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SCIENTIFIC DIRECTOR'S REPORT
OF ATOMIC WEAPON TESTS
AT ENIWETOK, 1948

Annex 9

CONTAMINATION STUDIES

Part I

RESIDUAL CONTAMINATION IN THE CRATERS

[redacted]

337

NO 1 of 35 copies, series B

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Task Group 7.6 - Project Report

RESIDUAL CONTAMINATION IN THE CRATERS

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OPERATION SANDSTONE

by

CDR. H. L. Andrews, USPHS

R. E. Murphy

1 January 1949

Project 7.1-17/RS-3

TABLE OF CONTENTS

ABSTRACT

Residual contamination in the crater was measured after each of X-ray, Yoke, and Zebra explosions. A sample taken about 100 feet from each tower base was followed for decay using a Geiger-Muller counter and when sufficiently reduced in radioactivity to permit handling, the specific activity of the sample was determined. In addition to the crater samples, material from the skin of drone aircraft, collected by use of scotch tape, were examined after tests Yoke and Zebra.

For test X-ray, at about H plus 7-1/2 days, a crater survey was made extending along the Hartman line from 100 feet to 1200 feet from the base of the tower, measurements being taken at 100-foot intervals. At each station the radioactivity of soil samples was determined at one-inch, two-inch and four-inch-depths. Gamma radiation above the surface was determined with an ion chamber survey instrument.

Decay curves did not fit the expected curve for a mixture of fission products and Na^{24} but indicated that perhaps some other activity, not identified, was present. Fractionation of the fission products is another possible explanation. The best fit was obtained with $t^{-1.45}$ for the fission products but this was outside of any probable value

for this time period. At all distances studied the samples from two inches and four inches below the surface showed nearly pure fission product activity. Neutron induced activities were observed in concrete and steel at about 1000 feet from the tower base.

For test Yoke, at about H plus 57 hours, a crater survey was made extending from 1200 to 4500 feet from the tower base, and decay curves were taken of the samples. Samples were removed from the drone planes at about H plus 7 hours and decay curves were run. The drone plane decay curves are substantially different from the crater decay curves, probably because the ratio of fission products to activated surface material in the cloud was different from that in the dirt samples. As in test X-ray, the decay curves indicated a mixture of fission products, Na^{24} and perhaps some unidentified activity. Since all samples for test Yoke were taken at greater distances than for test X-ray, direct comparison is not possible.

For test Zebra, as in test Yoke, crater decay curves and drone plane decay curves did not agree. Again these indicated a mixture of fission products, Na^{24} and unidentified activity. No crater sampling survey was made.

It is concluded that failure of samples to follow the expected curve is perhaps due to large amounts of activity induced in unknown elements with fractionation another possible explanation. Because of the atypical nature of the surface, the data are not very useful for predicting the radiological hazards following air bursts.

OBJECTIVE

Measurements in connection with this project were made for the purpose of obtaining as complete information as possible about the radiation hazards existing in a land area which had been exposed to an air burst atomic bomb. They were designed to be useful in planning operations in the future as well as during OPERATION SANDSTONE itself. With reasonably good data obtained as soon as possible after the burst it is considered possible to extrapolate back so that the hazards existing very soon after burst can be determined.

HISTORICAL

Following the test at Alamagordo, measurements were made of radioactive material from the crater. These measurements were made primarily for determining the performance of the weapon and were not completely satisfactory for estimating the radiation hazards existing in the crater. The decay curves indicated the activity fell off according to $t^{-1.2}$. At Bikini measurements indicated that most of the residual contamination following the air burst was due to the neutron induced activity in the sodium of the sea water. In the underwater explosion at Bikini most of the activity resulted from fission products and the decay rate followed a $t^{-1.3}$ law. It was hoped that the present project would provide more complete information on the radioactive situation existing after an air burst bomb.

EXPERIMENTAL

As soon as possible after each detonation, which in practice turned out to be about H plus 7-1/2 hours, a sample of crater material collected from a point about 100 feet from the tower base was delivered to Task Group 7.6 on the USS BAIROKO. Aliquots of this sample were finely ground with a mortar and pestle and thin layers of this material were put into sample cups for measurement. The specific activity of this material as received was so high that original samples could not be weighed. Specific activities were determined from later measurements made on samples large enough for accurate weighing.

One sample was run using a thin window beta sensitive counter having a window of about 2.0 mg. per $cm.^2$ equivalent thickness, and a second sample cup was run using a thick wall gamma sensitive counter with an equivalent wall thickness of about 200 $mg./cm.^2$. These counter tubes were connected to General Radio Company type 1500-A counting rate meters which in turn were connected to Esterline-Angus continuous chart recorders. The sizes of the initial samples were adjusted so that a counting rate of approximately 18,000 counts per minute was obtained. After the samples had decayed so that only about 600 counts per minute were obtained, the samples were replaced with larger ones to bring the counting rate back to about 18,000 per minute.

After the initial rapid decay had taken place some of the samples were transferred to counter tubes connected to type 161-G scaling circuits of the Instrument Development Laboratories. Counts were taken on these scaling circuits at appropriate intervals and, wherever possible, the samples were left in position between measurements. This was not always possible because the analytical requirements incidental to radiation health protection required the use of scaling circuits on several occasions.

In addition to the crater samples described in the foregoing paragraphs, scotch tape samples, taken from the drone airplanes, were run on tests Yoke and Zebra. These samples were obtained by applying a piece of scotch tape to the leading edge of the wing of a drone plane known to be contaminated and then stripping the scotch tape and sending it to the laboratory for analysis. In the laboratory a small portion of the tape was placed in a sample cup with the sticky side up so that the beta measurement would not be affected by the absorption of the scotch tape backing.

All of the counting equipment used in these measurements had been carefully calibrated before the measurements were started and calibrations were repeated at frequent intervals throughout the run. Beta calibrations were made using standard samples of radium D plus E, making use of the 1.17 Mev beta particles from radium E. Gamma-ray calibrations were made using Co^{60} secondary standards which had been checked against Co^{60} standards furnished by the National Bureau of Standards. Frequent determinations were made of the resolving time of the GM counters and all data obtained from the records were corrected for this resolving time. All the samples had a sufficiently high specific activity so that very thin samples could be used, and none of the results were corrected for self absorption.

On X-ray plus 7 days a crater survey was made extending along the Hartman line from 1200 feet to 100 feet from the base of the tower. Readings were taken at stations at 100-foot intervals; the 400-foot distance was omitted because of over-exposure to radiation. At each station soil samples were obtained by driving into the ground a sharpened piece of aluminum tubing to a depth of about 6 inches. When this tubing was removed it contained a core sample of soil down to a depth of about 4 inches. These were carefully wrapped to prevent loss of material and were taken aboard the USS BAIROKO for analysis. At each station gamma intensity measurements were made with an ion chamber survey instrument held about 3 feet from the ground. The intensities given in this report are averages of readings taken over a radius of about 10 feet from the station. In addition, surface samples were taken at each station by carefully scraping up the top layer, not over 1/16 of an inch deep, from an area close to the station which had obviously not been disturbed since the blast.

In the laboratory these samples were prepared for analysis by grinding, and decay curves were run in the same way as for the crater samples described in the foregoing paragraph. Samples from the aluminum tubing were obtained by drilling holes through the tubing at distances of 1 inch, 2 inches, and 4 inches below the surface of the soil samples inside the tube. Through these holes small samples were extracted for analysis. In addition to the foregoing described measurements, measurements were made on surface samples brought in at irregular intervals by the monitoring group.

RESULTS

1. X-ray Crater

Figures 1 to 4 show the decay curves obtained from the crater samples collected at about H plus 4 hours. An inspection of these curves, particularly the log-log plots, shows that the decay is far from the $t^{-1.2}$ law expected for fission products. From the semilog plots it is evident that a large fraction of the activity was due to 14.8 hour Na^{24} produced by the Na^{23} (n, γ) Na^{24} reaction.

Attempts were made to fit the observed decay curves with an equation of the type

$$A = K\epsilon^{-\lambda t} \text{ plus } \frac{L}{t^{1.2}} \qquad (1)$$

where A = observed activity (counts per minute)

λ = decay constant of Na^{24} = 0.0468/hour

t = time in hours

K and L = constants

The first term in Eq. (1) gives the contribution of Na^{24} to the total activity, and the second is the fission product contribution. By choosing two points on the observed decay curve the two constants can be evaluated.

When this process was carried out it was found that the decay predicted by Eq. (1) did not fit the observed decay curves. The fit depended on the points chosen for the determination of K and L and by a suitable choice a reasonably good fit could be obtained at either short or long times, but not at both. It appeared certain that the sample contained some other induced constituent which was decaying with a half-life considerably longer than that of Na^{24} or that fractionation of the fission products had occurred, thereby changing the second term of Eq. (1).

In an attempt to determine other constituents Eq. (1) was extended by adding terms of the type

$$M_{\epsilon}^{-\lambda' t}$$

and using values for λ' appropriate to constituents which might have been present in appreciable quantities. Among the isotopes suspected and tried were

14.3 day P^{32} from P^{31} (n, γ) or S^{32} (n,p)
8.5 day Ca^{41} from Ca^{40} (n, 2n)
12.4 hour K^{42} from K^{41} (n, γ)
180 day Ca^{45} from Ca^{44} (n, γ)

No consideration was given to S^{35} from Cl (n,p) because the soft beta emission unaccompanied by gammas would have been detected with very low efficiency by the beta counters and would have produced no response in the gamma counters.

Even with two additional exponential terms in Eq. (1) there was little improvement in the fit beyond that expected from the fact that more points were forced to coincide in the determination of the constant terms. The lack of fit is beyond the experimental error, but at the present time it is not known what elements are producing the deviation from the expected curve. Longer term measurements may serve to identify them.

Some attempts were made to obtain a better fit by adjusting the exponent of t in the fission product term. These attempts were not successful. It may be noted that the best fit was obtained with $t^{-1.45}$ but this is outside of any probable value and undoubtedly represents a compensation for the unknown elements or for the possible fractionation.

The results of the crater survey of X-ray plus 7 days are shown in Figures 5 to 10. It should be noted that in Figures 5 to 10 the relative heights of the curves are without significance. The large spread in the values of specific activity did not permit a ready comparison of decays, so the heights in Figures 5 to 10 were adjusted arbitrarily. The slopes of the various curves were not changed by the adjustment and may be compared directly.

A comparison of these curves with the expected $t^{-1.2}$ fission product decay shows that at all distances studied the samples from 2" and 4" below the surface show nearly pure fission product activity. The samples taken from nearer the surface show a decay corresponding to various mixtures of fission products and other constituents. The fact that surface samples did not follow the expected $t^{-1.2}$ fission product decay while samples at 2" and 4" below the surface did follow the expected decay is strong evidence against fractionation and for the formation of unidentified induced activities. Fractionation, however, is still believed to be a possibility.

To calculate the percentage activity due to fission products the assumption was made that the only other active constituent was Na^{24}. This is not true, but the error is not great and is probably less than the sampling error resulting from the use of data from the small samples which were taken. Table I shows the percentage of fission products calculated in this way at H plus 186 hours, the time at which measurements were begun.

Table I

Percent F. P. at 186 Hours

		A	B	C	D
Depth		0	1"	2"	4"
Distance	100 ft.	46	100	100	100
	200 ft.	48	69	100	100
	300 ft.	42	42	100	100
	500 ft.	44	100	100	---
	600 ft.	32	100	---	---
	700 ft.	37	100	100	---
	800 ft.	35	100	100	100
	900 ft.	44	47	100	100
	1000 ft.	36	36	100	100
	1100 ft.	98	100	100	100
	1200 ft.	100	100	100	100

The results shown in Table I are somewhat surprising. In view of the penetrating power of neutrons it is difficult to explain the low values of induced activity shown by the one inch samples, and the absence of induced activity at greater depths. The presence of fission products in the lower samples is explained by assuming that the fission products settled out on the surface and were carried down into the soil by subsequent rains. Neutron-induced isotopes will be produced throughout the entire volume receiving the neutrons and hence will not be washed down by rain.

Equally surprising is the absence of induced activity in the surface sample at 1200 ft. Measurements made on a variety of samples taken from above the ground surface show that there was a substantial neutron flux at 1200 ft. The original surface material with the induced activity may have been carried away in the bomb cloud.

The total specific activities as calculated from the beta measurements are listed in Table II.

Table II

Specific Activity at 186 Hours

microcuries per milligram

Depth		A Surface	B 1"	C 2"	D 4"
Distance	100 ft.	7.3×10^{-3}	1.3×10^{-3}	9.7×10^{-4}	1.3×10^{-3}
	200 ft.	5.1×10^{-3}	1.7×10^{-3}	4.6×10^{-4}	5.3×10^{-4}
	300 ft.	7.6×10^{-3}	1.4×10^{-2}	1.3×10^{-3}	8.6×10^{-4}
	500 ft.	6.5×10^{-3}	3.2×10^{-6}	5.1×10^{-6}	---
	600 ft.	3.0×10^{-3}	2.0×10^{-5}	---	---
	700 ft.	0.115	3.7×10^{-4}	4.9×10^{-5}	---
	800 ft.	7.5×10^{-4}	1.5×10^{-4}	1.0×10^{-4}	2.4×10^{-5}
	900 ft.	5.6×10^{-3}	1.1×10^{-2}	4.0×10^{-5}	5.7×10^{-6}
	1000 ft.	0.058	5.5×10^{-4}	6.1×10^{-5}	1.1×10^{-5}
	1100 ft.	1.7×10^{-5}	2.1×10^{-5}	1.4×10^{-5}	7.0×10^{-6}
	1200 ft.	7.9×10^{-6}	5.7×10^{-6}	2.6×10^{-6}	1.7×10^{-6}

The data of Table II are plotted in Figure 11 together with the readings of an ionization chamber survey meter. It will be noted that there are two "hot spots" at 700 ft. and 1000 ft. respectively. These "hot spots" appear only in the surface samples and are not evident in either the sub-surface samples or the survey meter readings. The survey meter readings show a maximum at 800 ft. which may be due to the gamma radiation from the two "hot spots".

The total residual fission products left in the crater were estimated by the following procedure: Each radioactive assay was assumed to be representative of an annular volume extending to equal distances from the sampling point. Thus the 800 ft. surface sample was assumed to represent the conditions in a ring of radii 750 and 850 ft. to a depth of 1/2", and the 900 ft. 2" sample, the conditions in a ring of radii 850 and 950 ft. from depths of 1-1/2" to 3". The specific activity of the sample was multiplied by the total mass of sand in the appropriate volume, assuming a density of 2.0. This activity was corrected by applying the proper percent fission product obtained from the decay curves so that the contribution of Na^{24} was excluded. The results were then corrected by the $t^{-1.2}$ law to H plus one hour. No calculations were made for the contribution beyond a radius of 1250 ft. This probably introduces very little error because the specific activities at 1100 and 1200 ft. are low.

The values found by this calculation are:

Total fission products in crater at H plus one hour	2.3×10^7 curies.
Total fission products in crater at H plus 186 hours	6.4×10^4 curies.

The sampling errors in this estimate are undoubtedly large but this method appeared to be the only way of approximating the figure from the data at hand. Since these values are only a small fraction of the total fission products resulting from the explosion it may be concluded that most of the active material was carried away in the cloud.

Lack of facilities prevented a comprehensive study of beta and gamma energies. One gamma absorption curve was run at H plus 15 hours with the results shown in Figure 12. The absorption curve is characteristic of a monoenergetic gamma ray with a half-value thickness of 1.13 cm. of lead. This half-value layer corresponds to a photon of 1.3 Mev energy. The activity of the sample at H plus 15 hours was approximately 75% Na^{24} and 25% fission products. The photon energy observed agrees as well as can be expected with the 1.38 Mev gamma ray from Na^{24}. The 2.76-Mev gamma ray emitted in cascade with the 1.4-Mev photon was not observed, probably because of a lower counter efficiency for the higher energy and because the lead absorption coefficients for the two energies are not greatly different.

Some of the random samples measured are of interest particularly in connection with the low induced activity found in the soil samples at 1000 ft. On H plus two days a sample of the cement from the O.C.E. structure at 1000 ft. was carefully removed. The sample was taken from the interior of the proximal wall and care was exercised to prevent its contamination with residual active products. The beta decay curve on a finely powdered aliquot of this sample is shown in Figure 13. Most of the activity is due to Na^{24} induced by neutrons. The specific activity of the sample at H plus 22 hours was 2.8×10^{-4} microcuries per milligram. Since the original sodium content of the cement is unknown this figure cannot be used to determine the neutron flux.

Neutron induced activities were also observed from samples taken from the interior of iron stakes driven into the ground just in front of the 1000 ft. O.C.E. structure. The samples studied were about 3" above the ground level at the time of the blast. The decay curve, Figure 14, is complex and has not been analyzed into its components. The specific activity at plus 130 hours was 4.8×10^{-3} microcuries per milligram.

The cement sample from the 1000 ft. O.C.E. structure appears to differ in activity from a sample taken from the base of zero tower. The first measurements on the latter sample curve were made at H plus 272 hours and unfortunately measurements on the other samples were terminated at about H plus 150 hours so they are not directly comparable. As Figure 15 indicates the tower base sample shows an activity with a half-life of at least 19 days with shorter-lived components.

2. Yoke Crater

Measurements were started on the Yoke crater sample at about H plus 9 hours and on the scotch tape samples from the drone planes at H plus 7 hours. The decay curves are shown in Figures 16 to 23. As in the previous test the crater decay curves indicate a mixture of Na^{24} and fission products. Other active materials may be present for observed curves cannot be fitted with a two-constant equation having terms for Na^{24} and fission products.

The decay curves for the drone plane samples are substantially different from the curves from the crater samples. The differences cannot be attributed to fractionation but are probably due to differences in the amounts of surface material picked up and carried into the cloud along with the fission products.

Lack of time prevented a crater survey comparable to the one carried out for the X-ray crater. On Yoke plus 3 days a series of surface samples was collected along a radial line from the Yoke tower. The specific activities as measured at H plus 57 hours are given in Table III.

Table III

Distance ft.	microcuries/milligram
1200	0.083
1500	6.6×10^{-6}
1800	1.9×10^{-6}
2100	7.0×10^{-7}
2700	1.4×10^{-6}
3000	4.8×10^{-8}
3300	4.6×10^{-8}
3600	5.8×10^{-5}
3900	1.7×10^{-8}
4200	1.0×10^{-9}
4500	1.2×10^{-8}

The samples were all taken from greater distances than in the X-ray crater survey and so direct comparison is not possible. The data seem to indicate, however, that at about 1200 ft. the contamination drops sharply to relatively low values. This is not inconsistent with the findings for the X-ray crater.

3. Zebra Crater

The decay curves for the 2 samples are shown in Figures 24 to 31. Once again the curves show a mixture of Na^{24} and fission products together with unidentified components. The decay of the drone samples does not agree with the decay of the crater samples. Here again the lack of agreement is probably due to the pickup from the surface of variable amounts of contamination or to fractionation of the fission products. No crater sampling survey was made so there is no data corresponding to that obtained from X-ray and Yoke.

4. Alpha Measurements

Some alpha particle measurements were made using Eastman nuclear particle emulsions and a Simpson proportional counter. Alpha particle tracks were identified in the photographic emulsion but quantitation was made difficult by the background fog produced by the high beta and gamma activity. Quantitative results from the track counts did not check with the results from the proportional counter and no satisfactory explanation for this discrepancy has been found.

Alpha activity in all samples was low so that long counting times were required to obtain significant results. Values of beta/alpha ratios on soil samples were about 10^5 at plus 72 hours for both X-ray and Yoke tests. This corresponds to a plutonium content of about 10^{-3} micrograms per gram of soil but this figure is not accurate beyond order of magnitude.

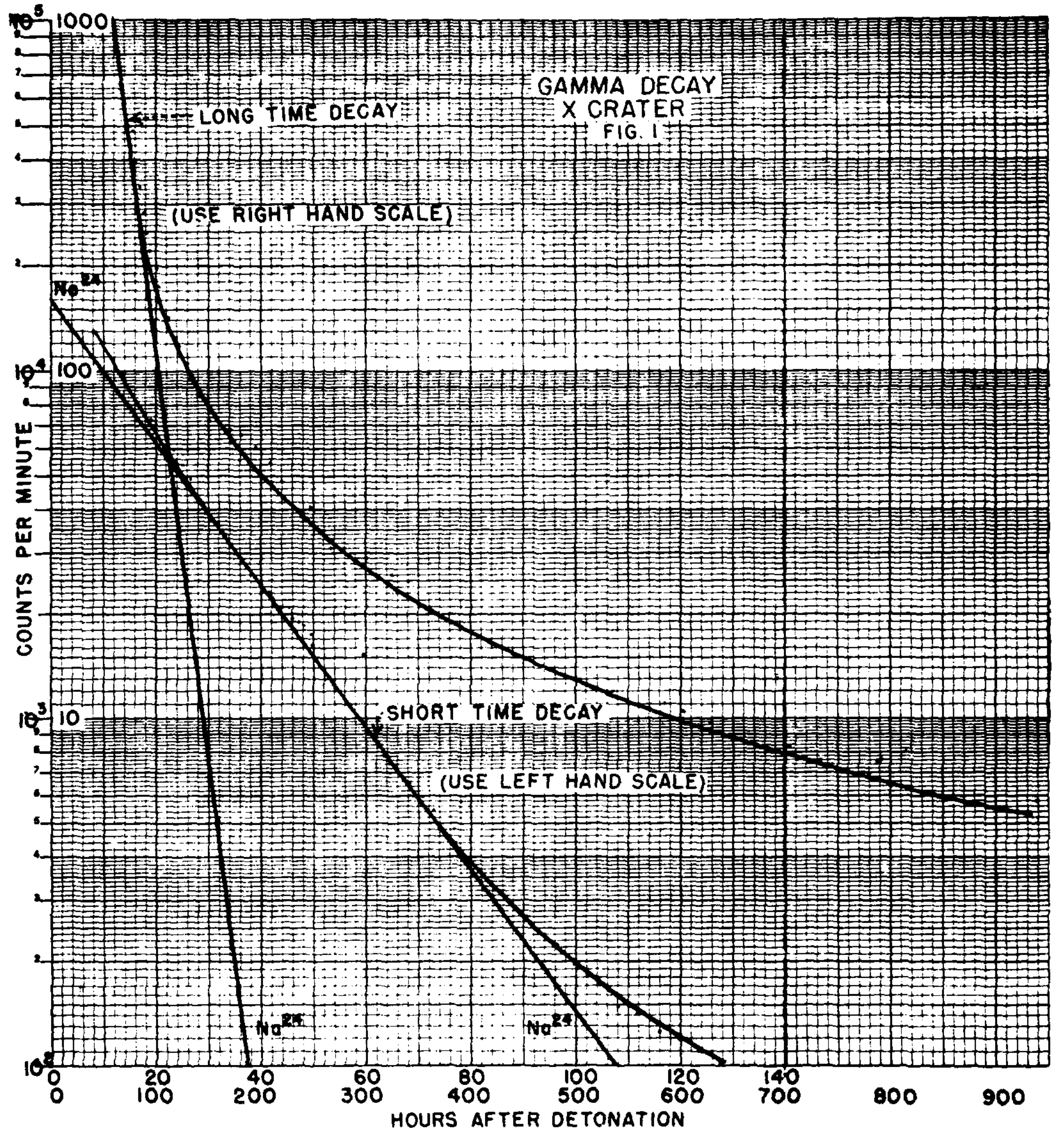
DISCUSSION AND CONCLUSIONS

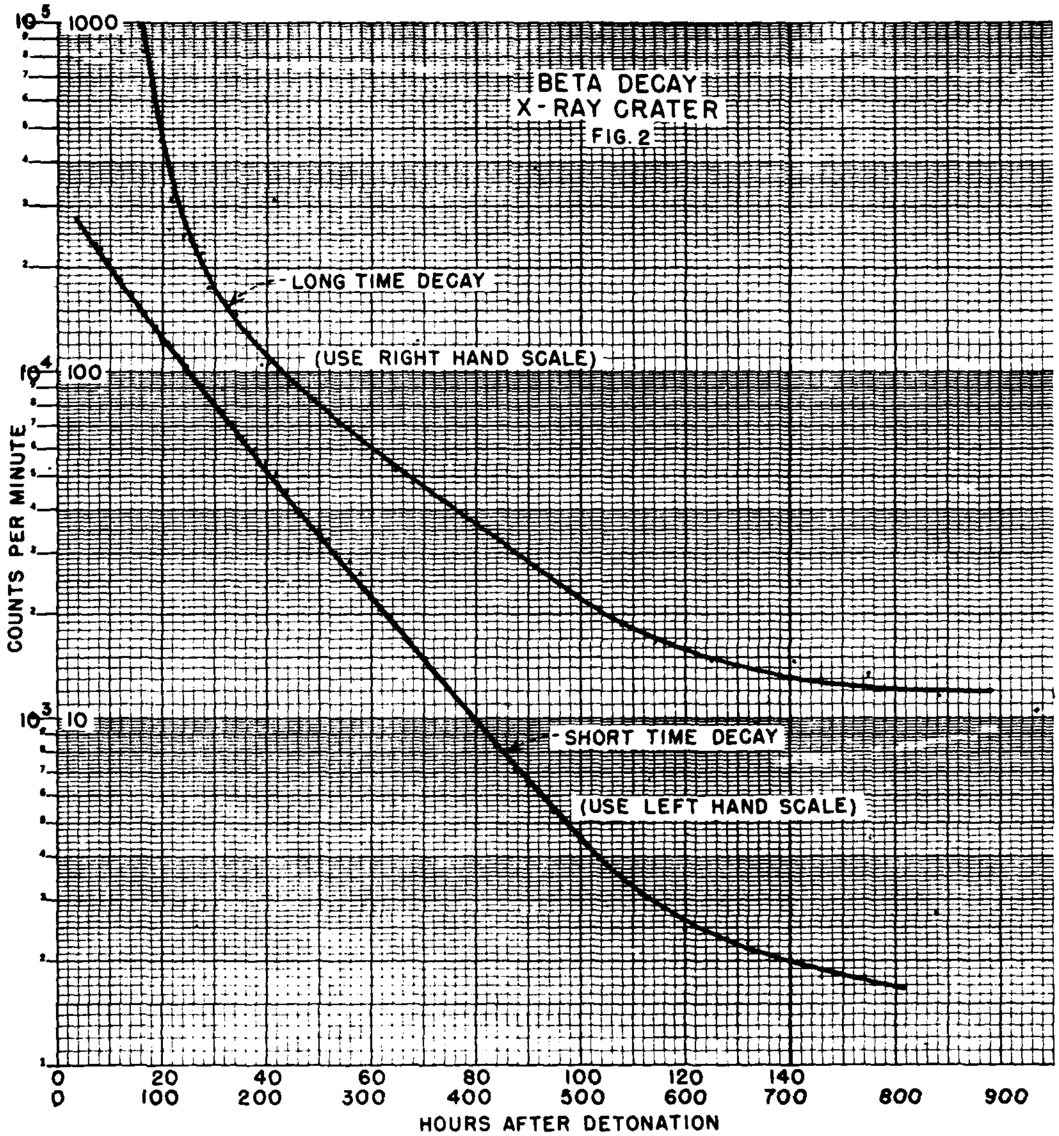
The outstanding result of all of the decay curves is the failure to find components corresponding to the $t^{-1.2}$ law to be anticipated for fission products. This is due to the large amounts of induced activities observed or to fractionation. The amounts of these activities varied from sample to sample and contained unidentified isotopes so that a separation of the composite decay curve was not obtained. It is probable that with long-continued runs such a separation could be obtained. The value of such an analysis, however, is rather doubtful.

