	0.005 0.013	0.009
18D12	5.4	1.0	0.006	0.006	20A121	4.0 5.0	0.5 2.0	0.002 0.012	0.007
18D13	5.4	1.0	0.006	0.006	20A122	4.0 5.0 27	2 10 Bkg	0.002 0.010	0.006
16P01 to 19P80	10.4 to 10.9 12 to 12.5	0.7 0.7	0.0009 0.001	0.001					
19P88	3.3	1.0	0.004	0.004					
19P89	3.4	0.6	0.002	0.002					
19P90	3.4	0.7	0.003	0.003					
19P91	3.4	0.5	0.002	0.002					
19P92	3.5	0.7	0.003	0.003					

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Table B-1 (continued)

Stake location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)	Stake location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)
20A123	5.0	2.2	0.013	0.013	20J7	25.4	2.0	0.055	0.055
20A124	4.0	2.0	0.009		20J9	25.4	1.5	0.041	0.041
	5.0	3.5	0.021	0.015	20J11	25.4	2.0	0.055	0.055
20A125	4.0	4.0	0.010		20J15	25.7	1.0	0.028	0.028
	5.0	5.0	0.030		20J19	25.7	Bkg		Bkg
	27	1.0	0.029	0.026	20P101	3.7	16	0.069	
20A126	4.1	6.0	0.029			26.3	2	0.057	
	4.9	5.5	0.032	0.030		74.7	1.2	0.104	0.077
20A127	4.1	8.0	0.039		20P102	3.7	30	0.129	
	4.9	5.5	0.032	0.035		26.3	3	0.085	
Junction	4.3	5.0	0.025			74.6	1.3	0.112	0.109
20A and 20F	27	2.0	0.058	0.042	20P103	3.8	27	0.123	0.123
20A128	4.9	6.5	0.038	0.038	20P104	3.8	25	0.111	
20A129	4.8	7.5	0.043	0.043		26.3	3	0.085	
20A130	4.7	9.5	0.052	0.052		74.6	1.3	0.114	0.103
20A131	4.7	13	0.072	0.072	20P105	3.8	23	0.103	0.103
20A132	4.7	15	0.083	0.083	20P106	3.8	26	0.116	0.116
20A133	4.7	17	0.094		Intersection				
	26.7	2	0.058	0.076	30C and 30G	2.4	Bkg		Bkg
20A134	4.7	14.5	0.080	0.080	30C1 to 30C14	1.6 to 1.7	0.05	0.0001	0.0001
20A135	4.7	16	0.088		30C15	1.7	0.05	0.0001	0.0001
	26.7	3	0.086	0.087	30C16	1.7	0.05	0.0001	0.0001
20A136	4.6	19	0.105	0.105	30C17	1.8	0.8	0.0016	
20A137	4.6	19	0.105			24	1.2	0.031	0.016
	26.6	4	0.114	0.109	30C18	1.8	1.5	0.003	
20A138	4.6	21	0.116	0.116		24	1.2	0.031	0.017
20A139	4.6	24	0.130		30C19	1.8	10	0.020	
	26.6	4	0.114	0.122		24	2	0.051	0.035
20A140	4.6	23	0.127	0.127	30C20	1.9	30	0.063	
20A141	4.6	21	0.116			24	3	0.077	
	26.6	3.5	0.10	0.108		48.2	1	0.054	0.065
20A142	4.4	24	0.124		30C21	1.9	35	0.074	
	26.5	3	0.086	0.105		24.1	4	0.103	
20A143	4.4	26	0.137			48.2	1	0.054	0.080
	26.5	4	0.114	0.125	30C22	2.0	80	0.178	
20A144	24.9	5.0	0.135			24.1	8	0.207	
	74.3	1.2	0.105	0.120		48.2	2	0.108	
20A145	24.9	3.0	0.081			72	1	0.084	0.164
	74.4	1.5	0.130	0.105	30C23	2.0	200	0.446	
20A146	25	4	0.108			24.2	16	0.415	
	74.5	1.3	0.114	0.111		48.2	3.5	0.190	
20E1	25.5	1	0.028	0.028		72	5	0.420	
20E6	25.5	1	0.028	0.028		144	<1	<0.160	0.427
20J1	25.3	3	0.082	0.082	30C24	2.0	600	1.34	
20J3	25.3	2.5	0.068	0.068		24.2	40	1.04	
20J5	25.3	2.5	0.068	0.068		48.3	10	0.545	
						72	12	1.01	
						144	2	0.32	1.13
					30C25	2.0	1000	2.23	
						24.2	70	1.82	
						48.3	15	0.81	