All of the craters were atypical in that detonations over soil of the type encountered are not to be expected. For this reason a large scale continuation of the decay curves seems unwarranted. Some measurements are being continued on one sample from each crater.

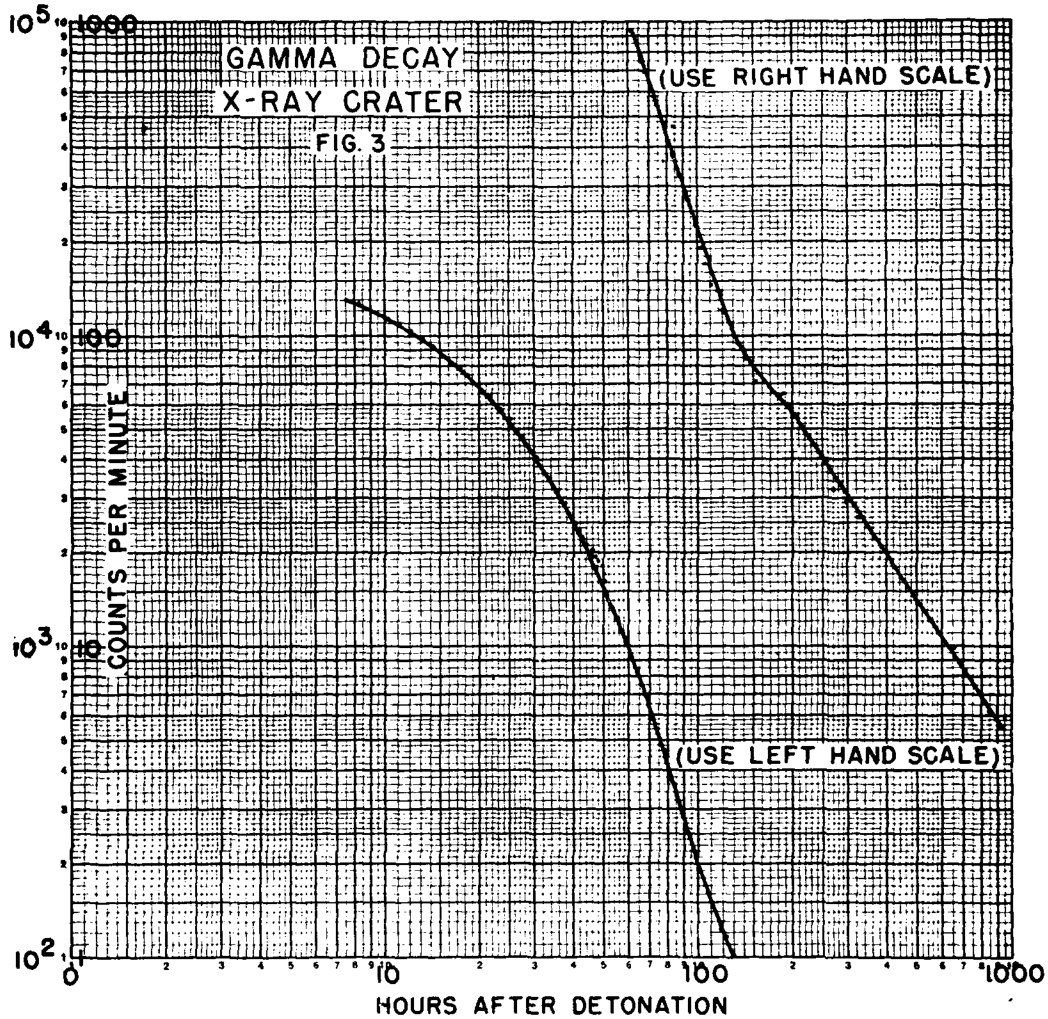
No clearcut evidence of fractionation was obtained because of the large and variable amount of induced activity.

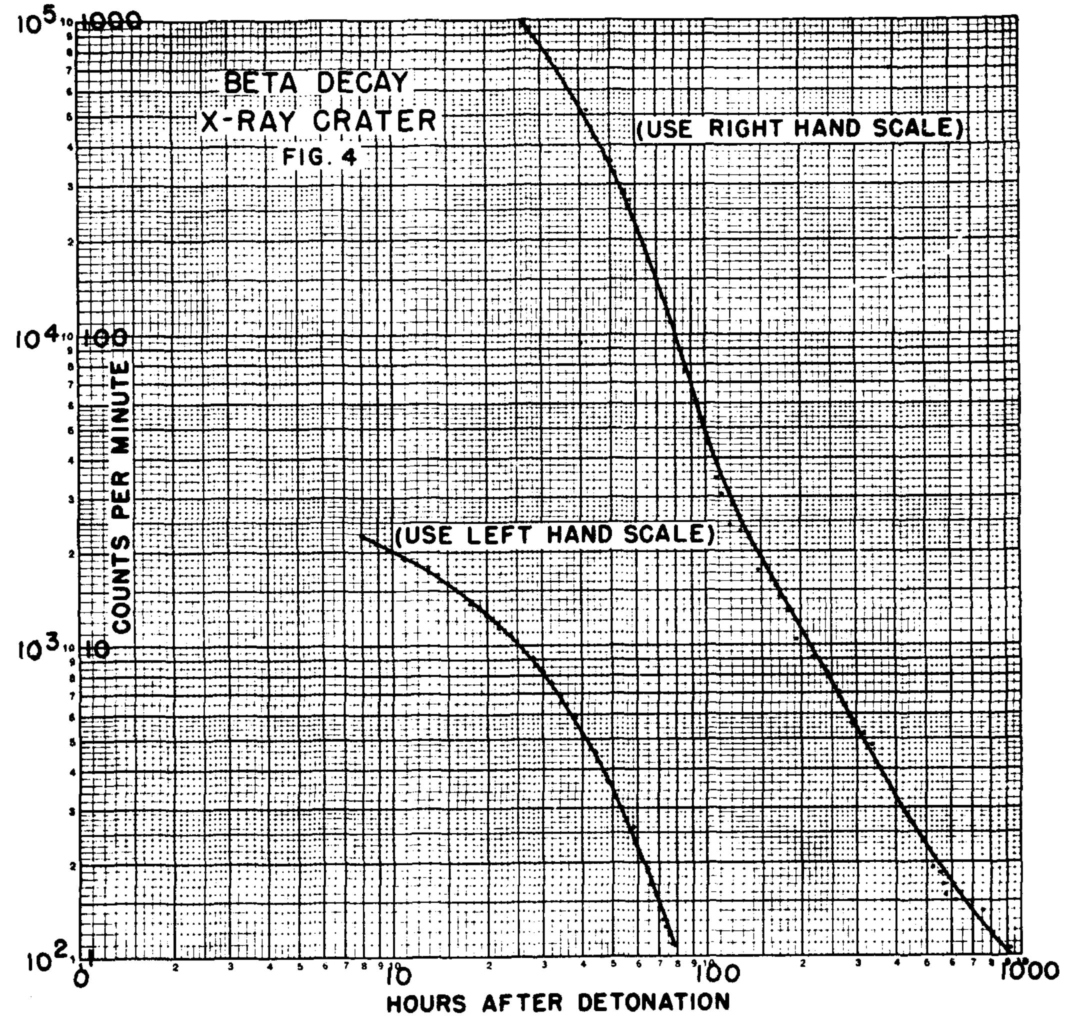
Because of the atypical nature of the surface the data obtained are not very useful in predicting the radiological hazards following an air burst. It is hoped that subsequent tests may be held over more typical terrain so that a complete analysis can be obtained.

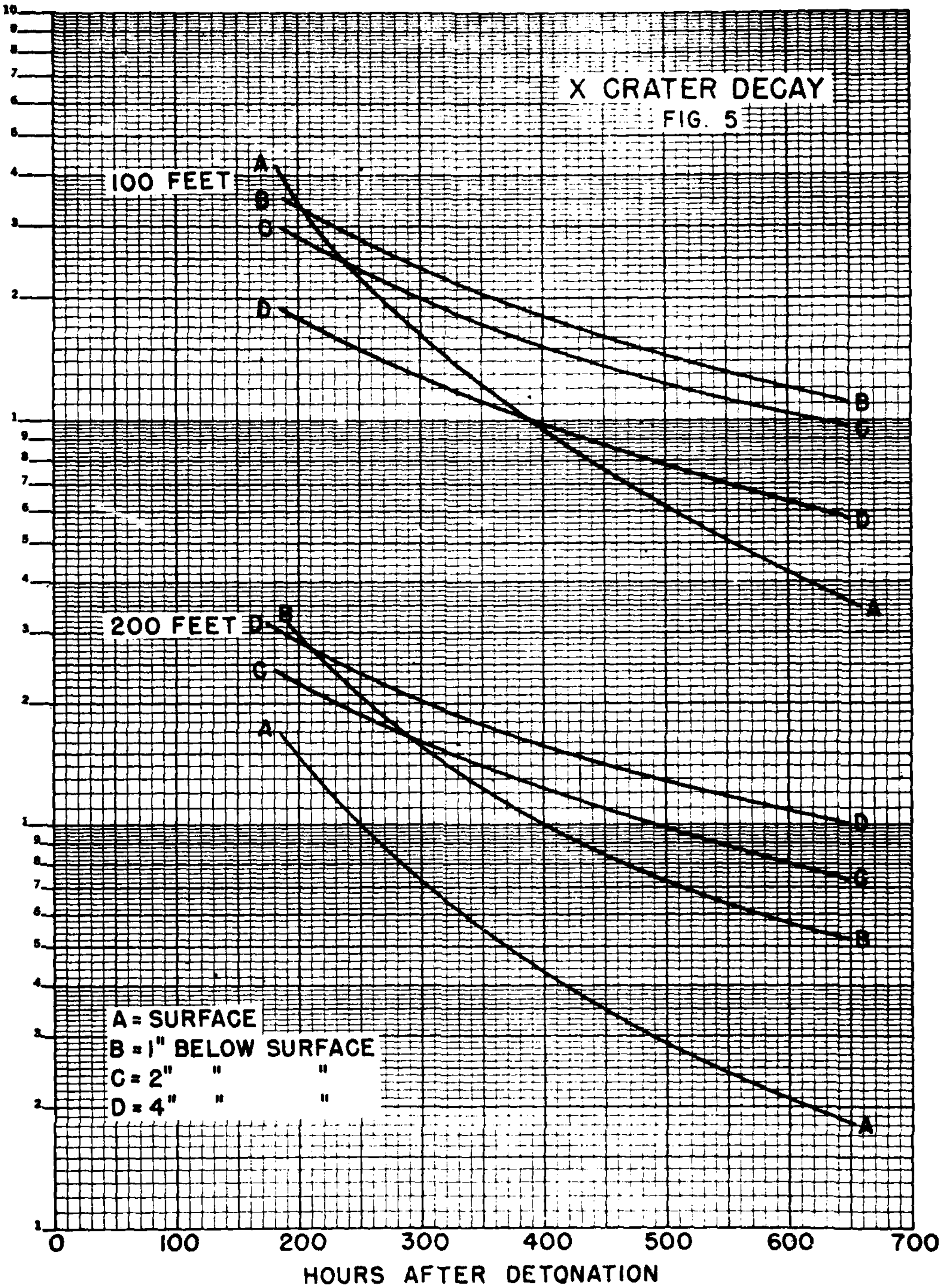

GAMMA DECAY
X CRATER
FIG. 1
LONG TIME DECAY
(USE RIGHT HAND SCALE)
SHORT TIME DECAY
(USE LEFT HAND SCALE)
COUNTS PER MINUTE
HOURS AFTER DETONATION
Na24
Na24
Na24

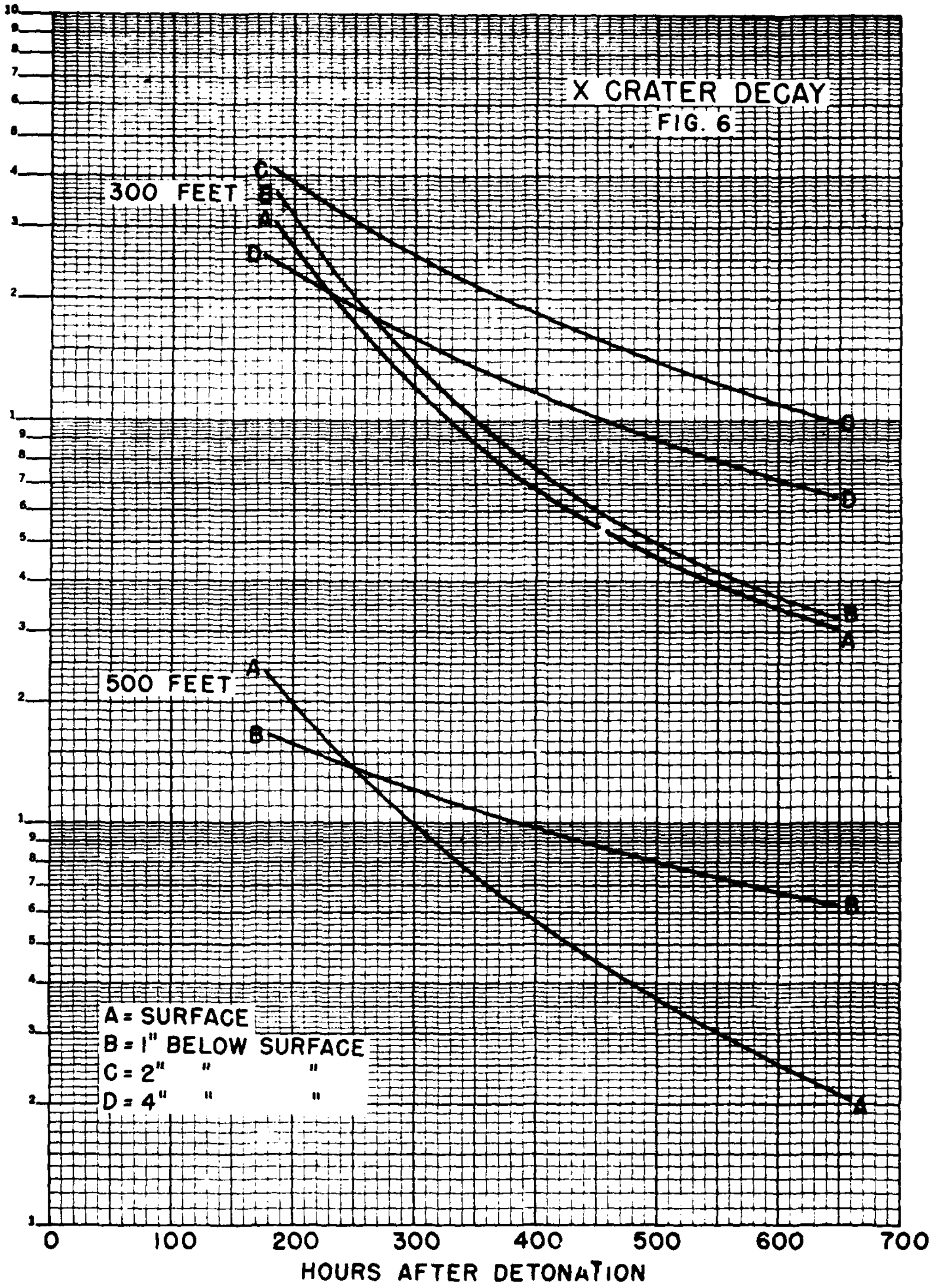


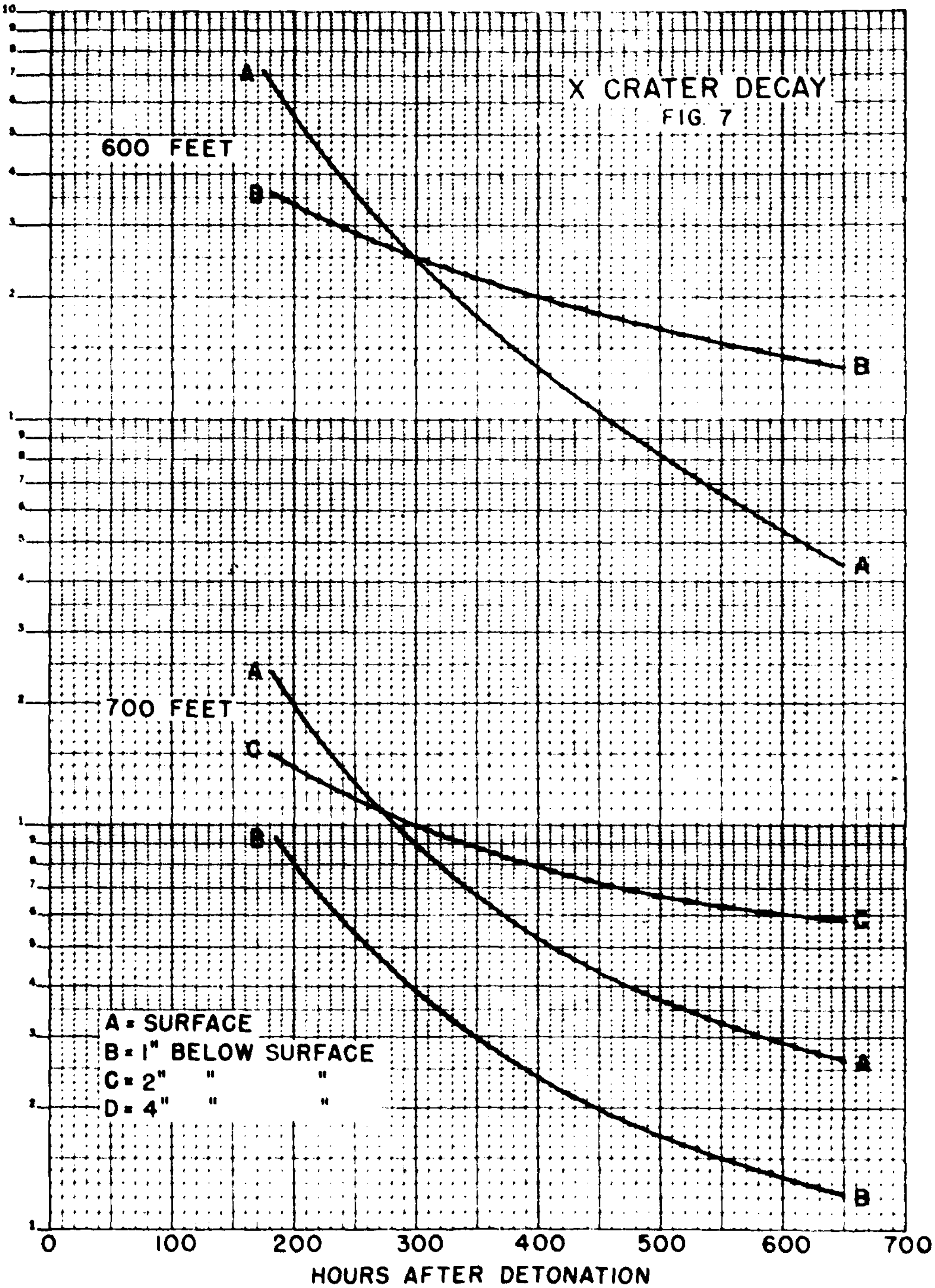
BETA DECAY
X-RAY CRATER
FIG. 2
LONG TIME DECAY
(USE RIGHT HAND SCALE)
SHORT TIME DECAY
(USE LEFT HAND SCALE)
COUNTS PER MINUTE
10^5 1000
10^4 100
10^3 10
0 20 40 60 80 100 120 140
0 100 200 300 400 500 600 700 800 900
HOURS AFTER DETONATION

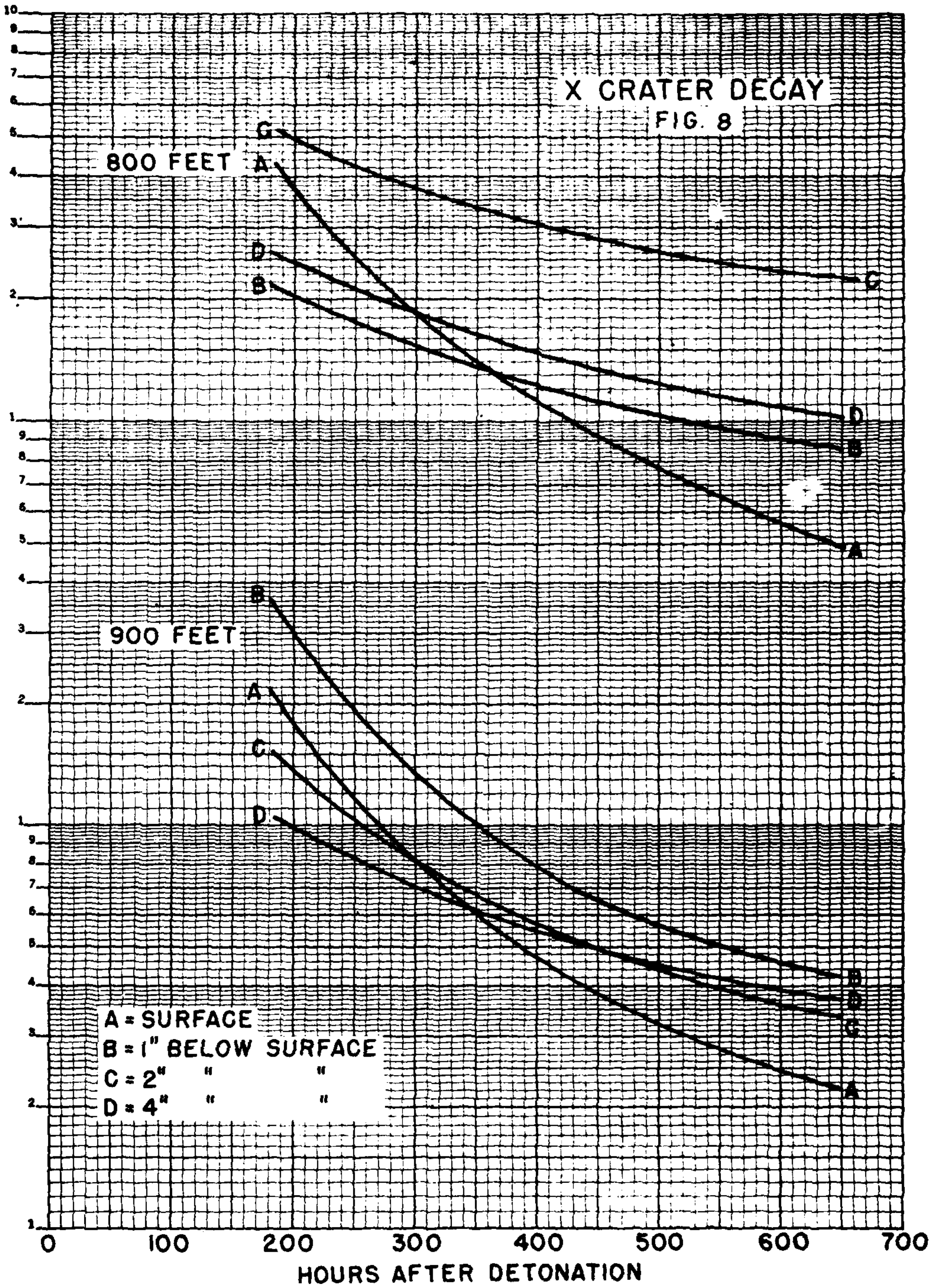

GAMMA DECAY
X-RAY CRATER
FIG. 3
(USE RIGHT HAND SCALE)
(USE LEFT HAND SCALE)
COUNTS PER MINUTE
10^5
1000
10^4
100
10^3
10
10^2
1
0
10
100
1000
HOURS AFTER DETONATION

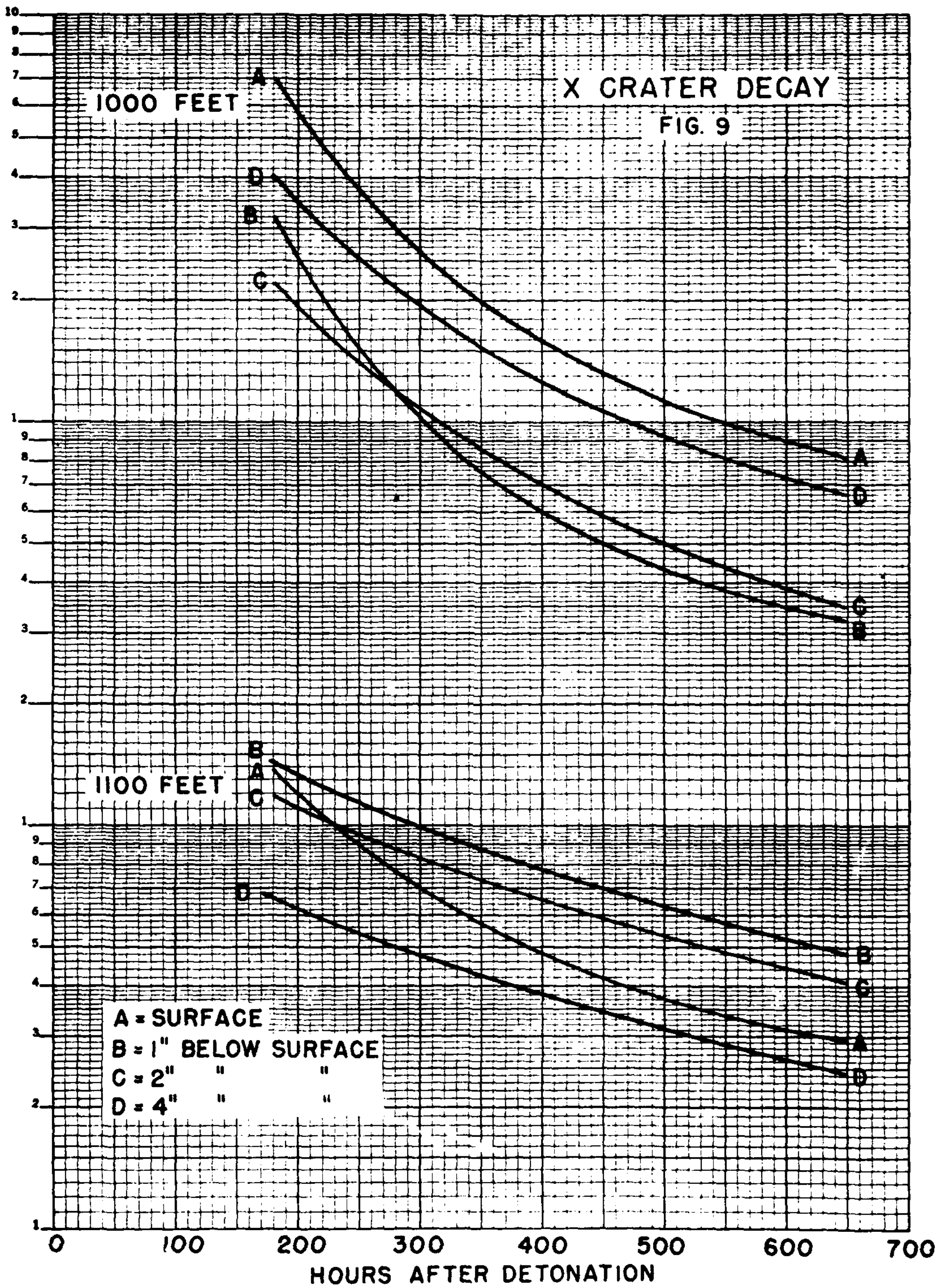

BETA DECAY
X-RAY CRATER
FIG. 4
(USE RIGHT HAND SCALE)
(USE LEFT HAND SCALE)
COUNTS PER MINUTE
HOURS AFTER DETONATION
10^5
10^4
10^3
10^2
1000
100
10
1
10
100
1000

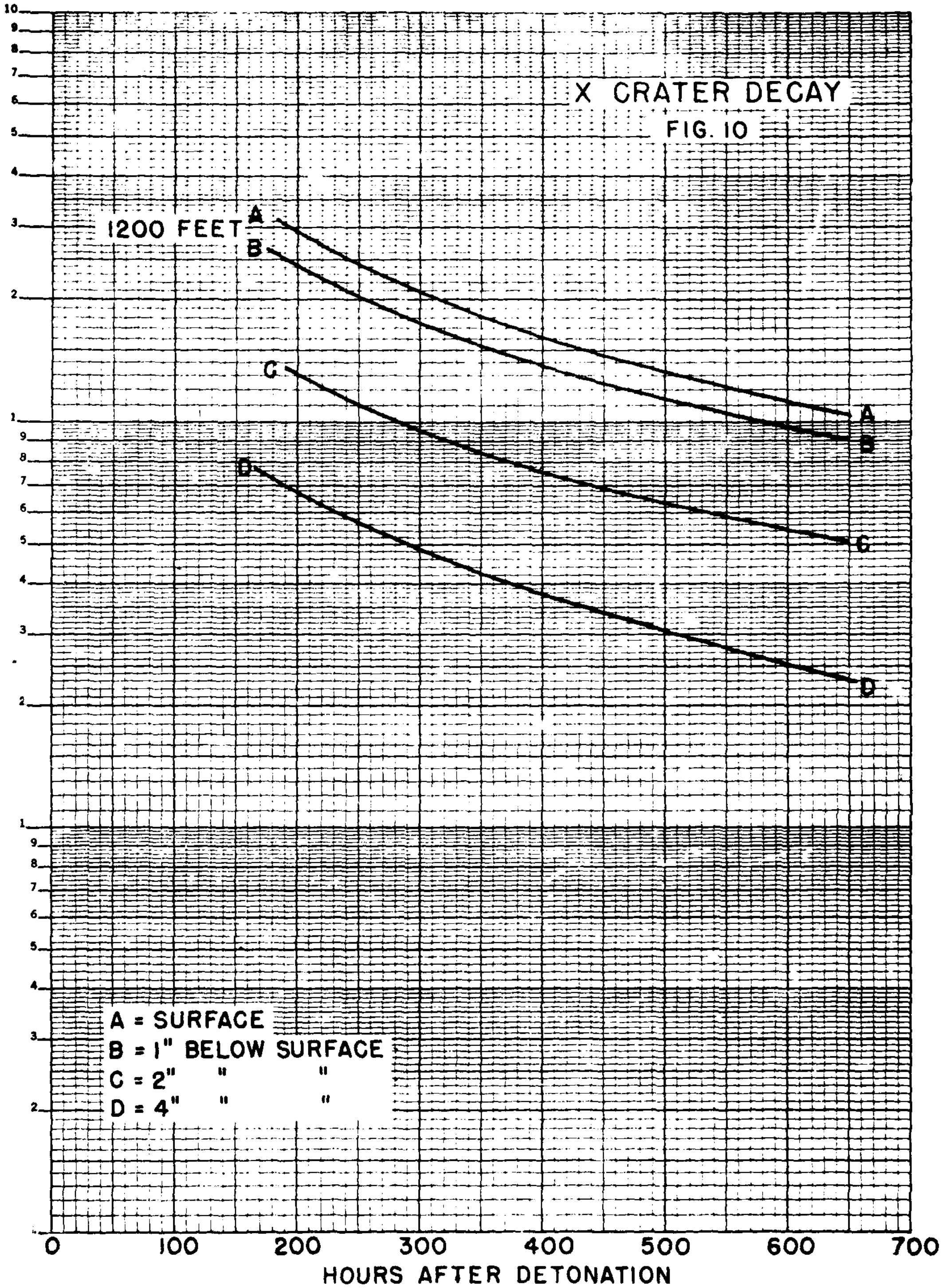

X CRATER DECAY
FIG. 5
100 FEET
200 FEET
A
B
C
D
A = SURFACE
B = 1" BELOW SURFACE
C = 2" " "
D = 4" " "
0
100
200
300
400
500
600
700
HOURS AFTER DETONATION

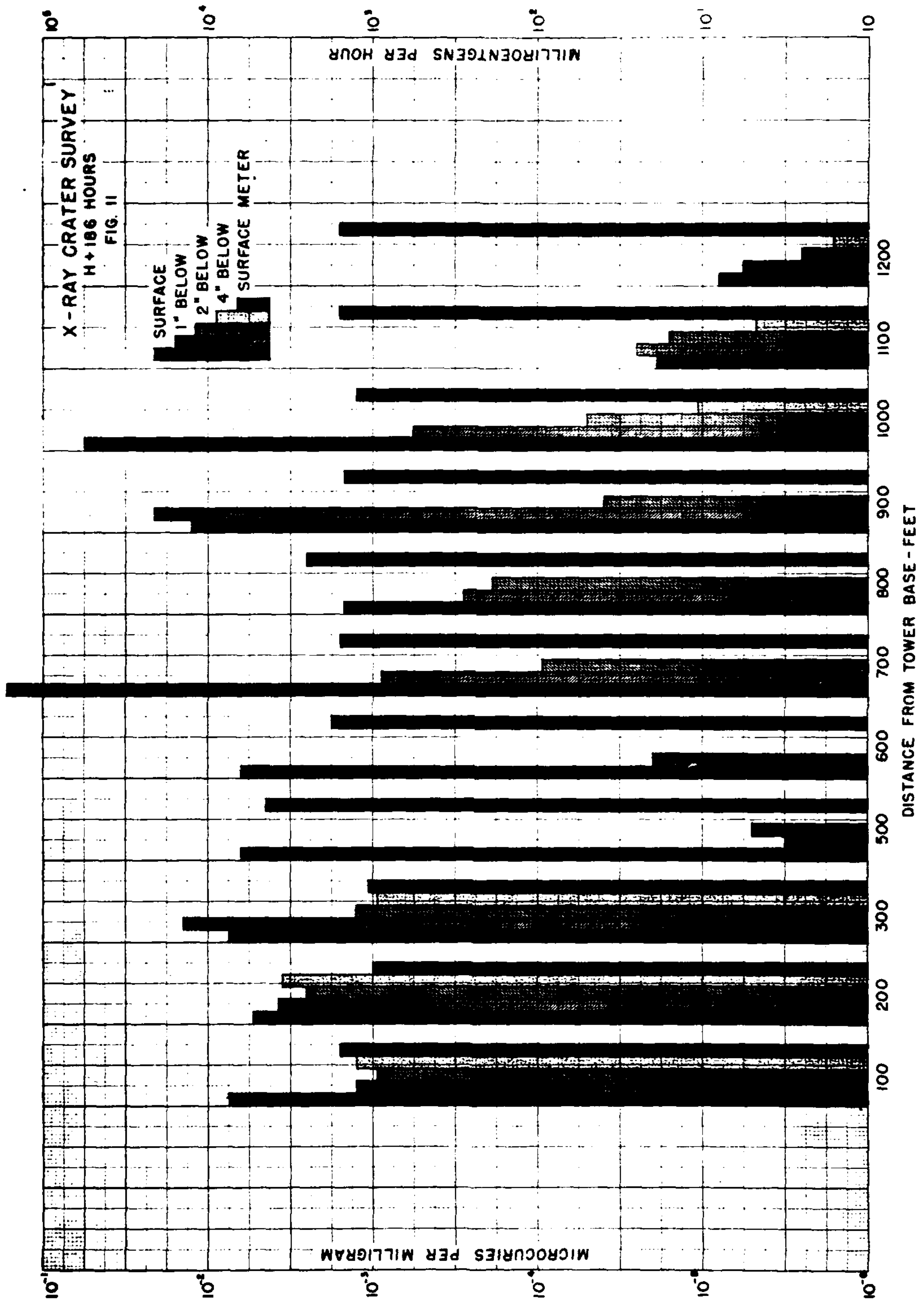

X CRATER DECAY
FIG. 6
300 FEET
500 FEET
A = SURFACE
B = 1" BELOW SURFACE
C = 2" " "
D = 4" " "
A
B
C
D
0
100
200
300
400
500
600
700
HOURS AFTER DETONATION

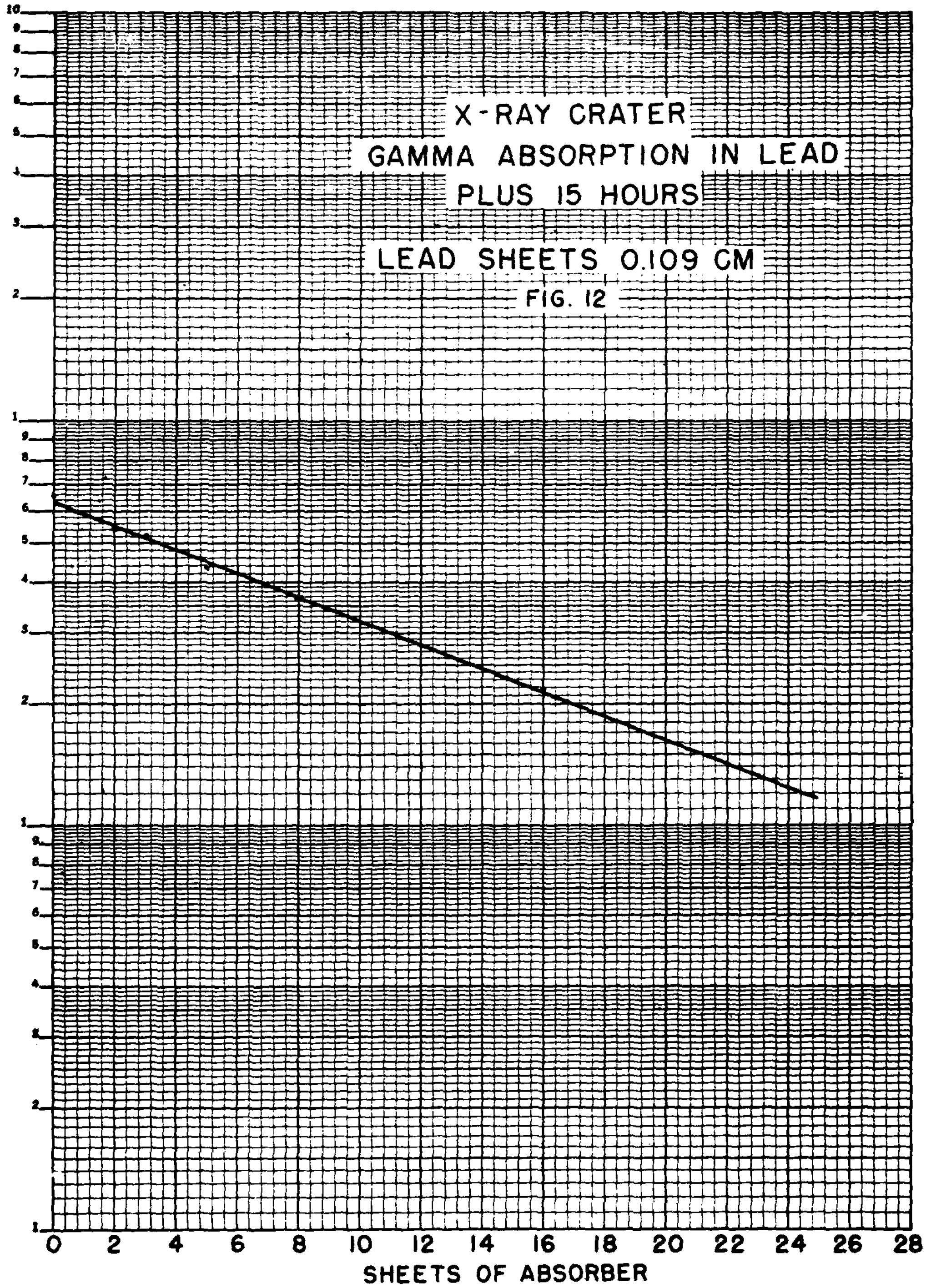

X CRATER DECAY
FIG. 7
600 FEET
700 FEET
A = SURFACE
B = 1" BELOW SURFACE
C = 2" " "
D = 4" " "
A
B
C
0
100
200
300
400
500
600
700
HOURS AFTER DETONATION


X CRATER DECAY
FIG. 8
800 FEET
900 FEET
A = SURFACE
B = 1" BELOW SURFACE
C = 2" " "
D = 4" " "
HOURS AFTER DETONATION
0
100
200
300
400
500
600
700

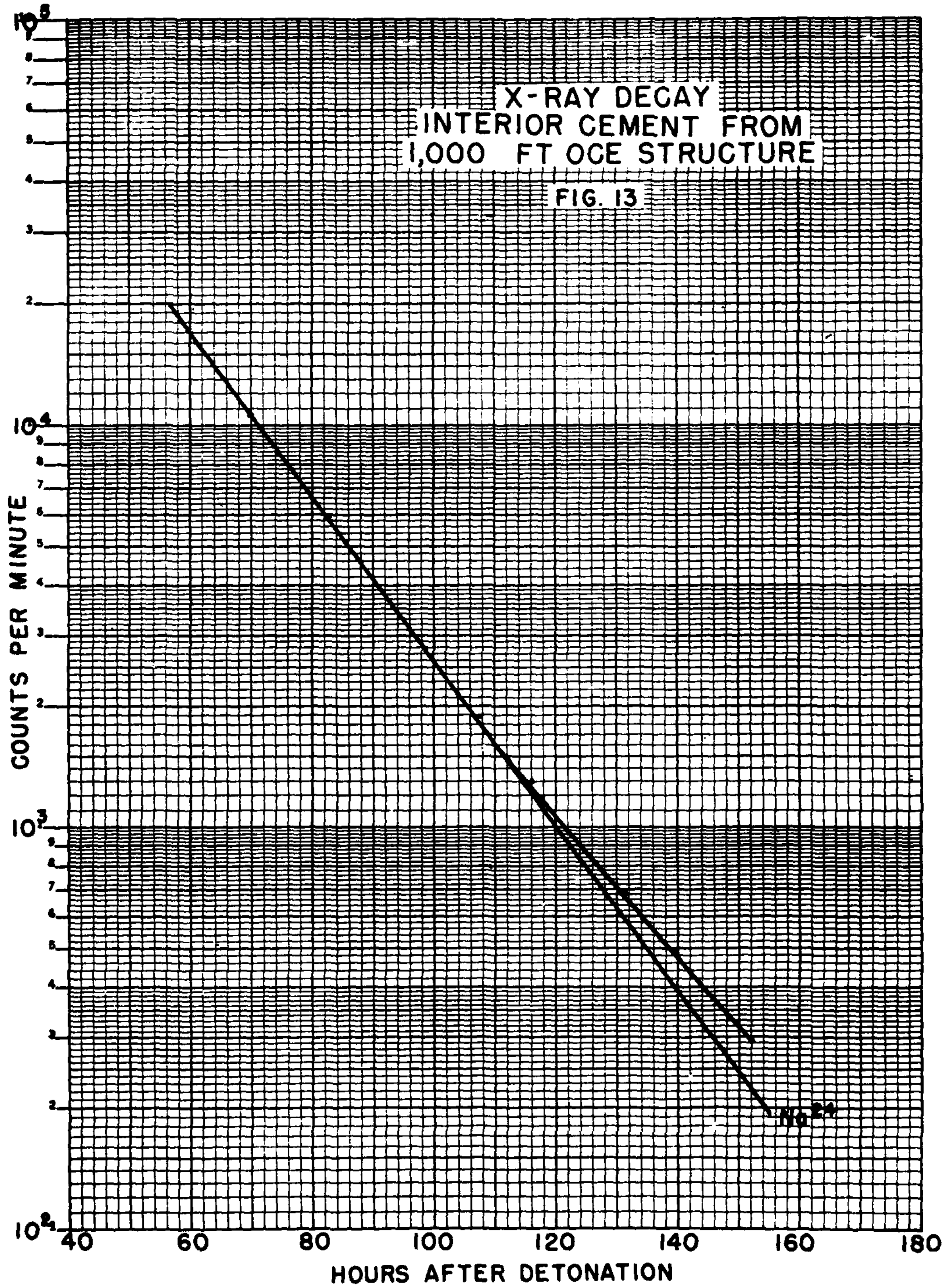

X CRATER DECAY
FIG. 9
1000 FEET
1100 FEET
A = SURFACE
B = 1" BELOW SURFACE
C = 2" " "
D = 4" " "
A
B
C
D
10
9
8
7
6
5
4
3
2
1
0
100
200
300
400
500
600
700
HOURS AFTER DETONATION