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Table B-1 (continued)

Stake location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)	Stake location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)
30C25 (contd)	72 144	18 3	1.51 0.48	1.85	30C35	2.5 24.6	1.0 0.5	0.003 0.013	0.008
30C26	2.0 24.3 48.3 72 144	1000 50 13 20 4	2.23 1.30 0.71 1.68 0.64	1.74	30C36	24.6	0.5	0.013	0.013
30C27	2.1 24.3 48.4 72 144	1000 70 20 20 5	2.37 1.82 1.09 1.68 0.80	1.960	30C37	2.5 24.6	Bkg 0.6	Bkg 0.016	0.008
Junction 30C and 30D	24.6 72 144	40 22 5	1.06 1.85 0.8	1.45	30C38	24.7	0.5	0.013	0.013
30C28	2.1 24.3 48.4 72 144	300 20 7 6 1	0.71 0.52 0.38 0.50 0.16	0.58	30C39	24.7	Bkg	Bkg	Bkg
30C29	2.1 24.4 48.5 72 144	40 2 0.7 1.3 <1	0.095 0.053 0.038 0.109 <0.16	0.086	30C40	2.4 24.7	Bkg Bkg	Bkg	Bkg
30C30	2.1 24.4 48.5 72	25 1.2 0.5 1	0.059 0.032 0.027 0.084	0.050	30C41	24.7	Bkg	Bkg	Bkg
30C31	2.7 24.5	7.0 1.2	0.021 0.032	0.026	30C42	24.8	0.5	0.013	0.013
30C32	2.7 24.5	80 13	0.244 0.343	0.293	30C43	24.8	0.5	0.013	0.013
30C33	2.7 24.5	100 12	0.306 0.316	0.311	30C44	2.9 25.1	1.0 0.7	0.003 0.019	0.011
30C34	2.6 24.6	42 3.5	0.125 0.092	0.109	30C45	25.1	1.0	0.027	0.027
					30C46	25.1 75.3	3.5 1	0.095 0.089	0.092
					30C47	3.0 25.2 25.3	10,000 60 100	35.2 1.6 2.7	2.2
					30E1	2.3	5	0.013	0.013
					30E2	2.3	2	0.005	0.005
					30E3	2.3	2	0.005	0.005
					30E4	2.4	2	0.005	0.005
					30F1 to 30F22	3 to 3.6	0.05	0.0002	0.0002

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Table B-2. Monitor readings at marked locations other than road stakes.

Location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)	Location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)
Danny Boy	1.9	60	0.127	0.127	L-29	55	6	0.38	
Hole U19H	50.5	1	0.057	0.057		49.7	3.5	0.20	0.29
Hole U19F	51	1	0.058	0.058	L-30	50.3	0.7	0.04	0.04
L-1	28.2	3000	92	92	L-31	51.5	0.5	0.03	0.03
L-3	174	3200	600	600	L-32	48.6	<1	<0.05	<0.05
L-4	174	1200	224	224	L-33	48.8	1.5	0.08	0.08
L-5	173	10	1.8	1.8	L-34	49.5	9.5	0.53	0.53
L-9	28.1	160	4.9	4.9	L-35	50	7	0.4	0.4
L-12	173	70	13	13	L-36	50.6	2	0.1	0.1
L-13	173	3	0.55	0.55	L-37	51	1.5	0.09	0.09
L-15	49	50	2.8	2.8	L-38	51	1.3	0.075	0.075
L-16	28.3	1000	31	31	L-42	49	3.0	0.17	0.17
L-17	28	45	1.4	1.4	L-43	48.7	1	0.055	0.055
L-18	28	17	0.52	0.52	Photo 1	28.4	150	4.6	
L-19	28	4	0.12	0.12		40	50	2.8	
L-22	28.6	8	0.25	0.25		75.6	40	3.6	
L-23	29	4	0.12	0.12		146	4	0.64	
L-26	174	0.6	0.11	0.11		172	4	0.74	3.7
L-27	53.5	1	0.06		Photo 3	1.66	Bkg ^a		Bkg
	48.1	0.9	0.05	0.055	Tower 1	26	6000	170	170
L-28	54.5	40	2.5		Tower 2	26	2000	54	54
	49	20	1.1	1.8	Tower 3	26	110	3.1	3.1
					Tower 4	26	25	0.7	0.7
					Tower 5	26	10	0.28	0.28