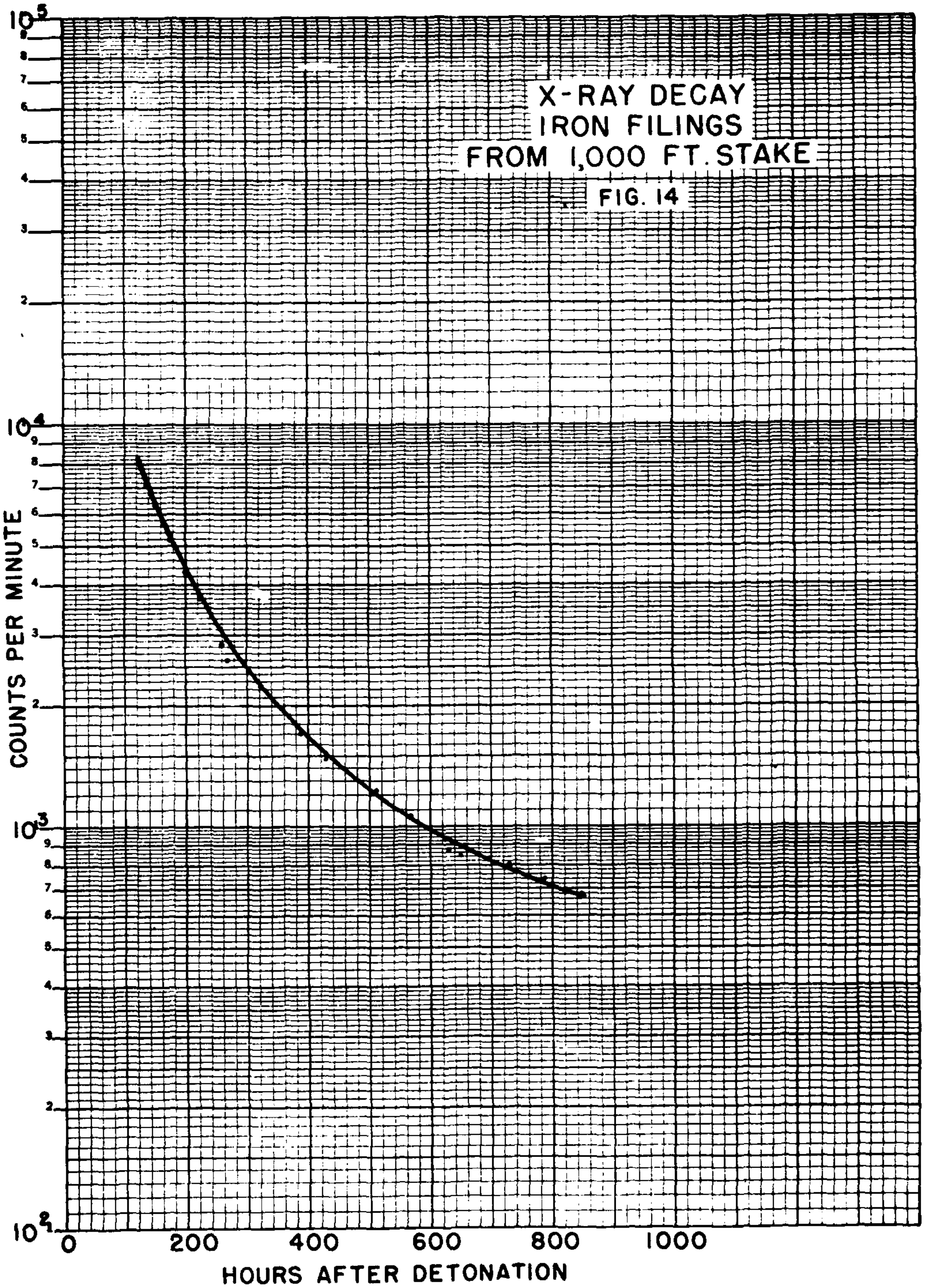

X CRATER DECAY
FIG. 10
1200 FEET
A
B
C
D
A = SURFACE
B = 1" BELOW SURFACE
C = 2" " "
D = 4" " "
10
9
8
7
6
5
4
3
2
1
0
100
200
300
400
500
600
700
HOURS AFTER DETONATION

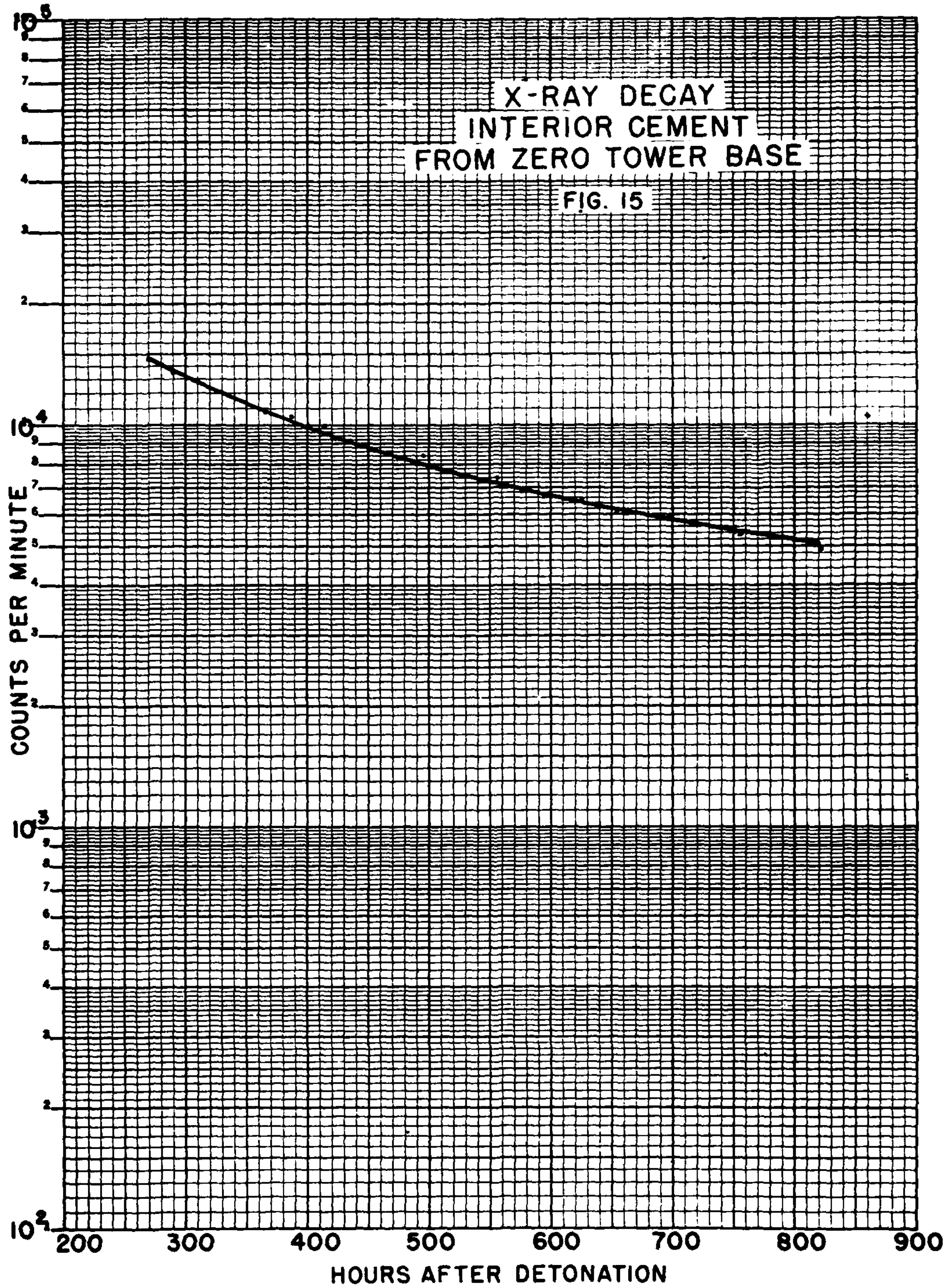

X-RAY CRATER SURVEY
H + 186 HOURS
FIG. 11
SURFACE
1" BELOW
2" BELOW
4" BELOW
SURFACE METER
MILLIROENTGENS PER HOUR
MICROCURIES PER MILLIGRAM
DISTANCE FROM TOWER BASE - FEET

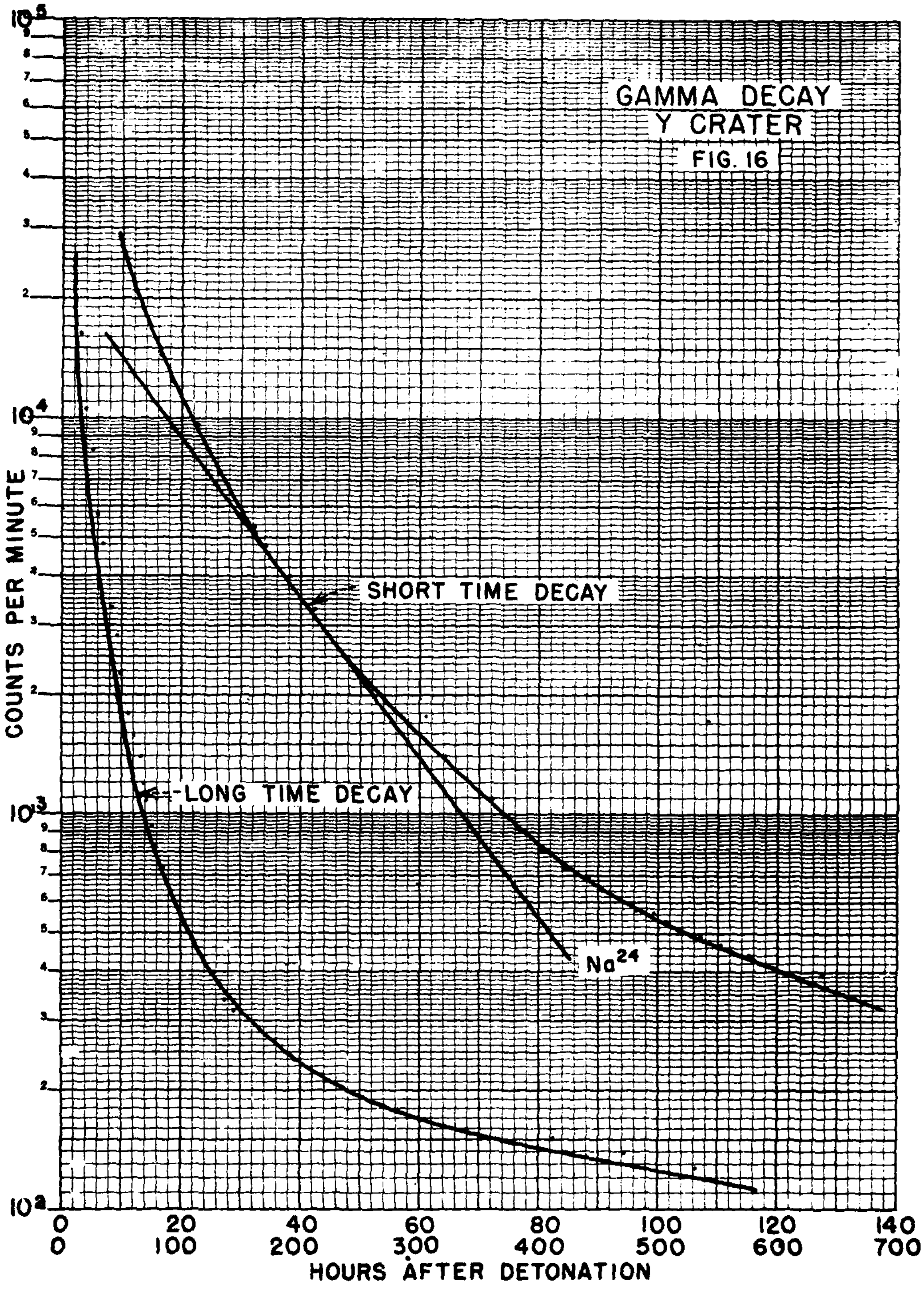


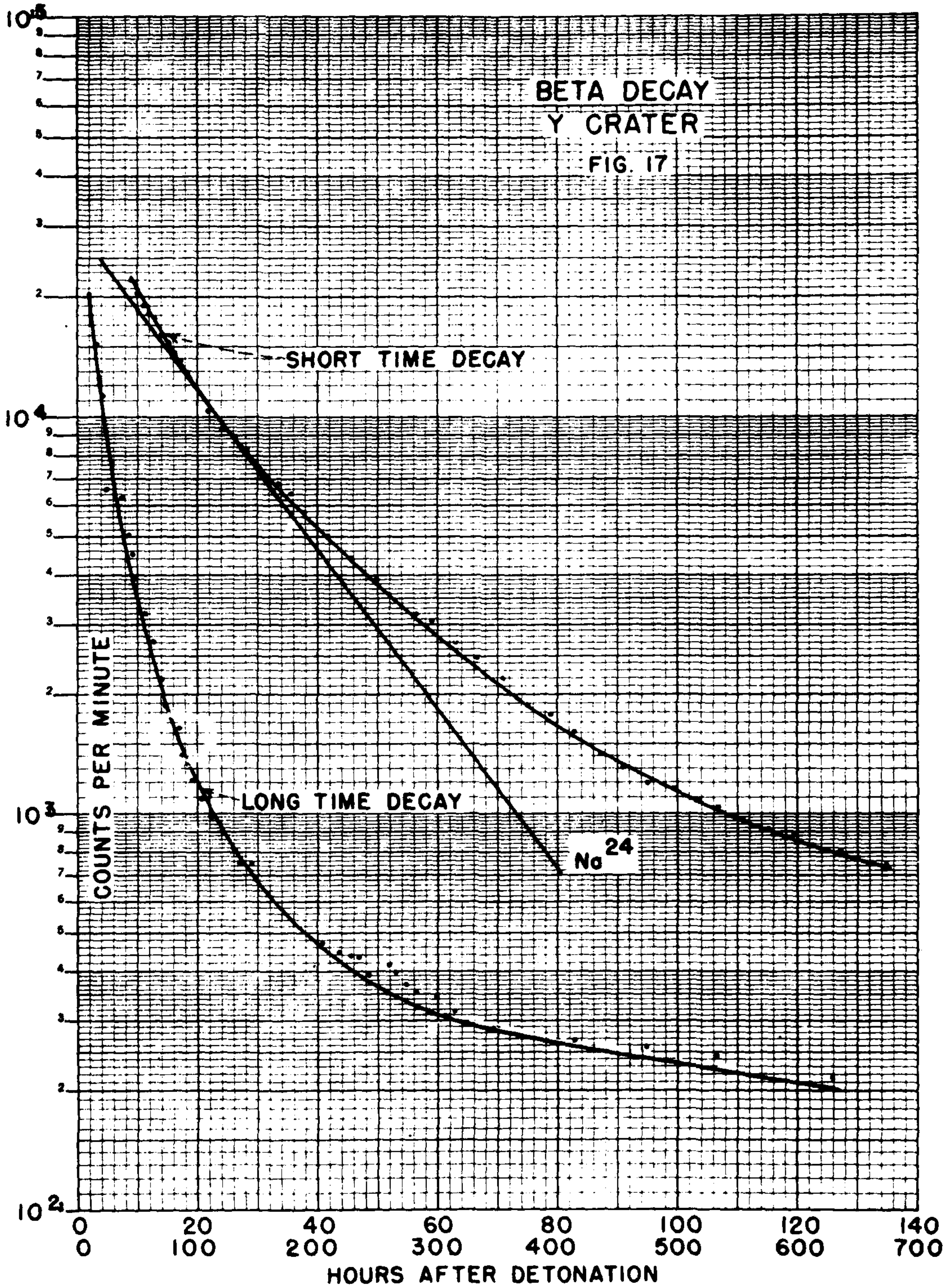
X-RAY CRATER
GAMMA ABSORPTION IN LEAD
PLUS 15 HOURS
LEAD SHEETS 0.109 CM
FIG. 12
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
SHEETS OF ABSORBER


X-RAY DECAY
INTERIOR CEMENT FROM
1,000 FT OCE STRUCTURE
FIG. 13
COUNTS PER MINUTE
HOURS AFTER DETONATION
10^5
10^4
10^3
10^2
40
60
80
100
120
140
160
180
Na^{24}

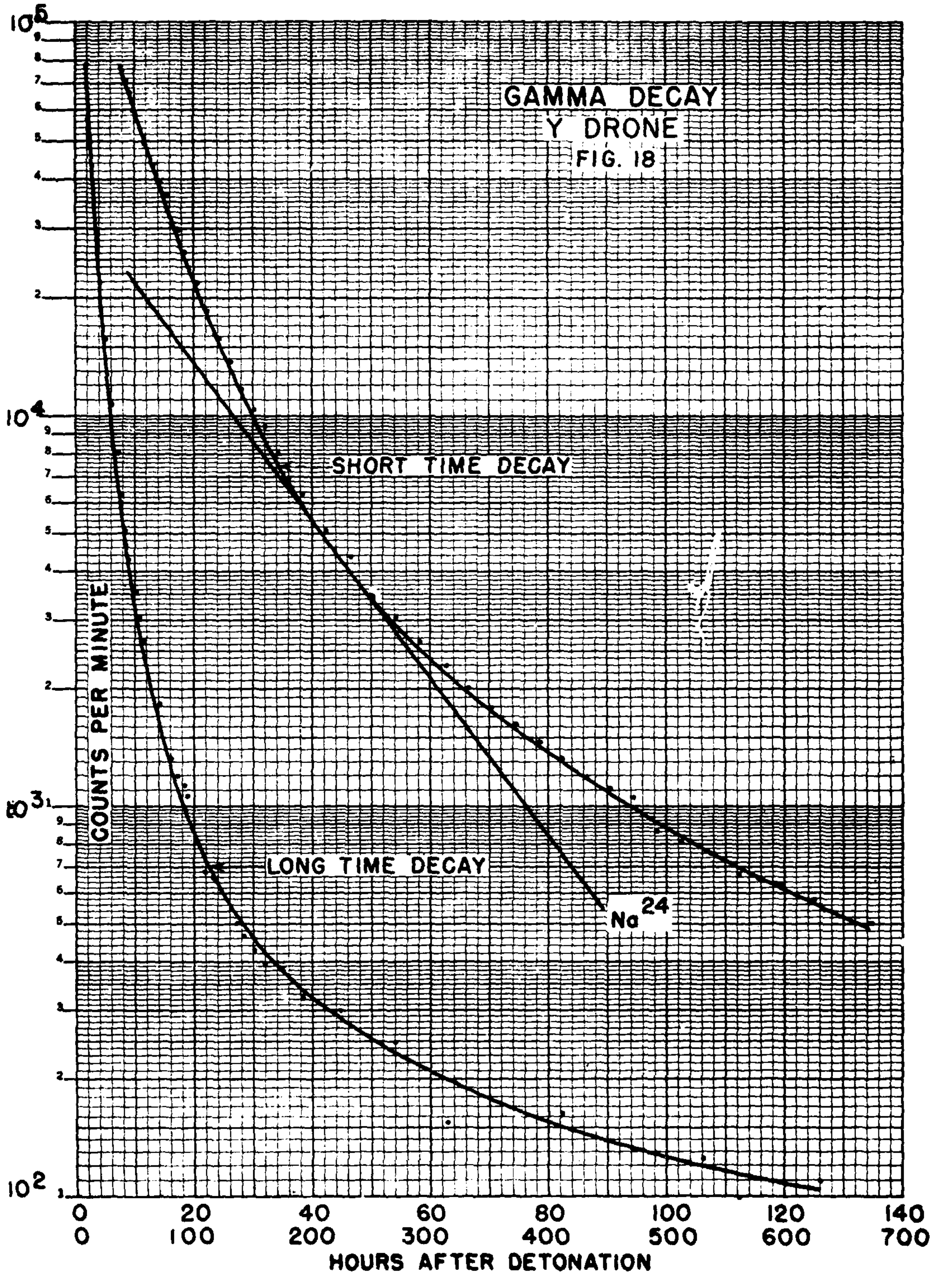

X-RAY DECAY
IRON FILINGS
FROM 1,000 FT. STAKE
FIG. 14
COUNTS PER MINUTE
HOURS AFTER DETONATION
10^5
10^4
10^3
10^2
0
200
400
600
800
1000

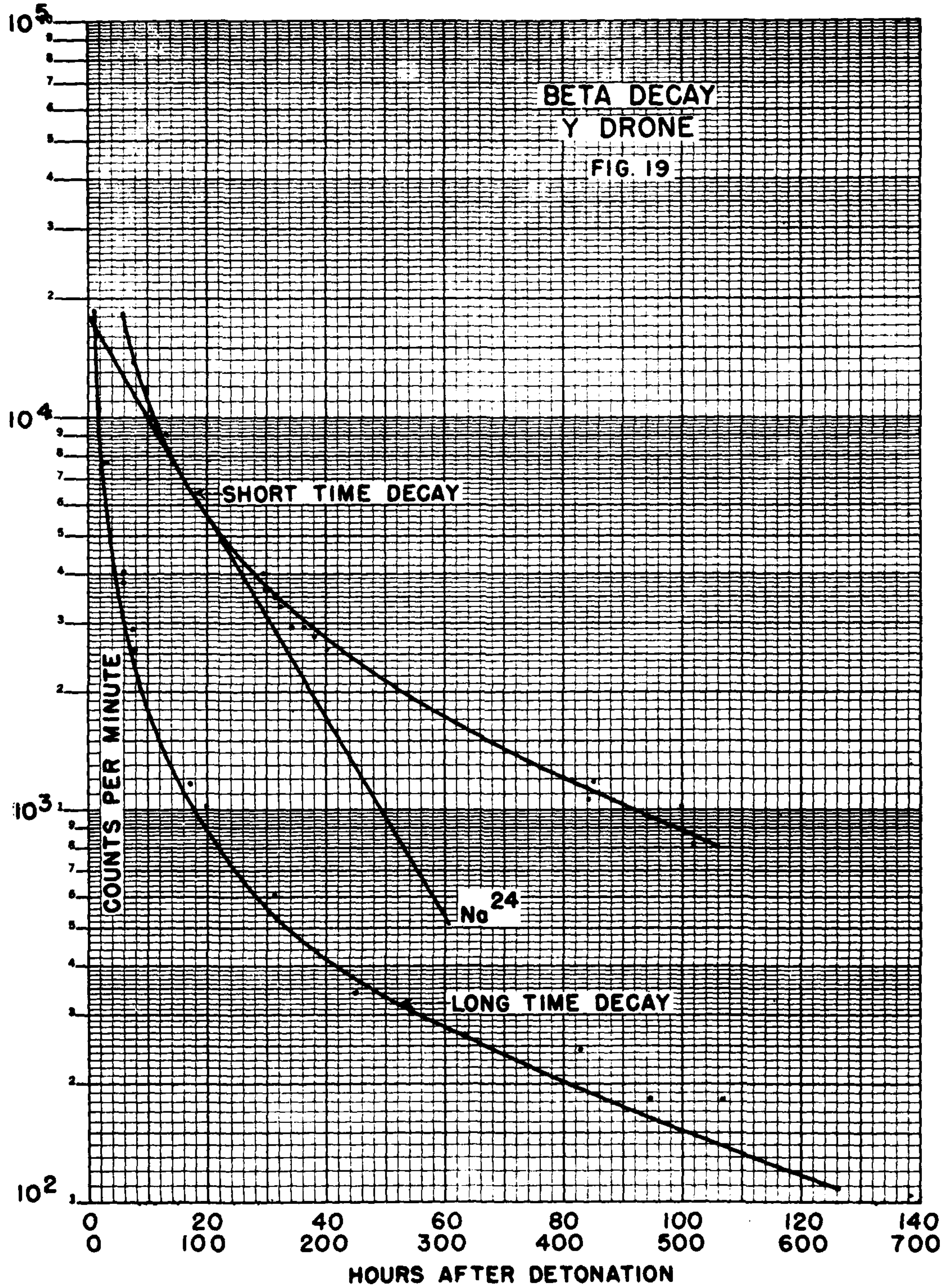

X-RAY DECAY
INTERIOR CEMENT
FROM ZERO TOWER BASE
FIG. 15
COUNTS PER MINUTE
HOURS AFTER DETONATION
200
300
400
500
600
700
800
900


GAMMA DECAY
Y CRATER
FIG. 16
SHORT TIME DECAY
LONG TIME DECAY
Na^{24}
COUNTS PER MINUTE
10^5
10^4
10^3
10^2
0 20 40 60 80 100 120 140
0 100 200 300 400 500 600 700
HOURS AFTER DETONATION

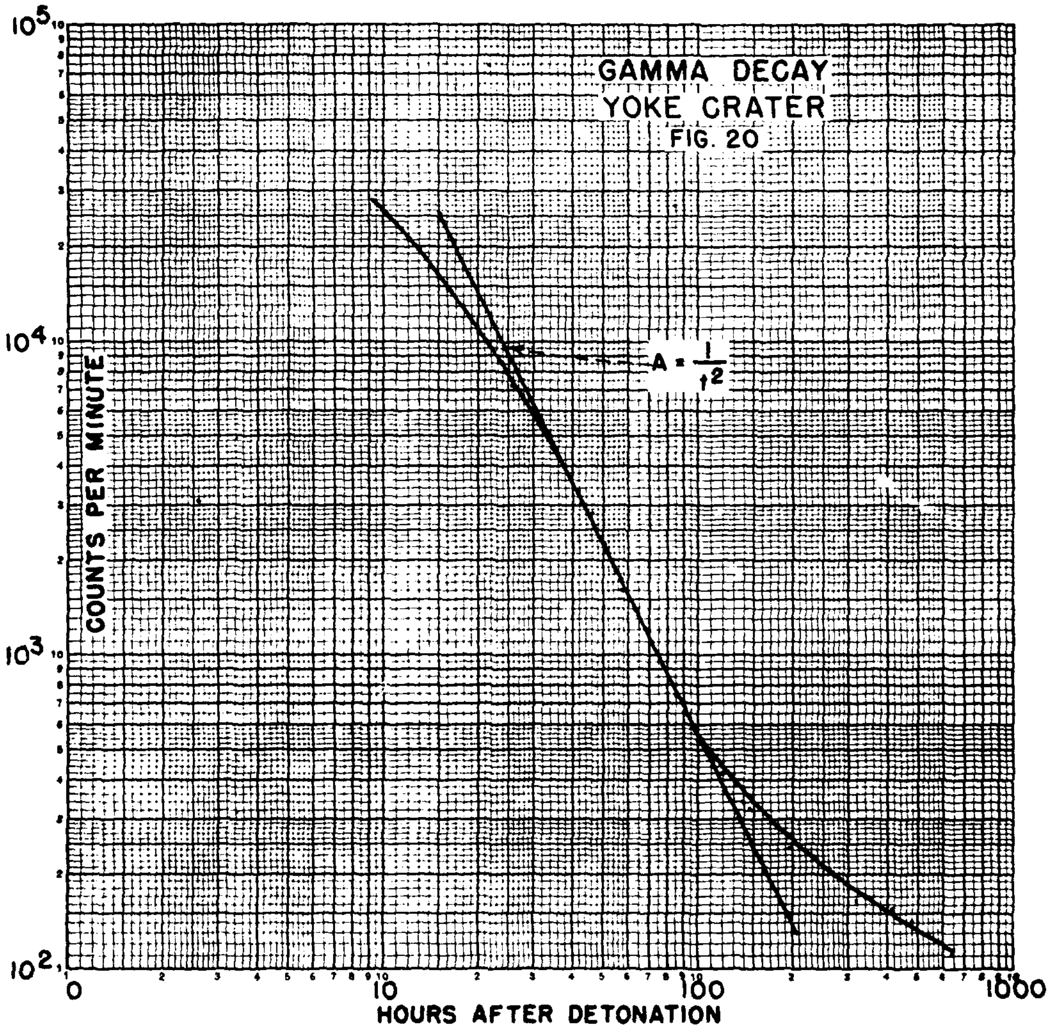


BETA DECAY
Y CRATER
FIG. 17
SHORT TIME DECAY
LONG TIME DECAY
Na 24
COUNTS PER MINUTE
HOURS AFTER DETONATION

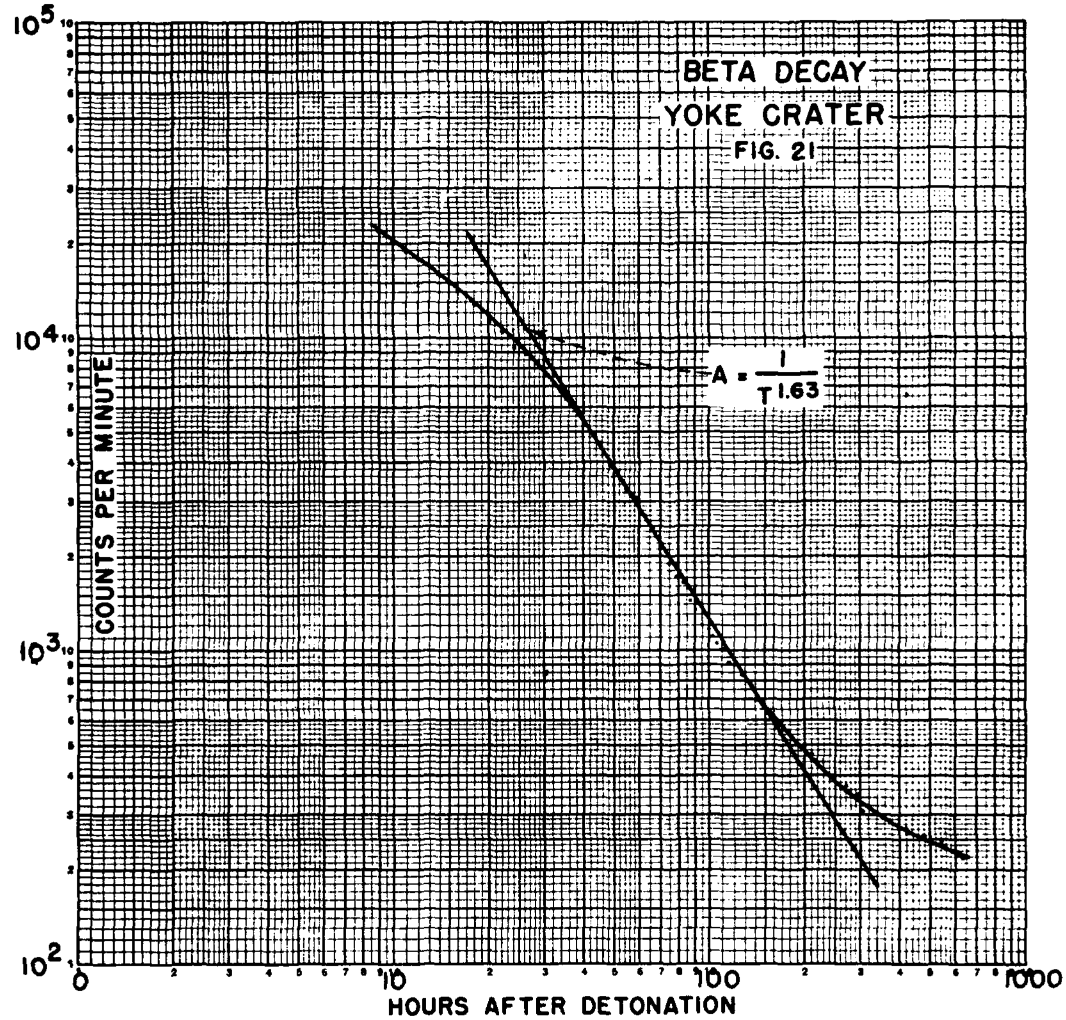

GAMMA DECAY
Y DRONE
FIG. 18
SHORT TIME DECAY
LONG TIME DECAY
Na 24
COUNTS PER MINUTE
HOURS AFTER DETONATION
10⁵
10⁴
10³
10²
0 20 40 60 80 100 120 140
0 100 200 300 400 500 600 700



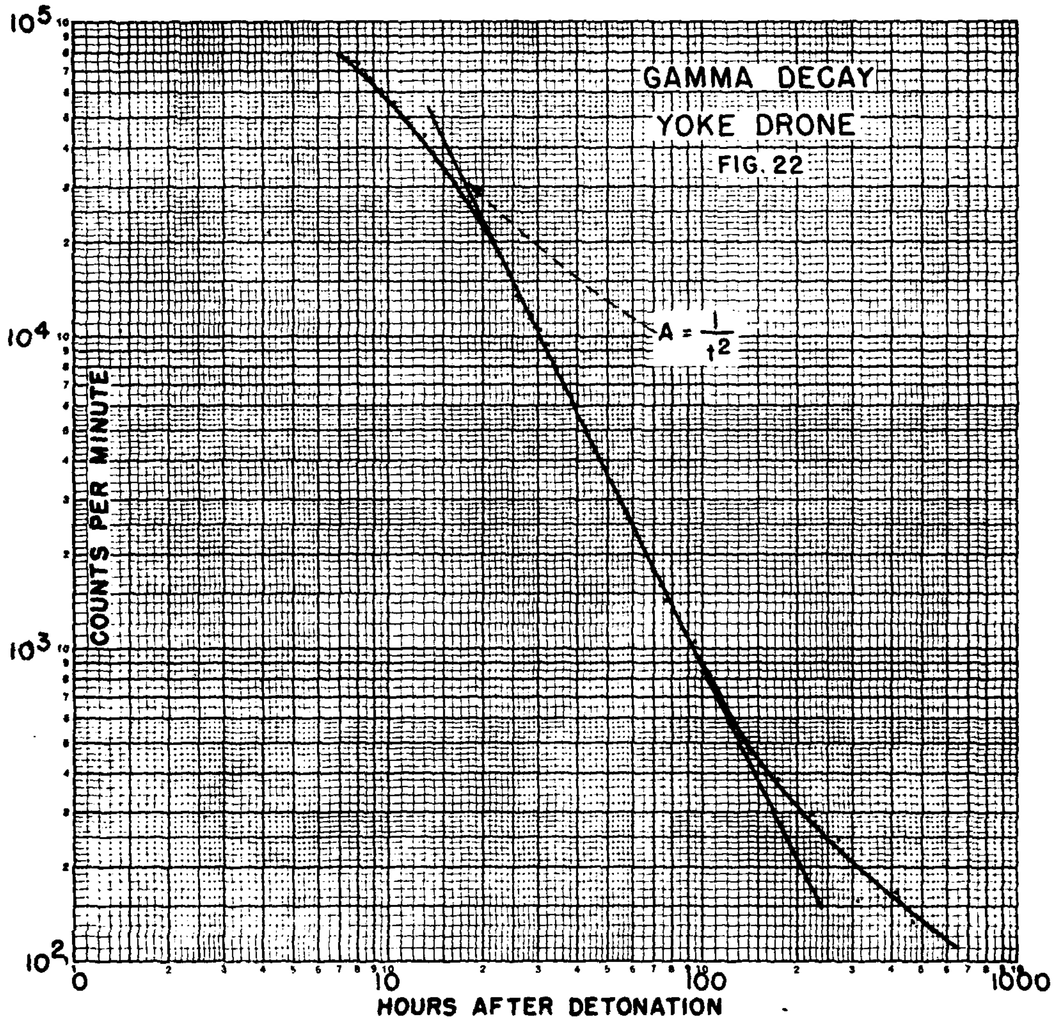
BETA DECAY
Y DRONE
FIG. 19
SHORT TIME DECAY
Na^{24}
LONG TIME DECAY
COUNTS PER MINUTE
10^5
10^4
10^3
10^2
0 20 40 60 80 100 120 140
0 100 200 300 400 500 600 700
HOURS AFTER DETONATION



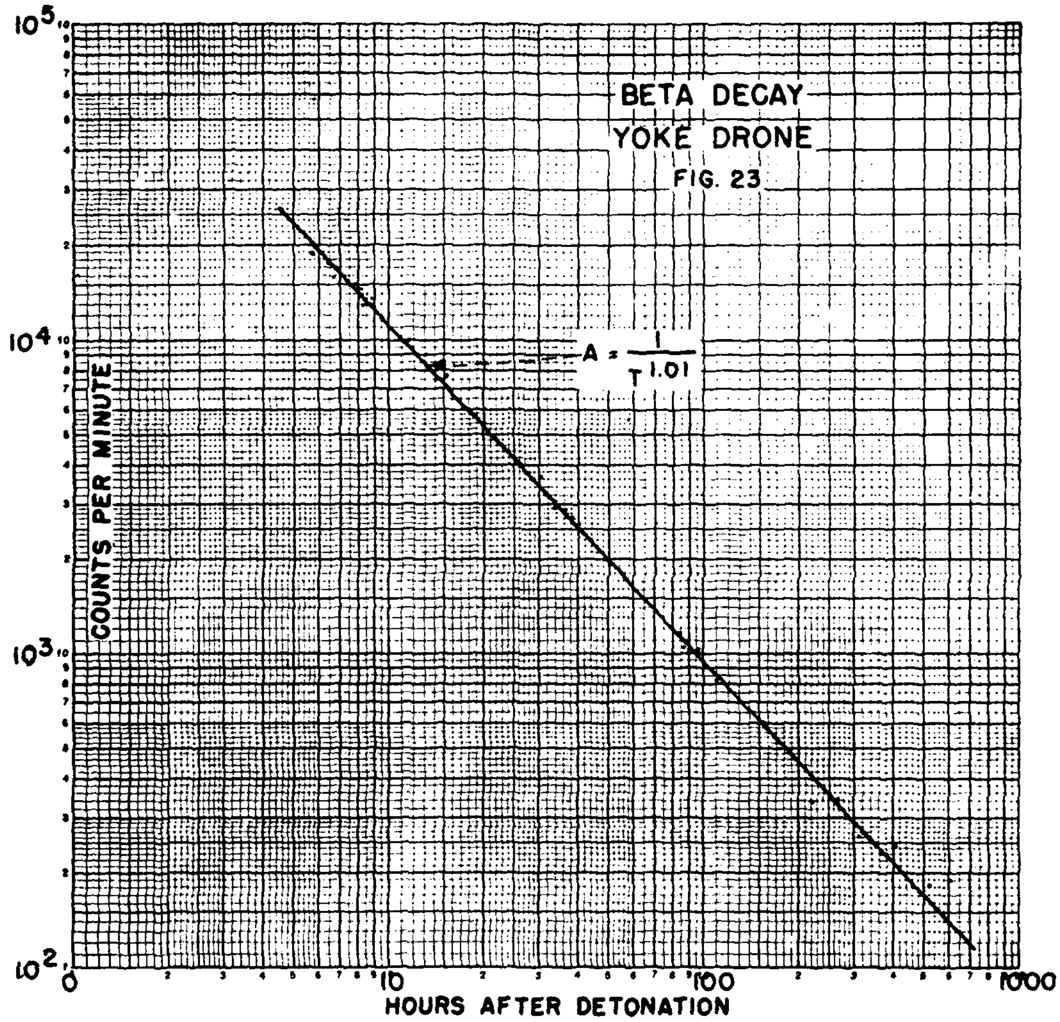
GAMMA DECAY
YOKE CRATER
FIG. 20
$A = \frac{1}{t^2}$
COUNTS PER MINUTE
10^5
10^4
10^3
10^2
0
10
100
1000
HOURS AFTER DETONATION

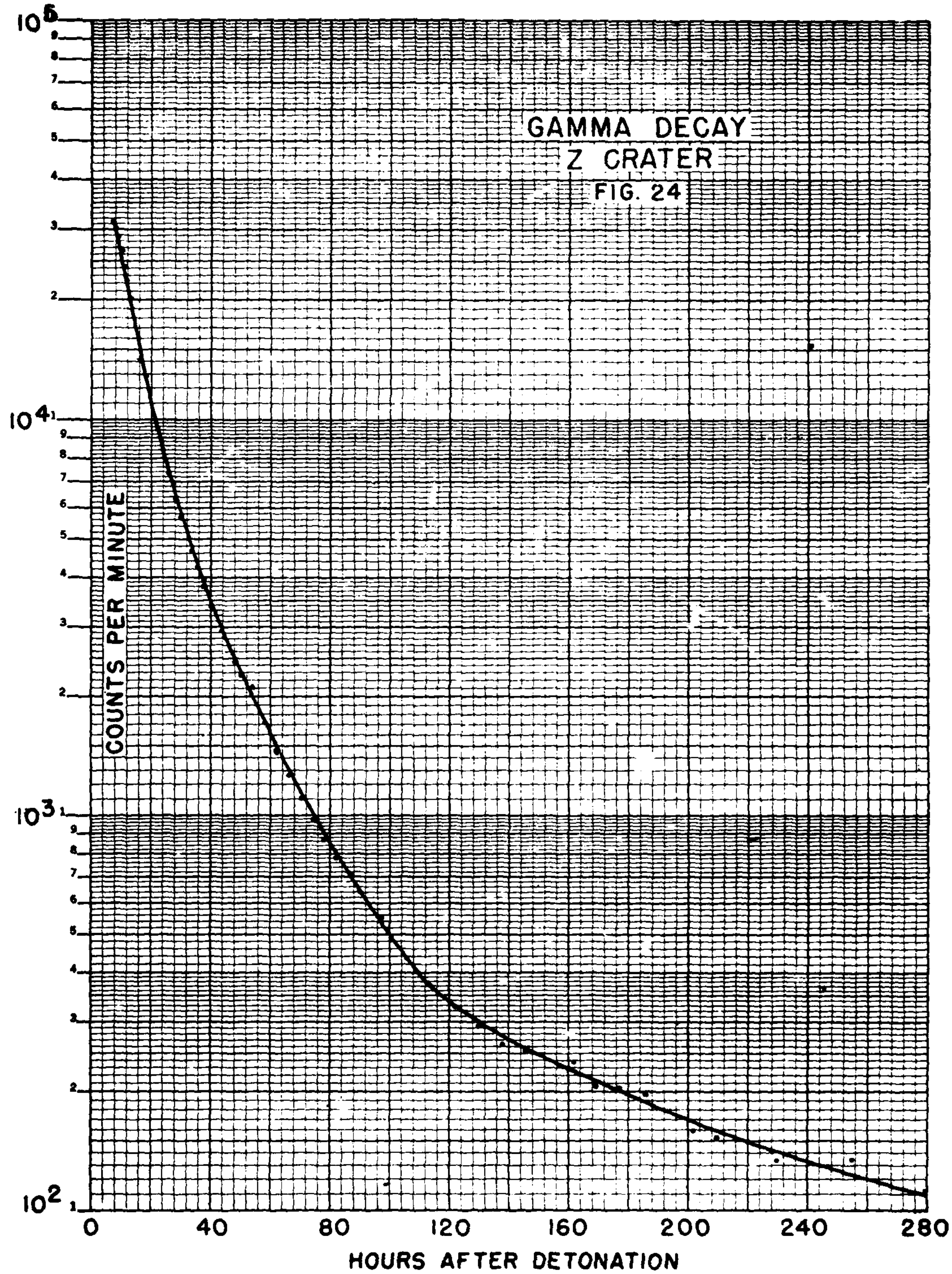


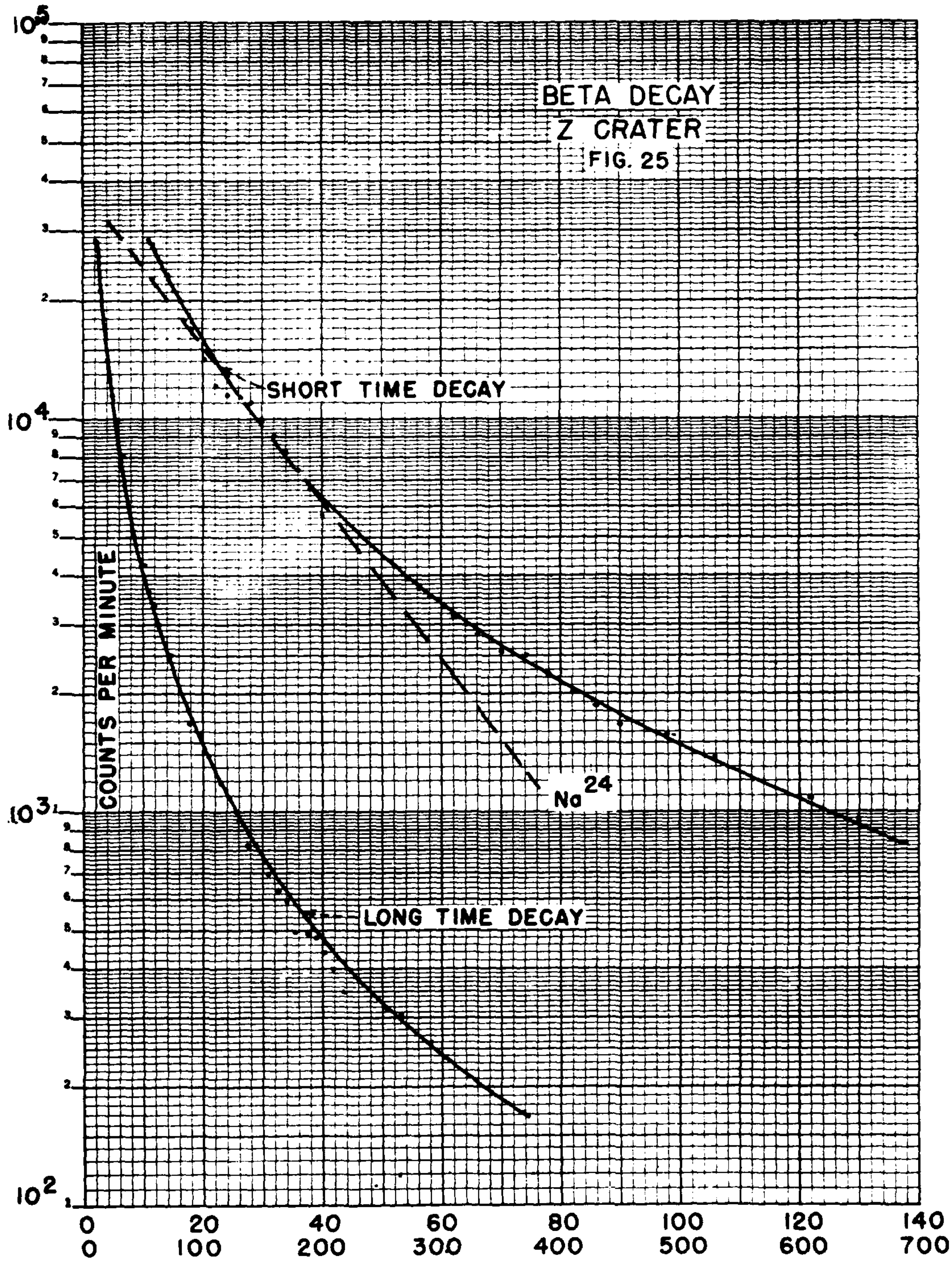
BETA DECAY
YOKE CRATER
FIG. 21
$A = \frac{1}{T^{1.63}}$
COUNTS PER MINUTE
HOURS AFTER DETONATION
10^5
10^4
10^3
10^2
0
10
100
1000