^aBkg = background.

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Table B-3. Monitor readings at estimated locations.

Estimated location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)	Estimated location	Time after shot (hr)	Exposure rate (mR/hr)	Corrected to H+1 hour (R/hr)	Best estimate (R/hr)
0.1 mi E of 30C45 North road	3	10	0.035	0.035	100 yds E of 30C47	25.2	200	5.4	5.4
0.1 mi E of 30C46 North road	3 51.5	100 1	0.35 0.06	0.2	0.1 mi E of 30C47	25.3	1,000	27	27
0.2 mi E of 30C46 North road	3 51.5 144	1,000 10 1	3.5 0.6 0.16	0.6	Cliff S of Photo 1	49	5	0.28	0.28
0.3 mi E of 30C46 North road	51.7 144.5	100 10	5.8 1.6	3.7	150 yds S of Photo 1	49	10	0.55	0.55
0.4 mi E of 30C46 North road	52	1,000	59.5	59.5	100 yds S of Photo 1	49	15	0.83	0.83
0.5 mi E of 30C46 North road	77.5	1,000	89.2	89.2	225 ft N of Photo 1	49	100	5.5	5.5
0.6 mi E of 30C46 South road	75.5	5,000	445	445	450 ft N of Photo 1	49.4	1,000	56	56
0.6 mi E of 30C46 North road	51.7 144	10,000 1,000	590 160	370	600 ft E of crater	171	700	127	127
0.7 mi E of 30C46 Center road	51.8	10,000	590	590	500 ft E of crater	170.5	1,500	275	275
0.7 mi E of 30C46 South road	75.5	1,000	90	90	740 ft S of GZ	49.6	10,000	560	560
0.45 mi E of 30C46 South road	75.4	100	9	9	NE corner trailer park	25.5 77.5	1,000 80	27.5 7.4	18
Between 30C46 and 30C47	25.2	20	0.54	0.54	E fence trailer park	25.5 144	300 20	8.2 3.2	5.7
					Bunker entrance	25.5	100	2.7	2.7
					150 yds W of crater	25.5	10,000	275	275
					100 yds W of crater	25.3	10,000	273	273

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Appendix C

Shot-Time Meteorological Conditions

Table C-1 contains a brief summary of the observed shot-time meteorological data.