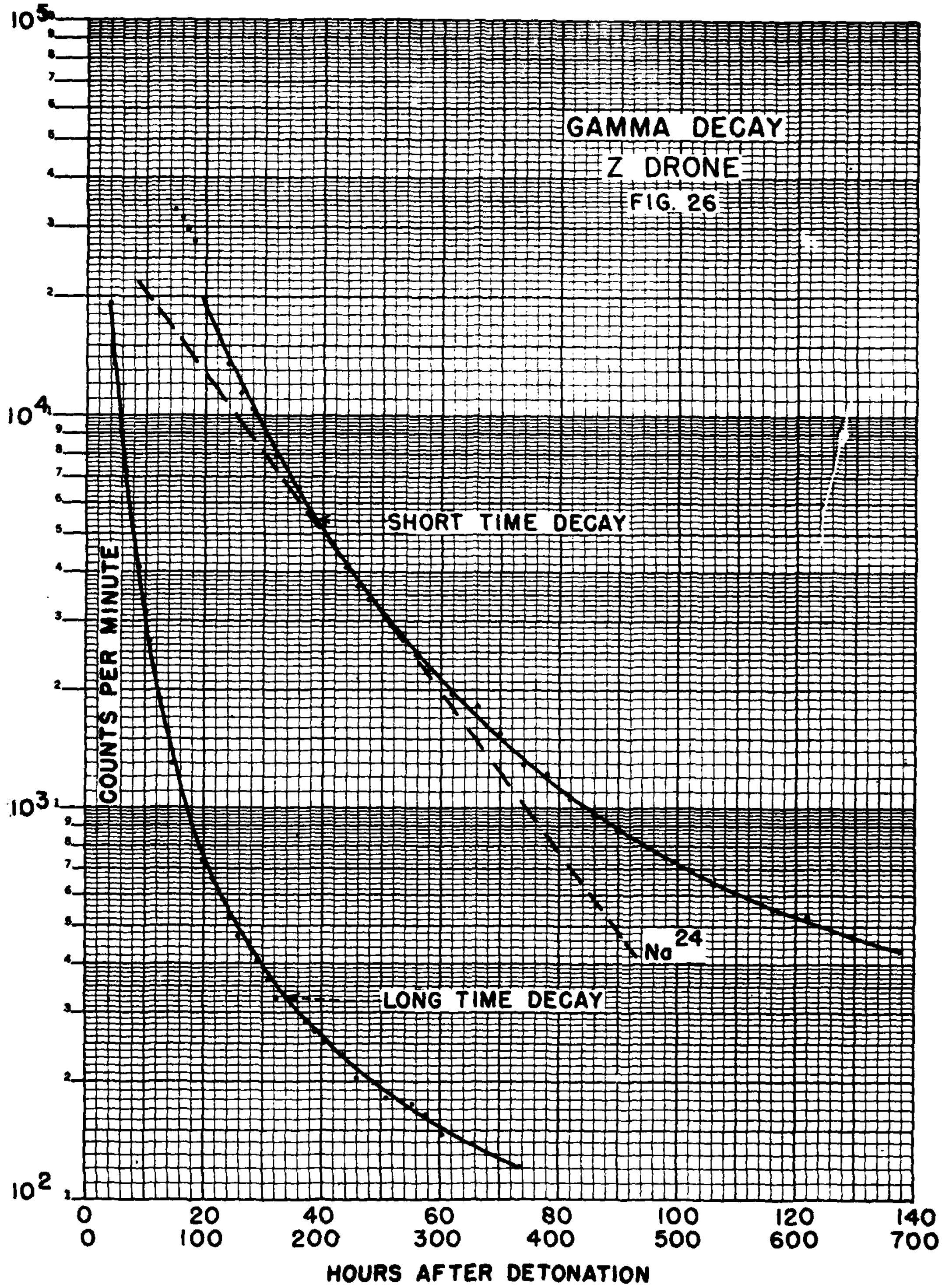


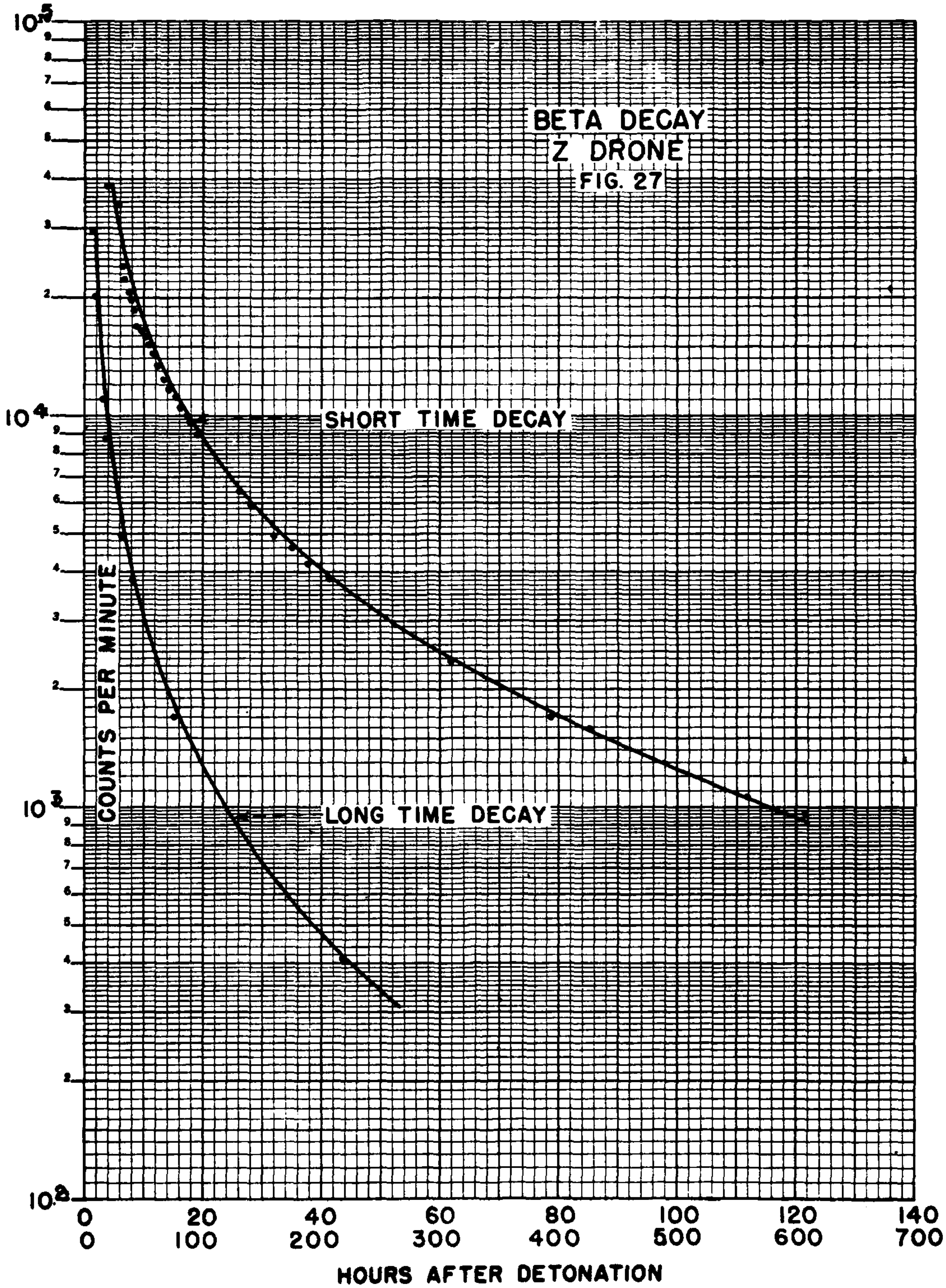
GAMMA DECAY
YOKE DRONE
FIG. 22
$A = \frac{1}{t^2}$
COUNTS PER MINUTE
10^5
10^4
10^3
10^2
0
10
100
1000
HOURS AFTER DETONATION

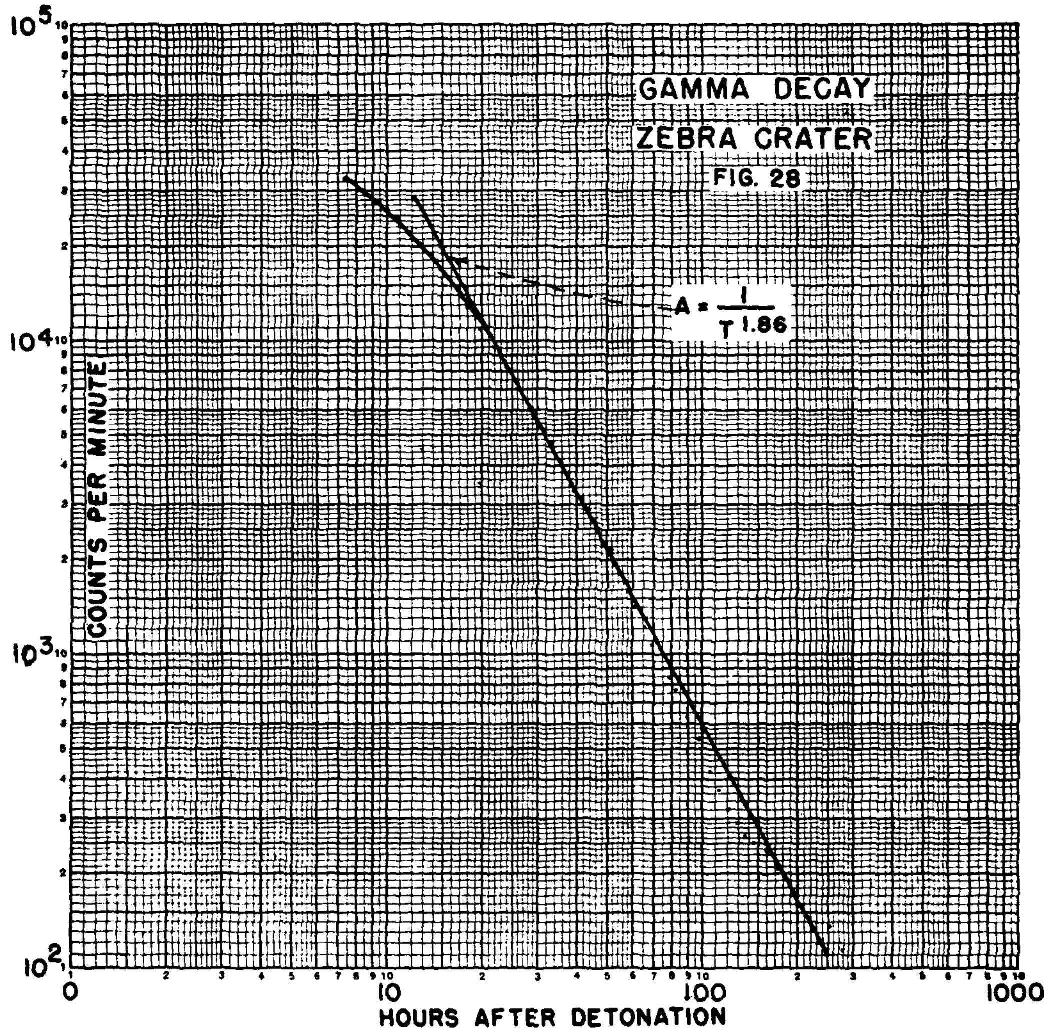

BETA DECAY
YOKE DRONE
FIG. 23
$A = \frac{1}{T^{1.01}}$
COUNTS PER MINUTE
10^5
10^4
10^3
10^2
0
10
100
1000
HOURS AFTER DETONATION

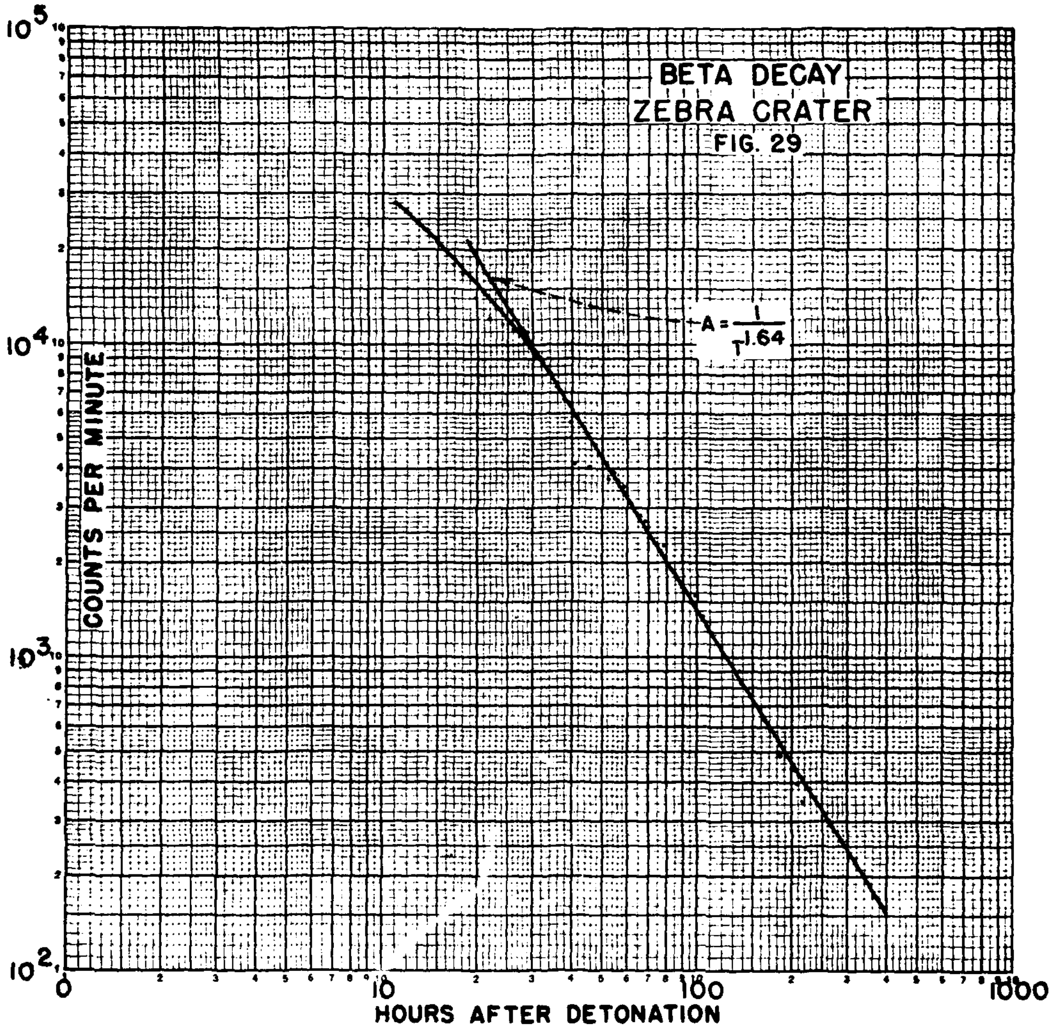

GAMMA DECAY
Z CRATER
FIG. 24
COUNTS PER MINUTE
10^5
10^4
10^3
10^2
0
40
80
120
160
200
240
280
HOURS AFTER DETONATION

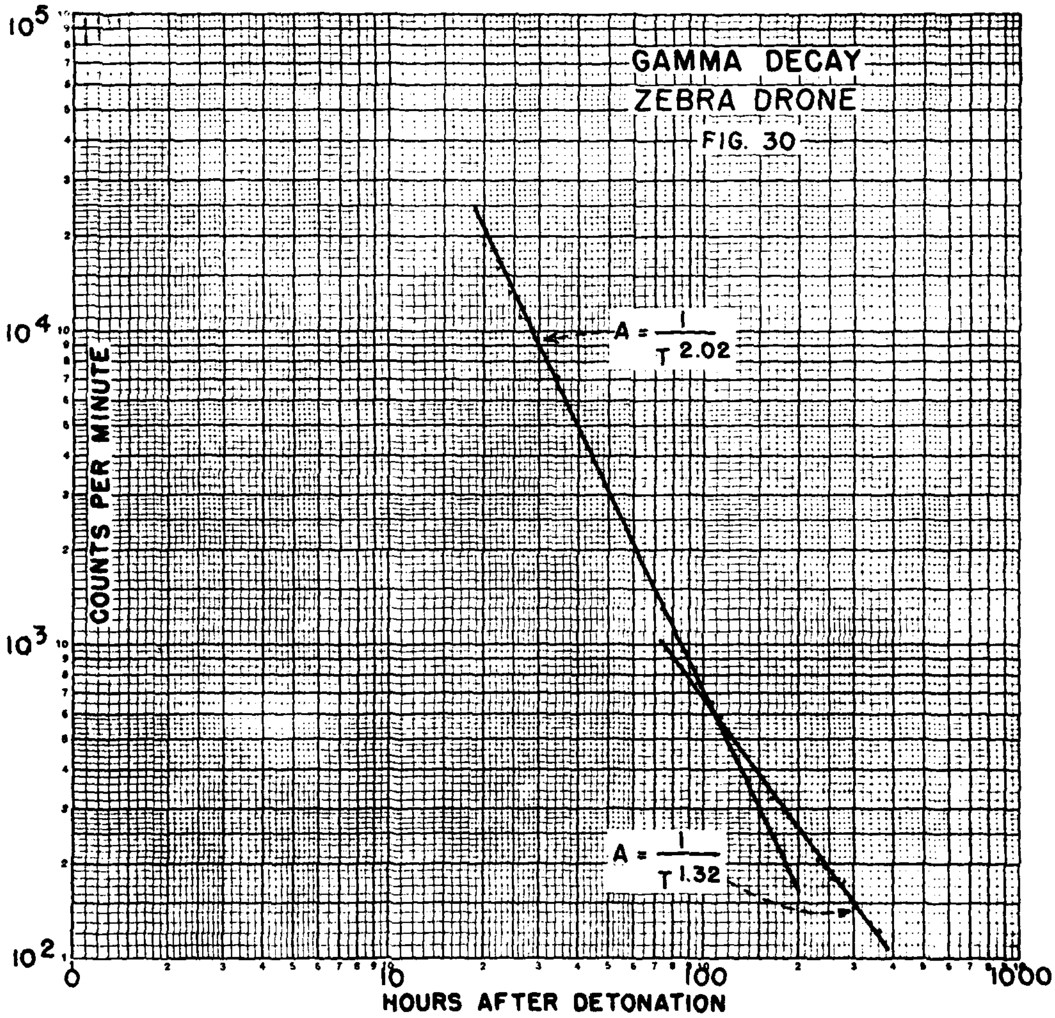

BETA DECAY
Z CRATER
FIG. 25
SHORT TIME DECAY
Na^{24}
LONG TIME DECAY
COUNTS PER MINUTE
10^5
10^4
10^3
10^2
0 20 40 60 80 100 120 140
0 100 200 300 400 500 600 700
HOURS AFTER DETONATION

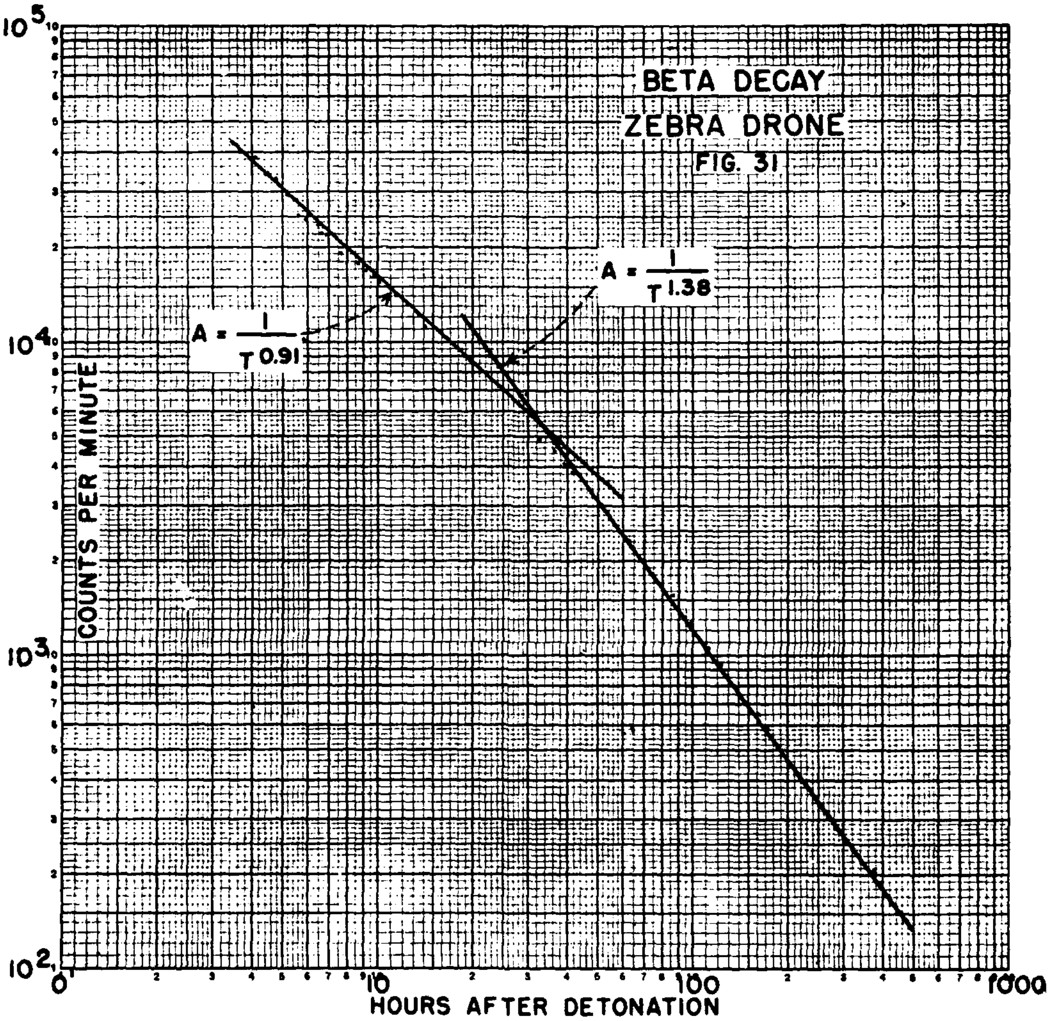

GAMMA DECAY
Z DRONE
FIG. 26
SHORT TIME DECAY
LONG TIME DECAY
Na 24
COUNTS PER MINUTE
10^5
10^4
10^3
10^2
0 20 40 60 80 100 120 140
0 100 200 300 400 500 600 700
HOURS AFTER DETONATION


BETA DECAY
Z DRONE
FIG. 27
SHORT TIME DECAY
LONG TIME DECAY
COUNTS PER MINUTE
HOURS AFTER DETONATION
10^5
10^4
10^3
10^2
0 20 40 60 80 100 120 140
0 100 200 300 400 500 600 700


GAMMA DECAY
ZEBRA CRATER
FIG. 28
A = 1/T^1.86
COUNTS PER MINUTE
HOURS AFTER DETONATION
10^5
10^4
10^3
10^2
0
10
100
1000


BETA DECAY
ZEBRA CRATER
FIG. 29
$A = \frac{1}{T^{1.64}}$
COUNTS PER MINUTE
HOURS AFTER DETONATION
10^5
10^4
10^3
10^2
0
10
100
1000


GAMMA DECAY
ZEBRA DRONE
FIG. 30
$A = \frac{1}{T^{2.02}}$
$A = \frac{1}{T^{1.32}}$
COUNTS PER MINUTE
10^5
10^4
10^3
10^2
0
10
100
1000
HOURS AFTER DETONATION


BETA DECAY
ZEBRA DRONE
FIG. 31
A = 1 / T 1.38
A = 1 / T 0.91
COUNTS PER MINUTE
HOURS AFTER DETONATION
10^5
10^4
10^3
10^2
1
10
100
1000

SCIENTIFIC DIRECTOR'S REPORT

OF ATOMIC WEAPON TESTS

AT ENIWETOK, 1948

Annex 9

CONTAMINATION STUDIES

Part II

AIR SURVEY OF GROUND CONTAMINATION

[redacted]

Task Group 7.6 - Project Report

C-47 Radiological Reconnaissance Survey

AIR SURVEY OF GROUND CONTAMINATION

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OPERATION SANDSTONE

by

LCDR E. R. KING, (MC) USN

Project Officer

30 June 1948

Project 7.1-17/RS(BA)-4

[redacted]

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

ABSTRACT

Air radiological surveys were conducted with a C-47 airplane on eight occasions during the three atomic weapons' tests at OPERATION SANDSTONE. A single survey at low altitudes was also conducted with a Type HO3S helicopter following the third test. These surveys provided information which could be used to estimate intensities of surface contamination and to measure the extent of the radiation field above the crater. It was observed that the radiation at 1,000 feet was approximately 1/120 of the average intensity in the crater itself. Crater activities estimated by means of this factor and an average intensity measured at 1,000 feet might have been in error by as much as a factor of two. The maximum altitude at which radiation could be detected a few hours after each test was 7,000 feet. The results obtained from these surveys are considered to be of sufficient accuracy to warrant continued analysis. Preliminary work has indicated that the crater acts as a point source for altitudes greater than 1,000 to 2,000 feet. Various types of existing field survey instruments were tested and a number of improvements are recommended. The over-all results of the project indicate that the aerial survey shows promise as a possible method of measuring the approximate extent of a contaminated area in the event of atomic warfare.

OBJECTIVE

The objective of this project is threefold: (1) to provide an aerial reconnaissance survey for the determination of intensities of gamma radiations within the blast area without exposing personnel to harmful intensities of radiations such as would be encountered in surface operations; (2) to accumulate data for confirmation of theoretical calculations regarding the attenuation of gamma radiation above large land and sea area sources; and (3) to test instruments which would be practical for use in aerial surveys of contaminated areas in the event of atomic warfare.

HISTORICAL

The first aerial survey of a land area exposed to an atomic bomb explosion was made at the Trinity site approximately one year after that test had been conducted. This survey was made in a small single engine airplane. The delay from the date of the test to the date of the survey somewhat limited its practical value, but it pointed out the possibilities of this type of operation (1)*. Activity at altitudes as high as 1000 feet was measured in the Trinity air survey.

At Bikini aerial radiological surveys at altitudes up to 4000 feet were made with PBM type aircraft after each test. Accuracy of the results of this survey was hampered by the types of instruments used, by the inability to locate quickly the position at which a reading was made, and by shifting lagoon currents which constantly changed the radiation intensity of specific areas of the contaminated water. No surveys of contaminated land areas were made at Bikini. Nevertheless, the tests at Bikini proved that it was possible to obtain reasonably reproducible values for the decrease in radiation field with altitude (2).

Hirschfelder, Hull, and Magee have made a number of theoretical calculations of attenuation of gamma radiation in air above an infinite contaminated land or sea source. Their studies involved gamma radiations of a number of different energies and took into account multiple scattering. The experimental data from the aerial surveys following test Baker at Bikini gave values in agreement with those

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* Numbers in parentheses indicate references on page 40 of this report.

calculated for three million electron volts (3 Mev) gamma radiation. A number of uncertainties still exist in these calculations and further experimental confirmation is required.

EXPERIMENTAL

The present project was proposed by the U. S. Navy, Bureau of Aeronautics and endorsed by the Armed Forces Special Weapons Project and the U. S. Air Force. It was approved by the Scientific Director of OPERATION SANDSTONE and assigned to the cognizance of Task Group 7.6.

MATERIALS AND EQUIPMENT

All available types of portable radiac instruments for use in the aerial survey were flight tested to determine their adequacy for this purpose. The following types were given particular study:

a. National Technical Laboratories, Geiger Counter Model MX-5.

b. Victoreen Instrument Company, Ionization Chamber Model 247-A-Sp (high range).

c. National Technical Laboratories, Ionization Chamber Model MX-6.

The aerial survey of ground contamination was made in a C-47 type airplane furnished by Commander, Task Group 7.4. The C-47 was checked prior to each test. A desk was installed with a sunken compartment to hold the radiation detection instruments. Special lights were available; a red light with the switch in the navigator's compartment to indicate the exact time over the point zero, and a green light operated from the copilot's seat which registered the time on a particular flight leg. Headphone and microphone leads were available for use by the Radiological Safety officer.

Film badges were worn by each member of the crew on each mission and dosimeters were carried on the plane.

CALIBRATION PROCEDURES

All instruments were calibrated on the ground and in the air with a radium source prior to their use in the aerial radiological survey. Measurements were made of the time constant of the various instruments.

DECAY

All readings were corrected for decay as follows: The X-ray crater readings were corrected to X-ray hour plus 1, the Yoke crater readings corrected to Yoke hour plus 6, and the Zebra crater readings corrected to Zebra hour plus 2. The variance in the corrections was due to different times in which the test day missions were started, all corrections being made to the approximate hour of starting each mission. The decay correction curves were obtained as a part of Project 7.1-17/RS-3, Residual Contamination of Crater (3), in which decay curves were measured for actual samples obtained from each crater. These curves were converted into correction factor curves; whereby the decay factor for any time may be obtained and multiplied by the reading to give a figure corrected for decay. Please see Appendix 1, Figure 23; Appendix 2, Figure 19; and Appendix 3, Figure 14. All graphs and charts shown use radiation intensities which have been corrected for decay with the exception of those for the Gross Section Radiation Field which use actual readings.

SURFACE MEASUREMENTS

On many of the graphs, ground areas and rates of radiation measured on the surface have been inserted. These are for direct correlation with the air readings and are also corrected for decay. At various points throughout the report, references have been made to the different craters and to crater readings. The crater is defined as the area around the point of detonation which is directly contaminated by the bomb explosion. It does not include the areas contaminated by material falling from the cloud. This area may extend 1000 feet or more from the initial position of the zero point.

Surface monitors, in measuring the crater areas on succeeding days, discovered that the intensities increased rapidly to a certain distance and then leveled off for a varying distance. Within a few inches of the tower stumps, or the ground between them, the radiation rate increased tremendously. For this reason, an average of the "plateau" of radiation which ranged from 100 to 1000 feet from the tower stumps (depending on the particular crater) was taken as the crater reading for this report. It is quite apparent that the very high intensities recorded within inches of the stumps, or cement blocks, or the ground between them could not be detected in the air in the presence of the radiation from the large contaminated area.

OPERATIONS

The survey was to provide rapid information on intensities of nuclear radiations within the blast area and to accumulate precise scientific data in regard to the attenuation of gamma radiation above land and sea surfaces contaminated by atomic bomb explosions.

For these operations the crew consisted of a pilot, copilot, navigator, radioman, and engineer. In addition to their regular duties, the following special tasks were assigned to crew members. The pilot studied and practiced the rather intricate flight pattern necessary for such an operation with the assistance of the copilot who timed each leg and cross leg with a stop watch. The copilot also notified the Radiological Safety officer the time each leg was started and completed by means of the specially installed green light, and kept a running log of the times of each leg, and the time over the point zero. The navigator computed the headings, true course, air speed, ground speed, and time over point zero of the different legs. He also checked the instant the plane passed over point zero in his driftmeter, and notified the Radiological Safety officer of this time by means of the specially installed red light. During the Phase 3 operations, he charted the course of the aircraft with the times over the strategic areas, using the plot as a fall-out chart. The radioman handled the radio traffic necessary for a special mission and in addition, on the test days, transcribed the coded messages given him by the Radiological Safety officer after each leg. The engineer assisted the Radiological Safety officer in his functions, and copied on prepared forms all readings taken by the monitor.

The crew of the C-47 aircraft were at Eniwetok on Peter (practice), X-ray, Yoke, and Zebra days by H-hour. After H-hour, the crew was prepared to take off immediately in case the cloud should drift across the island. The survey unit took off on the mission at H-hour plus thirty minutes and at 5000 feet altitude, orbited at a point five miles upwind from point zero until directed by Commander, Air Force, to proceed with the flight plan as outlined in the following paragraphs.

The survey plan consisted of three phases as follows:

Phase 1

When directed by Commander, Air Force, the C-47 commenced horizontal survey at 5000 feet. First leg was over point zero on a bearing determined so as to avoid any downwind contaminated air mass. All legs were made at a constant air speed and along a constant bearing for three miles on either side of point zero. The plane then turned and made another leg at an angle of 045° from the original leg. This maneuver was continued until a complete asterisk pattern with legs at an angle of 45° had been made. (In operations over the Yoke and Zebra craters only three legs were flown at 120° angle to each other.) After completing this horizontal flight pattern, the same pattern was flown at 4000 feet, 3000 feet, 2000 feet, 1000 feet, and lower if radiological safety conditions permitted.

Phase 2

After completion of Phase 3, the survey unit retired from the contaminated area and requested permission to survey above 5000 feet. When approval was received, the survey unit flew a six-mile leg at 6000 feet along the same axis as the first leg in Phase 1. The second leg was flown at 7000 feet on an axis 180° to the first leg. The unit was prepared to ascend by 1000-feet intervals on each reversal until normal background was reached.

Phase 3

Phase 3 was inserted primarily for radiological safety purposes in OPERATION SANDSTONE after the original plans had been submitted. This survey was flown after Phase 1, and is the fall-out survey. (Appendix 1, Figure 31; Appendix 2, Figure 27; Appendix 3, Figure 20.) Here the aircraft flew downwind from the crater for a distance of eight or ten miles and returned by four-mile cross legs spaced at a distance of two miles. This survey was to check areas possibly contaminated by fall-out from the cloud.

The survey unit was prepared to repeat the afore-mentioned flight on succeeding days if deemed necessary. When needed for radiological safety purposes, the air survey of ground contamination was continued in a helicopter, Type HO3S. The general plan for this survey was vertical flights over radioactive areas, taking readings of the radiation intensity at various altitudes. These aerial readings were to be integrated with surface readings made by ground monitors directly beneath the helicopter unit. The helicopter survey was not conducted until the ground radiation intensity was low enough to permit ground monitoring.

RESULTS

During the three tests the C-47 Aerial Radiological Reconnaissance Survey was flown on eight different days; three days over Engebi and Aoman (X-ray and Yoke Islands); and twice over Runit (Zebra Island). The particular days flown were X-ray, X-ray plus 6, Yoke, Yoke plus 1, Yoke plus 9, Zebra, and Zebra plus 1. The aerial survey was flown in a helicopter (Type HO3S) on Zebra plus 4.

In completing these surveys, two hundred and eight runs were made over the three craters, and three fall-out surveys were performed at a low altitude. The total time flown in actual radiological reconnaissance for all three tests was twenty-five hours.

Several complicating factors were encountered, especially on the first test. Slight to moderate contamination of the aircraft due to unexpected fall-out occurred following Tests X-ray and Yoke. Consequently, for Test Zebra, the time of the survey was set back to H plus two hours, instead of H plus one hour. The ion chambers used became badly saturated over 3000 milliroentgen per hour on X-ray day. This was corrected by the Instrument Group after experimentation by increasing circuit voltage. It was also found on Test X-ray that altitudes under 1000 feet should be flown in order to obtain data for an accurate estimate of the crater intensity. Consequently, altitudes were decreased to the point where the intensity was the maximum which could be measured by the available instruments. (The maximum intensity which could be recorded by the instruments used was 25,000 mr/hr.)

The results of the missions were most satisfactory. A tremendous amount of data were obtained and an analysis made for this report of as much as time permitted. It is recommended that further careful study be made of this material. The missions proved useful from the standpoint of radiological safety in that readings of high intensity areas could be taken, thus advising surface monitors of such areas. The fall-out survey proved practical in giving the surface monitors information on areas of high contamination. Ten types of instruments were tested during the surveys.

The primary objective of the mission, that of measuring the attenuation of gamma radiation in the air above a large contaminated surface, was accomplished; but the analysis is not yet completed and it is felt that much information was obtained which will further the study of this work. A study by Dr. T. N. White on the correlation of ground and air readings is included as Appendix 5.

There is also a series of graphs made from the results of each test by which a relatively good estimate of ground readings may be made from aerial surveys. One point of interest is that the same general curve exists for obtaining the correction factor used to determine ground intensities from aerial readings for all surveys made over the X-ray and Yoke craters. See Figure 1, page 34.

TEST X-RAY

The C-47 with crew took off from Eniwetok Island at plus 30 minutes and arrived ten miles upwind of point zero at plus 50 minutes, where it orbited awaiting further instructions. At plus 69 minutes, orders were received to proceed on the mission.

In approximately one minute the Radiological Safety monitor noticed an instantaneous reading of 120 mr/hr. He ordered the pilot to change course, and the navigator reported the plane under the uppermost fringe of the cloud. Although the plane was not in the fall-out area, it was apparent it had encountered some fall-out from the upper portions of the cloud which had moved in a direction 180° to the surface winds. The plane was moderately contaminated and the background remained at approximately 8 mr/hr for approximately one hour, decreasing to 1 mr/hr upon landing. This background reading was for gamma only, there being no beta encountered inside the plane. This background was subtracted from subsequent readings.

Phase 1 was then started at 0738 at an elevation of 5000 feet. Readings of 4 mr/hr were encountered at this level. The pattern was also flown at elevations of 4000, 3000, 2000, and 1000 feet. The highest rate of radiation of 3500 mr/hr was encountered at the 1000-foot elevation. This value when corrected for instrument error would give a reading of 8700 mr/hr. A discussion of this instrument error will be found on page 18 of this report.

As stated previously, an additional survey, the fall-out survey, or Phase 3, was added a few days before the first test. This mission consisted of flying directly downwind from the test island for a distance of eight miles and returning by cross legs of four-mile lengths with two-mile intervals between. The flight was made at an altitude of 200 feet with a constant air speed of 140 knots. Readings of 500 mr/hr were detected over the islands of Bogon, Bogairikk, and Teiteiripucchi which were directly west of Engebi (Zero Island) and were in the expected fall-out area. Lower readings were detected throughout the area, particularly over reefs and smaller islands.

Phase 2 was then started the first leg being at 5000 feet and other legs at 6000 feet, 7000 feet, and 8000 feet. The highest altitude flown where radiation was encountered was 8000 feet at plus four and one-half hours. This reading (0.1 mr/hr) is somewhat doubtful due to the high background in the aircraft. However, a definite rise above background was encountered at 7000 feet.

It had been anticipated that following Test X-ray some changes in the operation plan would have to be made. Such changes were found necessary and were instituted as soon as practicable.

Three complicating factors presented themselves on X-ray day. These were all corrected prior to the last mission. Before the actual survey was started, the airplane had been contaminated by fall-out, although there was none anticipated from the cloud at the height it was encountered. Consequently it was decided to stay out from under the cloud, no matter what its altitude, and if necessary to delay the beginning of the mission one hour. The latter was actually done for the Test Zebra day flight.

At the 1000-foot level on X-ray day, and the lower levels on X-ray plus one, the instruments appeared sluggish in high intensity flights. Following the X-ray plus one flight, the ion chambers were returned to the ship and recalibrated. It was found that the MX-6 type instrument was saturating on the 500 and 5000 mr/hr scales. This was especially true of readings over 3000 mr/hr. The instrument was found to read only 5000 mr/hr in a radiation field of 21,000 mr/hr. The instruments were calibrated using a large radium source, and all readings taken on the first two days were corrected for calibration.

Other instruments were obtained which had a higher voltage supply and were direct reading. These instruments were used for the remainder of the operation and were checked after each mission for calibration and functioning.

It was determined after the X-ray day flight that it would be necessary to fly at a lower level to obtain the proper curves and to extrapolate with sufficient accuracy the maximum reading versus altitude curve to ground level. On X-ray plus one, altitudes of 750 and 500 feet were flown and, while the resultant curves were better, it was decided that even lower levels should be tried. The intensity of the crater had decreased enough by X-ray plus six that flights at 250 and 100 feet were added to the Phase 1 plan. Readings of 800 mr/hr were recorded at the lower level.

Ground monitors were in the crater at this time, and their average reading was found to be 1800 mr/hr which reading was also determined approximately by extrapolation of the curve of maximum readings as a function of the altitude. On later missions, the altitude was decreased until the maximum limit of the instruments used was reached.

TEST YOKE

The C-47 with crew took off from Eniwetok Island at plus 31 minutes, and at plus 64 minutes was ordered to start on its survey. It had been orbiting ten miles upwind from Zero Island (Aoman) and the cloud was plainly visible and easily observed. This cloud, unlike the one over Engebi which conformed to the expected pattern, was spread out over a tremendous area at a much lower level. It was anticipated that certain legs of the survey could not be completed because of the close proximity of a portion of the cloud. At the turn between legs one and two, at the 5000-foot level, the cloud appeared very near; and although the course was changed, fall-out was contacted. The reading inside the aircraft rose to 150 mr/hr, but unlike the Test X-ray contamination, did not drop as rapidly and persisted at a relatively high level for some time. Several rain clouds were flown through; but when it became apparent that the background inside the plane was too high to make accurate measurements, the airplane was ordered to return to Eniwetok. Here the plane was monitored and allowed to sit and "cool off". Readings taken inside the plane were as follows:

Time		Reading mr/hr
0725	Fall-out encountered	150
0728	Aborting mission	48
0730		44
0731	Flying through rain clouds	44
0740	Flying through rain clouds	35
0756	Over base	30
0756	Over base	28
0805	Landed	25
0820	On Eniwetok	20
0857	On Eniwetok	18
1015	On Eniwetok	11
1232	On Eniwetok	6
1310	Take-off for resumption of mission	4

As indicated, the decay rate was rapid, and the plane took off under instructions at 1310 the same day. After a short time the background in the plane had dropped to 3 mr/hr, and it gradually dropped during the remainder of the mission.

In certain respects the mission was flown the afternoon of Yoke day more successfully than it could have been flown at plus one hour. For one thing, no cloud was present to disrupt the mission and there were no other airplanes in the vicinity, except two helicopters at very low altitude. The crater had decayed enough that it was possible to descend to 600 feet to make a survey and stay within the maximum limits of the instruments. On this occasion it was pointed out again how valuable it would have been to have an instrument that would measure higher intensities than 25,000 mr/hr. At 600 feet the highest intensity recorded was 21,000 mr/hr. One pass had been made at 500 feet, and the 247-A-Sp went off scale.

Following Phase 1, Phase 3 was carried out as planned. This survey was at 200 feet altitude and 140 knots constant air speed. It was found that fall-out had occurred on all islands north and west of Aoman, to and including Engebi (X-ray Island). Intensities as high as 6000 mr/hr were measured over the island adjacent to Aoman (northwest), Eberiru, and levels of 100 mr/hr or more were recorded over the other islands, including Engebi.

Because of the delayed mission on Yoke day, the reading at the 5000-foot level was negligible, and Phase 2 was not necessary.

As will be noted in the graphs and charts, only three legs were flown on Yoke day and on succeeding days. It had been decided following X-ray day that lower altitude flights were needed; so in order to compensate to some extent for the added dosage of radiation this would necessitate, three legs at each altitude were used instead of the original plan of four. These legs were to be 120° apart with the first leg always along the long axis of the island, unless fall-out or some other factor necessitated a change. The altitudes planned were as previously described, but also included flights at 1500, 750, and 500 feet. On later days it was possible to go even lower.

On Yoke plus 1 day the mission was repeated. The highest altitude where appreciable radiation was detected was at 3000 feet. The reading here averaged 31.3 mr/hr. The lowest level flown was 250 feet where an intensity of 25,000 mr/hr was recorded.

On Yoke plus 9 day the mission was repeated, and at the same time a survey party measured intensities in the crater itself. Thus it was again possible to correlate directly ground readings with air readings. The lowest intensity recorded on this day was at 50 feet where the reading was 600 mr/hr. This corrected for decay gave 120,000 mr/hr, and the curve of maximum readings as a function of altitude when extrapolated out came to approximately 260,000 mr/hr which was very near the average corrected ground reading for the crater outside the tower stumps.

Despite the contamination of the C-47 on Yoke day, it is felt that the results of the Yoke crater readings were satisfactory, more so than the X-ray crater readings. This will be discussed more in the next section of the report.

TEST ZEBRA

Prior to Test Zebra it had been decided that if the cloud appeared to be lingering in the area, the survey would be postponed until H plus 2 hours. It was also planned to do Phase 2 first, starting at 10,000 feet and working down, in order to determine accurately just how high the gamma rays could be detected.

The C-47 and crew took off from Eniwetok at plus 30 minutes, as on the previous tests, and reached its orbiting point ten miles upwind of Zero Island (Runit) in ten minutes. It orbited here until plus 118 minutes at 10,000 feet when it was ordered to start its mission. The cloud was not encountered.

No radiation was detected at altitudes above 7000 feet, at which altitude the instrument showed about twice background for the entire length of the leg. At 6000 feet a reading of 1 mr/hr was obtained. The survey was continued until a level of 400 feet was reached where the rate recorded was 21,000 mr/hr. It was not deemed necessary to go lower than this altitude as there were no instruments available that would measure that high rate.

Following Phase 2 and Phase 1, the fall-out survey was started. As on the previous tests, the islands upwind of the Zero Island were contaminated by fall-out, with Piiraai showing an intensity of 400 mr/hr, Biijiri and Rojoa 800 mr/hr, and islands north of Aoman having higher readings than they had just before Zebra day. The mission on Zebra day was carried out uneventfully, and it was felt the results here should be better than those obtained from any previous mission. However, the rapidity with which the operation was being terminated precluded the possibility of additional flights at a later date during which intensity measurements were made of the crater at point zero by ground monitors. In general, this detracted from the value of the survey as it is necessary to have a ground reading of the crater taken at the same time for checking with the extrapolated readings from the aerial survey.

On Zero plus one day the mission was repeated, and a reading of 0.5 mr/hr was recorded at 5000 feet. The flights were continued at altitudes down to and including 150 feet where the reading was 20,700 mr/hr. One leg was attempted at 100 feet, but the 247-A-Sp went off scale at 25,000 mr/hr.

INSTRUMENT TESTS

After checking several types of instruments as to range, sensitivity, needle fluctuation, time constant, and altitude effects, certain ones were chosen for the first test with the understanding that they might be exchanged later if deemed necessary. Those chosen for the routine surveys were the MX-5 and MX-6 of the National Technical Laboratories and the 247-A-Sp produced by the Victoreen Company. The MX-5 employed a Geiger-Mueller tube in detection of radiation, while the MX-6 and 247-A-Sp used ion chambers. The MX-5 was set on the 20 scale (range up to 20 mr/hr) and the MX-6's were set on 50, 500, and 5000 scales (ranges up to 50 mr/hr, 500 mr/hr, and 5000 mr/hr respectively). The 247-A-Sp was set on the 1000 X scale (range up to 25,000 mr/hr). It later was necessary to use an MX-6 on the 5 scale (range up to 5 mr/hr) when the MX-5 started saturating. These instruments were fitted into the space in the deck especially designed to hold them. During the mission all instruments, except the MX-5, were left on during the entire flight. The MX-5 was turned off when its upper limit was reached, then turned on after point zero had been passed and intensities within the range of the instrument were again encountered. This was necessary as the Geiger counters were known to saturate when exposed to high intensities, while it was not believed the ion chambers would.

As to the performance of these particular instruments, it can be said that as a whole they were satisfactory. However, the MX-5 saturated badly on X-ray plus six, Yoke, and Yoke plus one, but after a new tube was installed it performed much better. The MX-6 saturated in high intensities and it was necessary to install more batteries. The 247-A-Sp appeared to be quite adequate. It had been calibrated several times with a large source and needed no resetting or calibration curve. As stated previously, after X-ray plus one, no curves were necessary for the MX-6's as they were direct reading.

The mechanical time constant was checked for all previously mentioned instruments, plus the 247-A and the 263-A Geiger counter. These values were determined by exposing the instruments to an X-ray machine which was switched on and off for an instant. Adequate radiation intensities were produced by regulating the amperage of the machine so all the instruments could be tested.

Results are as follows:

MX-6	0 seconds
MX-5	0.2 seconds
247-A-Sp	0.2 seconds
247-A	0.2 seconds
263	0.2 seconds

In addition to saturating with their standard power supply, the MX-6 was also affected by humidity toward the latter part of the operation. It was necessary to remove the instrument from the case several times during the last few weeks. During Zebra day and Zebra plus one, two of the MX-6 instruments used were rendered useless by moisture collecting in them.

As will be pointed out, extremely high intensities, higher than the range of instruments available for this operation, can be measured in a rapidly moving airplane. Consequently, if instruments with higher ranges were available, lower altitudes could be flown and test results would be more significant. In tests these surveys could be made by teams with no one group exceeding a tolerance dose.

On Yoke day plus nine, an additional monitor was carried who checked four instruments in addition to those used by the regular Radiological Safety officer. These instruments were: Victoreen 263-A Geiger counter, Victoreen 247-A ion chamber, Victoreen 247-A-Sp ion chamber, and the Instrument

Developing Laboratories 2610 Geiger counter. As a whole the instruments were satisfactory, although they all displayed more of a mechanical time constant than the MX-6. In higher intensities, all of the Geiger counters had a tendency to saturate. Of the instruments tested, the Victoreen 247-A appeared much more stable and performed best, although readings on this instrument were not as high as those recorded by the regular monitor. The instruments regularly used on the mission were tested on all scales and gave readings within expectancy.

It should be stated that for the most part instruments used in this survey were for low altitude flights, usually under 5000 feet. On two occasions flights were made at an altitude of 10,000 feet. The air monitoring section, Task Unit 7.6.1, altitude tested all their instruments, and the effect of altitude upon these instruments is discussed in the report of Task Unit 7.6.1. Prior to X-ray day, an MX-5, three MX-6, and one 247-A-Sp were calibrated at 1000 feet intervals from 1000 to 7000 feet. The instruments were also calibrated at ground level and curves for both altitude and ground readings were drawn. The variance between readings at 7000 feet and ground level were negligible. Consequently, readings taken were not corrected for altitude calibration.