Table C-1. Meteorological data taken at Buggy I CP.^a

Surface observation at		Buggy I CP, 0903 PST, March 12, 1968			
Weather		2/10 altocumulus-8/10 cirrostratus			
Sky condition		Scattered, overcast			
Visibility		Unrestricted			
Atmospheric pressure		845.9 millibars 5095 ft MSL			
Temperature		10.6°C			
Dew point temperature		-6.3°C			
Relative humidity		30%			
Surface data (from RAOB)		5210 ft MSL, 0903 PST, March 12, 1968			
Atmospheric pressure		840 millibars			
Temperature		6.9°C			
Dew point temperature		-15.2°C			
Relative humidity		19%			
Upper air data at		Buggy I CP, 0903 PST, March 12, 1968			
Height (ft MSL)	Wind (deg/kts)	Pressure (mb)	Temperature (°C)	Dew point (°C)	Relative humidity (%)
5,100 ^b	180/06	846	10.6	-6.3	30
5,210	180/06	840	6.9	-15.2	19
6,000	170/13	818	4.8	-16.9	19
7,000	180/17	788	2.1	-18.6	20
7,950	190/24	760	-0.4	-20.2	21
8,000	190/24	759	-0.1	-19.4	22
8,800	210/26	736	3.4	-11.4	33
9,000	210/28	731	3.3	-11.8	32
10,000	220/26	703	1.9	-13.9	30
10,900	210/32	680	0.7	-15.4	29
11,000	210/33	676	0.1	-15.5	30
12,000	210/30	652	-2.3	-16.4	33
13,000	210/25	626	-5.2	-17.2	38
14,000	210/30	604	-7.7	-18.9	40
15,000	220/33	579	-10.7	-20.6	44
15,600	220/30	566	-12.1	-21.1	47
16,000	220/27	557	-12.8	-21.4	49
17,000	240/25	535	-14.4	-22.1	52
17,700	250/28	520	-15.5	-22.7	54
18,000	250/30	514	-16.3	-23.9	52
19,000	250/28	494	-18.1	-27.6	43
19,780	250/26	478	-19.5	-30.5	37
20,000	250/25	473	-20.2	-30.9	38
24,060	250/29	400	-30.3	-39.6	40
25,000	260/33	384	-32.7	-42.5	37
27,950	250/39	338	-40.0	-51.0	30
30,000	250/42	308	-45.0	—	—
35,000	280/48	243	-57.3	—	—
36,950	270/56	221	-62.3	—	—
40,000	280/69	190	-66.9	—	—

^aThe Buggy CP was about 7.5 miles ENE of GZ.

^bThe surface wind at Tower 1, 2200 ft SW of GZ was 190/12 at 0905 PST.

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Appendix D Selected Decay Curves

This appendix contains the individual best fit, normalized gamma decay curves (Figs. D-1 through D-5) used to produce the early-time decay curve shown in Fig. 4.

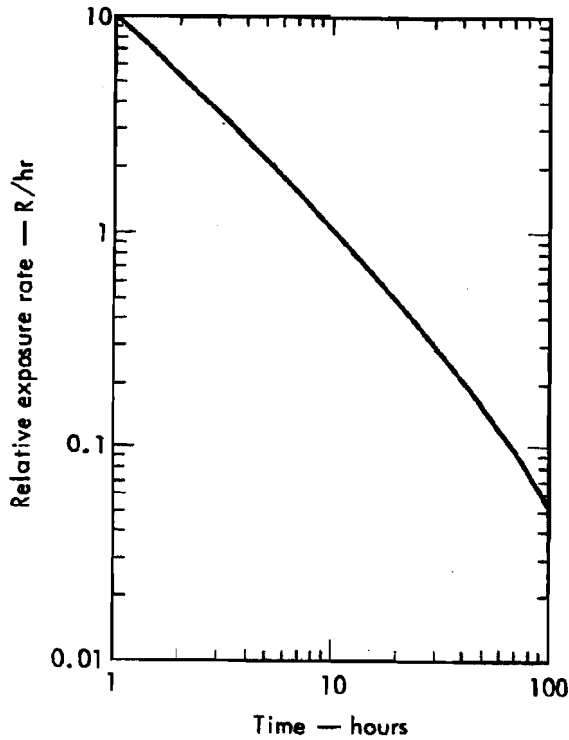


Fig. D-1. LRL gamma telemetry station 4.

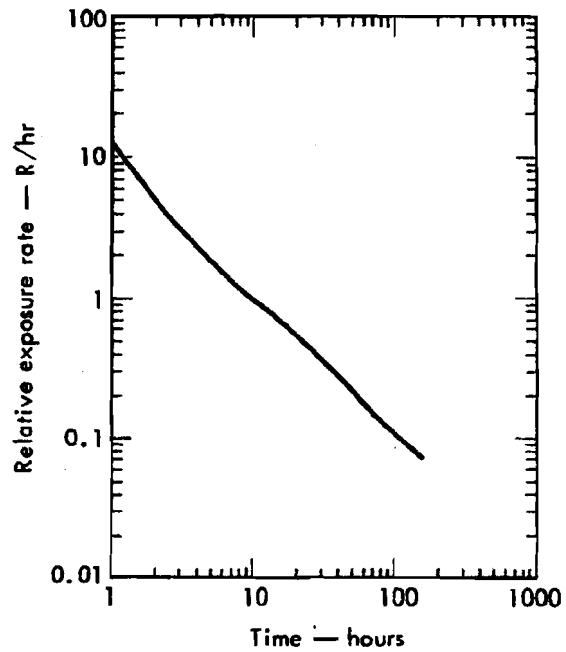


Fig. D-2. LRL gamma telemetry station 12.

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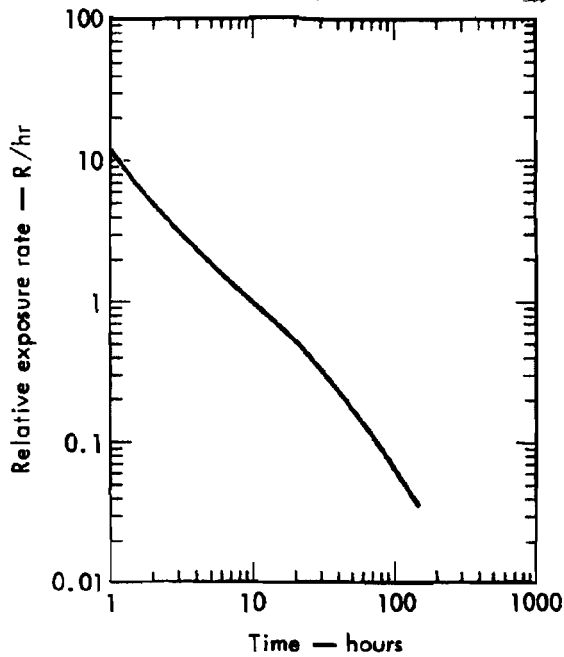


Fig. D-3. LRL gamma telemetry station 23.

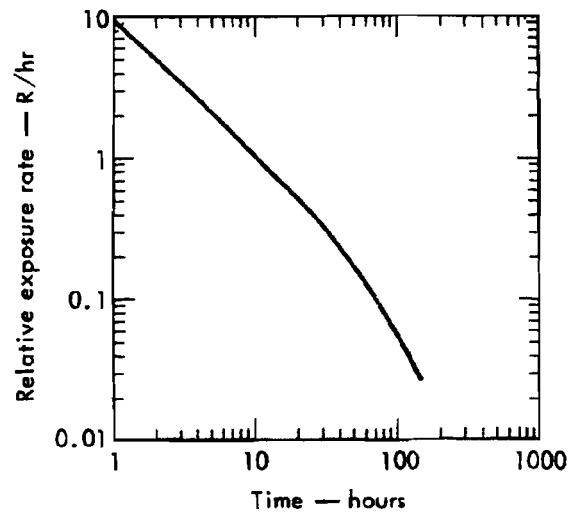


Fig. D-4. LRL gamma telemetry station 30.

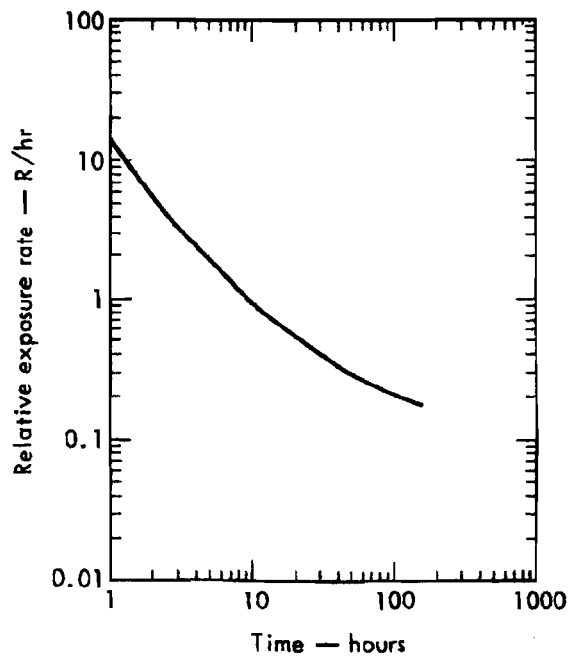


Fig. D-5. LRL gamma telemetry station 31.

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