DISCUSSION

As a result of this project a vast amount of data has been accumulated on the radiation field above the crater from an atomic bomb detonation. At this time it is only possible to make a very general analysis of these results, but it is planned to initiate continuing studies with a view to obtaining a better understanding of the phenomena involved. The detailed data obtained for X-ray, Yoke, and Zebra are included as Appendices 1, 2, and 3 respectively. For the purposes of this discussion the analysis has been broken down into the following categories:

Maximum Intensity At Each Altitude

The maximum intensity was measured for each traverse of the crater, and the average of these for all legs at a given altitude was taken to be the maximum intensity at that altitude. The detailed data for the various tests are presented in Figures 1 through 3 of Appendices 1 and 2 and Figures 1 and 2 of Appendix 3. The maximum intensity at each altitude has been plotted as a function of altitude in Figures 8 through 10 of Appendix 1, 7 through 9 of Appendix 2, and 6 and 7 of Appendix 3. The data were exceedingly reproducible for the maximum for the several legs at a given altitude and the variation with altitude followed a relatively smooth curve. The one possible exception is the X-ray plus six day survey on which the lower intensity readings were measured with an MX-5 type instrument which was saturating badly. Extrapolation to the ground level was attempted, and on two occasions ground measurements were actually made on the same day as the survey was flown. The extrapolated value obtained from the aerial survey agreed very closely with the values obtained by the ground monitors.

In order to apply these results obtained by means of the aerial survey to operational conditions, it is necessary to have a set of factors by which the air readings can be converted to the reading for the intensity on the ground. Such correction factors have been computed for all surveys made and the composite data plotted as a function of altitude in Figure 1 to this report. The curves for all surveys fall more or less along the same general line and therefore a final curve can be drawn which will be useful for all occasions. The factors obtained from such a curve should prove of considerable value in the event that prompt aerial survey would be required of a bombed area.

Boundaries Of The Radiation Field Above The Crater

The outer limits of the radiation field (this was selected as the 4 mr/hr line) have been plotted for each successive survey in Figures 4 through 7 of Appendix 1, 4 through 6 of Appendix 2, and 3 through 5 of Appendix 3. The boundaries for the separate legs provide a three dimensional picture of the volume within which the intensity was greater than 4 mr/hr. The pattern conforms in general to a large dome, and there was not much evidence of a decrease in the diameter at low altitudes. However, the surveys in general were carried out at relatively high altitudes, and it is quite understandable that this effect was not observed.

Following Test Zebra a very low altitude survey was made by means of a helicopter. This survey indicated that beyond 350 yards from the center of the crater the intensity increased with altitude up to 200 feet, while at 200 yards and closer the intensity increased as the ground was approached. Details of the survey are given in Appendix 4.

The presence of scattered areas of high activity in the periphery of the crater and on adjacent islands accounted to some extent for the irregularities in some of the boundaries of the radiation field. These highly active areas on the ground were also detected and measured by

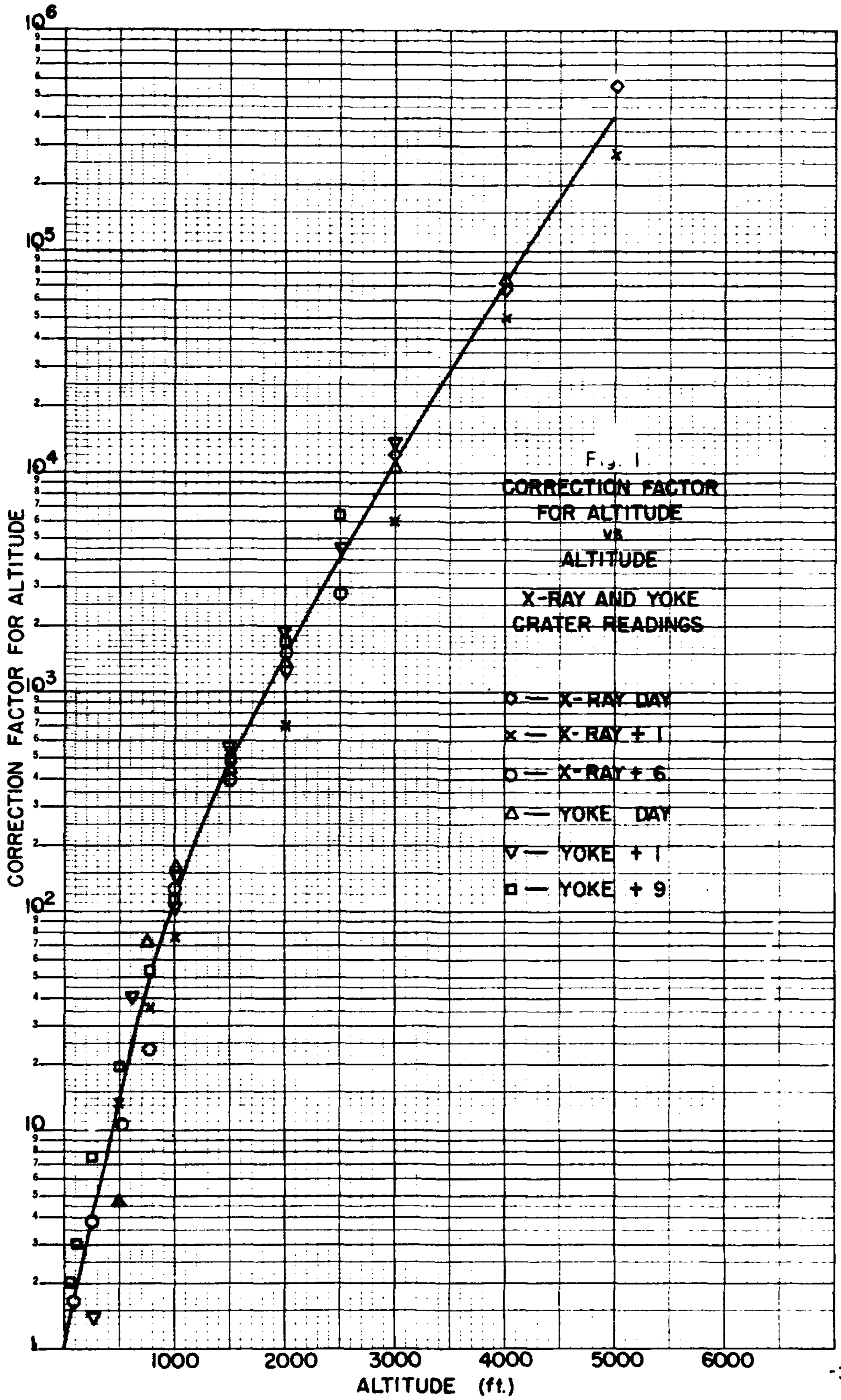


Fig. 1
CORRECTION FACTOR FOR ALTITUDE vs ALTITUDE
X-RAY AND YOKE CRATER READINGS
◇ — X-RAY DAY
× — X-RAY + 1
○ — X-RAY + 6
△ — YOKE DAY
▽ — YOKE + 1
□ — YOKE + 9
CORRECTION FACTOR FOR ALTITUDE
ALTITUDE (ft.)
1000
2000
3000
4000
5000
6000
1
10
10^2
10^3
10^4
10^5
10^6

ground monitors.

The highest altitude to which any radiation was detected was 8000 feet over Engebi at approximately H plus 4 hours and at 7000 feet over Runit at H plus 2 hours.

Intensity Of Radiation Field Above Crater

In Figures 11 through 22 of Appendix 1, 10 through 18 of Appendix 2, and 8 through 13 of Appendix 3, the intensity as measured on each leg has been plotted as a function of the distance from point zero. These figures demonstrate the extremely rapid rise and fall of the intensities encountered in flying over the crater. In general the fall is roughly symmetrical about the center, but on occasion contaminated downwind areas caused irregularities in the radiation field. The land mass areas have been inserted along the base line of the curves in order to explain some of these irregularities. However, it is to be noted that under most conditions this did not appreciably affect the distribution of the field, indicating that at least at the higher altitudes the crater acts as an approximate point source. It is to be noted that in the three test day surveys the base of the curves was considerably broader due to the higher intensities of radiation encountered.

Attenuation

In order to make a preliminary analysis of the factors involved in the attenuation of the gamma radiation as a function of altitude the intensity times the altitude squared was plotted as a function of altitude on semi-log paper. These plots and the basic data are included as Figures 24 through 27 of Appendix 1, 20 through 23 of Appendix 2, and 15 through 17 of Appendix 3. From these it will be seen that above an altitude of 1000 to 2000 feet the inverse square law is playing an important part in the decrease in intensity and that, therefore, at these altitudes the crater can be approximately treated as a point source. No attempt has yet been made to calculate the mean free path from the slope of these curves and to interpret the results. However, preliminary investigation reveals that these slopes are not too different for the various surveys. Below 1000 feet air absorption is playing the largest part in reducing the gamma radiation. Dr. White has attempted to correlate these results obtained by means of the aerial survey with those obtained from the ground survey, assuming that in both cases the crater could be considered as a radioactive source concentrated at some point. This analysis is presented in detail in Appendix 5.

Aerial Survey Of Fall-Out Areas

As Phase 3 of the aerial survey operations, passes were made at low altitudes over areas downwind of the crater. The results of these flights are shown in Figure 31 of Appendix 1, Figure 27 of Appendix 2, and Figure 20 of Appendix 3. These surveys indicated clearly which islands were contaminated and approximately to what extent. The results were confirmed when land parties went ashore and monitored the downwind islands.

CONCLUSIONS AND RECOMMENDATIONS

The results of the C-47 survey show that it is feasible to conduct an aerial reconnaissance of a bombed or contaminated area in order to determine the extent of the contaminated area and obtain a reasonably accurate estimate of the intensities involved. This type of survey would be invaluable in the event of atomic warfare since only by this method will it be possible to obtain a quick estimate of the radiological defense problems involved so that adequate planning can be undertaken without the delay required if ground monitors have to survey the area. With the present equipment it does not appear possible to detect by aerial methods the local "hot spots" within a contaminated area.

Aerial survey of a contaminated area appears sufficiently accurate to obtain data which can be used for detailed analysis of the radiation field produced. It is recommended that such analysis be undertaken with the present data and that similar operations be conducted in future tests.

Although the instruments used during the operation proved satisfactory, a number of improvements should be made in order that this type of survey can be adopted for operational use. They should be more adequately sealed in order to prevent damage by moisture and to protect against pressure changes. The time constant should be essentially zero and the instrument direct reading with a recording mechanism which would eliminate the errors due to the necessity of making rapid readings as the plane traverses the area. Since the plane itself may provide some shielding for the instruments, it is recommended that the counting tube or ion chamber be placed in a window in the deck of the plane. Instruments with a range of at least 100,000 mr/hr should be available for this work.

It is recommended that the development of this type of survey be given high priority so that it can be adopted as a standard operation in the event of atomic warfare.

REFERENCES

(1) "Trinity Air Survey" by Howard L. Walton, 17 April 1946, (Copy in Armed Forces Special Weapons Project files).

(2) "Nuclear Radiation Effects in Tests Able and Baker," Preliminary Report of, Series SLW/RS/-2 of 25 September 1946, Appendix III.

(3) "Residual Contamination of Crater," Project 7.1-17/RS-3, by CDR Howard L. Andrews, USPHS, 30 June 1948.

APPENDIX I

X-RAY CRATER CHARTS AND GRAPHS

CONTENTS

FIGURE I

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - X-RAY DAY

Altitude Feet	Leg	Reading	Plus Time (Minutes)	Decay Factor	Corrected Value (mr/hr) to H plus 1 hr
5000	1	4	83	1.35	5.2
	2	4	87.5	1.48	5.9
	3	[illegible]	92.5	1.55	4.6
	4	5	98.5	1.65	8.2
	Average	4	90.75	1.5	6.0
4000	1	24	110.5	1.8	43.2
	2	23	116.5	1.9	43.6
	3	25	121	2.0	50.0
	4	26	124.5	2.06	53.5
	Average	25	117.5	1.9	47.5
3000	1	140	140	2.33	326
	2	110	144.25	2.4	274
	3	95	148.25	2.48	236
	4	110	153.5	2.5	275
	Average	114	146.75	2.46	276
2000	1	800	186.5	3.05	2440
	2	700	196.5	3.25	2310
	3	600	206	3.4	2020
	4	800	215	3.58	2860
	Average	720	200	3.33	2400
1000	1	8600	229.5	3.80	32,620
	2	7600	236.5	3.95	29,850
	3	8000	242.0	4.02	32,200
	4	8000	248.5	4.12	33,000
	Average	8050	239.5	3.96	31,850

FIGURE 2

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - X-RAY PLUS 1

Altitude Feet		Leg	Reading	Plus Time (Hours)	Decay Factor	Corrected Value (mr/hr) to H Plus 1 hr
5000		1	0.4	26h37m	16.5	6.6
		2	0.8	26 42	16.6	13.2
		3	0.7	26 48	16.7	11.6
		4	0.8	26 53	16.8	13.4
	Average		0.7	26 40	16.6	11.6
4000		1	3	27h04m	17.0	51.0
		2	4	27 09	17.1	68.4
		3	5	27 15	17.2	86.0
		4	4	27 19	17.3	69.2
	Average		4	27 12	17.2	68.8
3000		1	32	27h29m	17.4	564
		2	35	27 35	17.5	624
		3	27	27 40	17.6	475
		4	31	27 45	17.7	548
	Average		31	27 37	17.6	546
2000		1	270	27h56m	17.9	4840
		2	240	28 02	18.0	4340
		3	270	28 08	18.1	4860
		4	240	28 13	18.2	4370
	Average		255	28 04	18.1	4630
1000		1	2500	28h22m	18.4	46,000
		2	2500	28 28	18.5	46,250
		3	2500	28 34	18.6	46,500
		4	2300	28 39	18.7	43,000
	Average		2450	28 30	18.5	45,250
750		1	5250	28h49m	18.7	98,000
		2	4600	28 55	18.9	87,200
		3	4600	29 05	19.0	87,500
		4	5000	29 07	19.1	95,500
	Average		4865	28 57	18.9	92,000

FIGURE 2

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - X-RAY PLUS 1
(Continued)

Altitude Feet		Leg	Reading	Plus Time (Hours)	Decay Factor	Corrected Value (mr/hr) to H Plus 1 hr
500		1	12,000	29h15m	19.3	230,000
		2	11,000	29 20	19.4	211,700
		3	13,500	29 26	19.4	261,000
		4	13,500	29 32	19.5	261,500
	Average		12,500	29 32	19.4	241,200

FIGURE 3

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - X-RAY PLUS 6

Altitude Feet		Leg	Reading	Plus Time (Days)	Decay Factor	Corrected Value (mr/hr) to H Plus 1 hr
3000		1	0.1	6.07	129	12.9
2500		1	0.5	6.09	129	64.5
		2	0.5	6.10		64.5
		3	0.5	6.10		64.5
	Average		0.5	6.10		64.5
2000		1	1.3	6.10	129	168
		2	1.3	6.10		168
		3	1.3	6.11		168
		4	1.4	6.11		181
	Average		1.32	6.11		172
1500		1	4	6.11	129	508
		2	2.2	6.11		284
		3	3.2	6.12		413
		4	3.6	6.12		465
	Average		3.25	6.12		421
1000		1	11.0	6.13	129	1420
		2	9.0	6.13		1160
		3	11.0	6.14		1420
		4	10.0	6.14		1290
	Average		10.2	6.14		1320
750		1	60	6.14	129	7750
		2	60	6.14		7750
		3	60	6.14		7750
		4	60	6.14		7750
	Average		60	6.14		7750

FIGURE 3

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - X-RAY PLUS 6
(Continued)

Altitude Feet		Leg	Reading	Plus Time (Days)	Decay Factor	Corrected Value (mr/hr) to H Plus 1 hr
500		1	120	6.15	129	15,500
		2	120	6.15		15,500
		3	150	6.15		19,400
		4	130	6.15		16,800
	Average		130	6.15		16,800
250		1	340	6.16	129	44,000
		2	410	6.16		53,000
		3	360	6.16		46,500
		4	350	6.16		45,000
	Average		340	6.16		44,100
100		1	800	6.17	129	101,000
		2	800	6.17		101,000
	Average		800	6.17		101,000

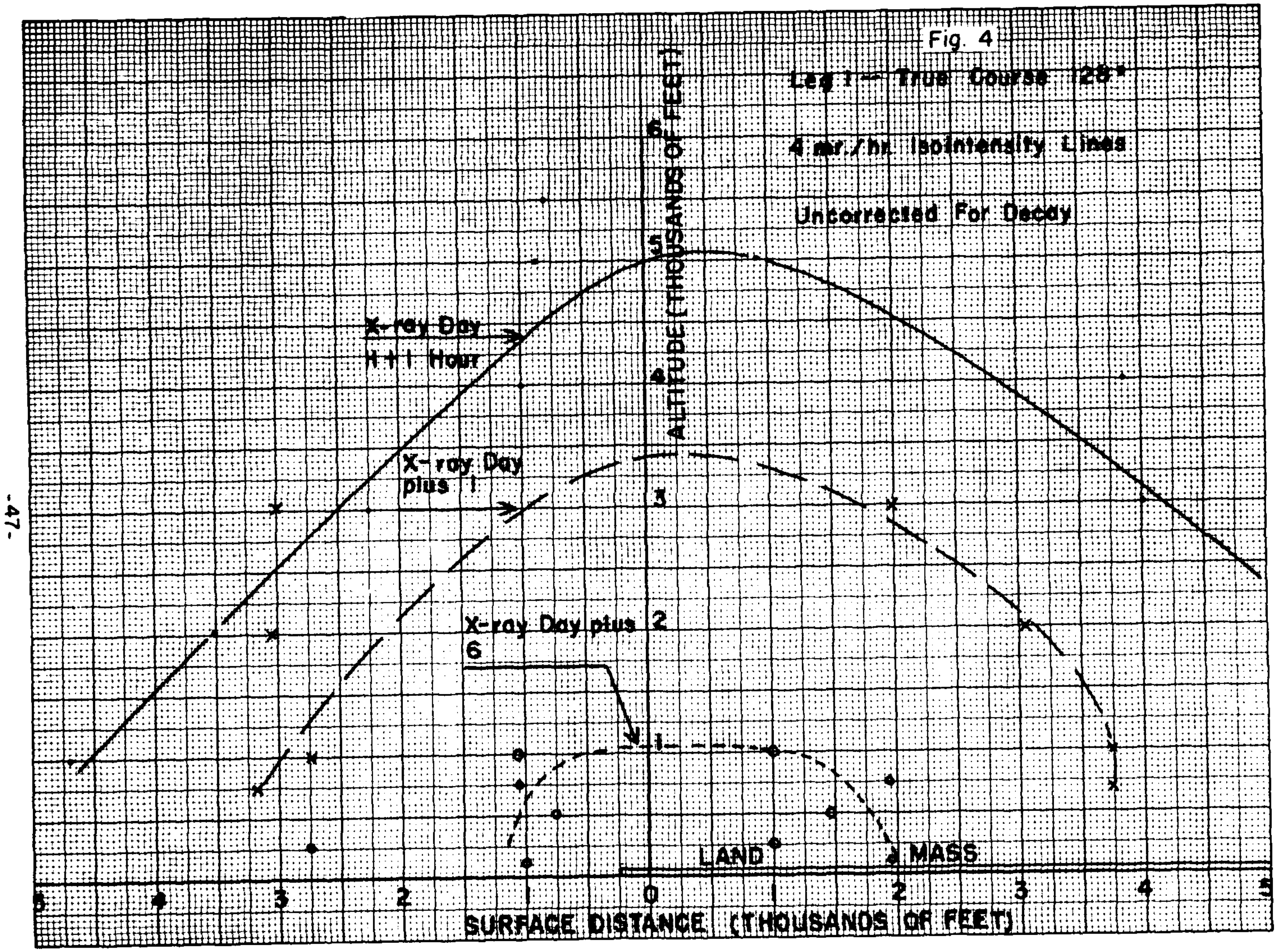


Fig. 4
Leg I — True Course 128°
4 mr./hr. Isointensity Lines
Uncorrected For Decay
ALTITUDE (THOUSANDS OF FEET)
X-ray Day H+1 Hour
X-ray Day plus 1
X-ray Day plus 2
6
LAND MASS
SURFACE DISTANCE (THOUSANDS OF FEET)

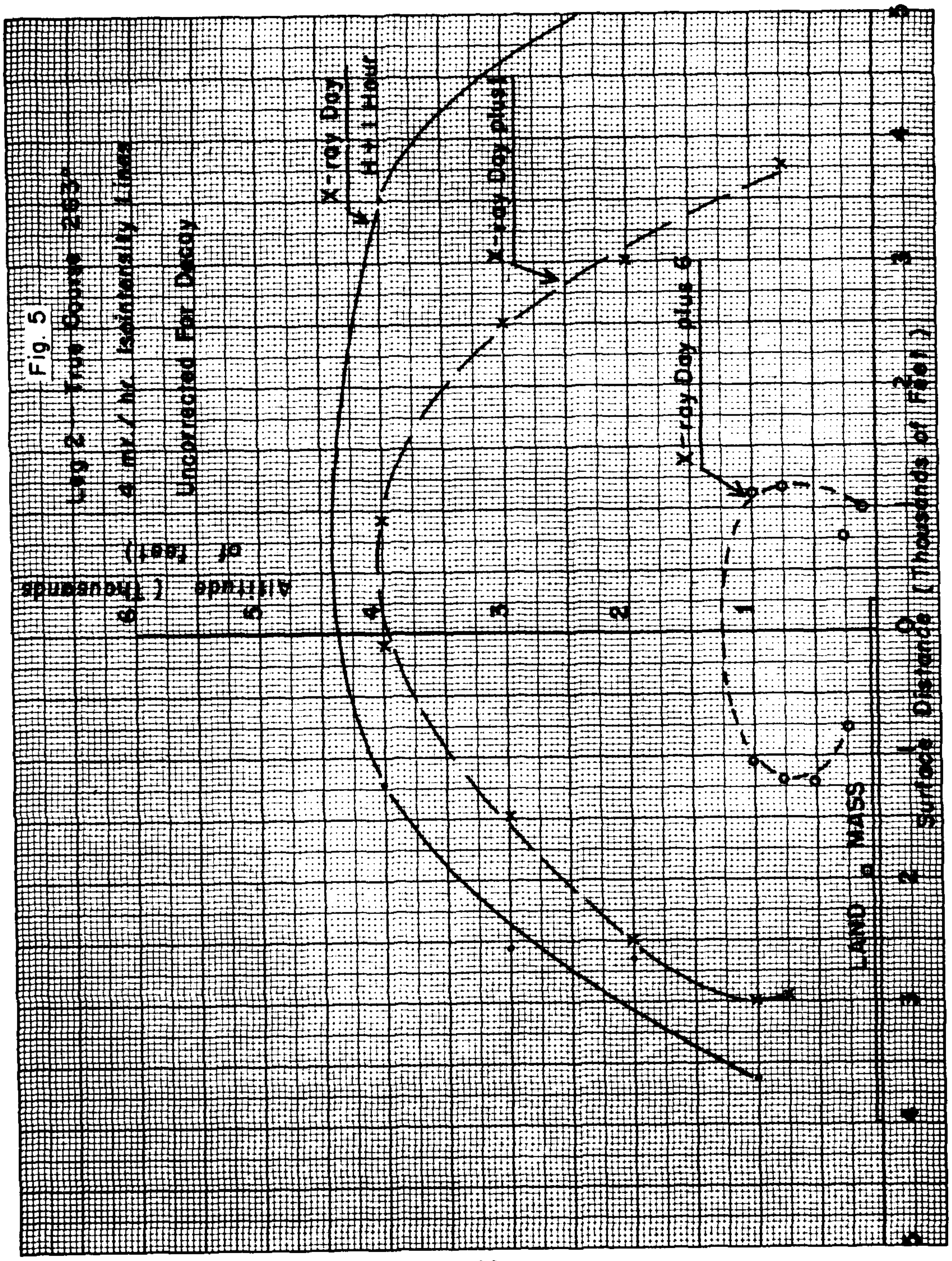


Fig. 5
Leg 2 True Course 263°
4 mr / hr Isointensity Lines
Uncorrected For Decay
X-ray Day
H + 1 Hour
X-ray Day plus 1
X-ray Day plus 6
Altitude (Thousands of feet)
LAND MASS
Surface Distance (Thousands of Feet)

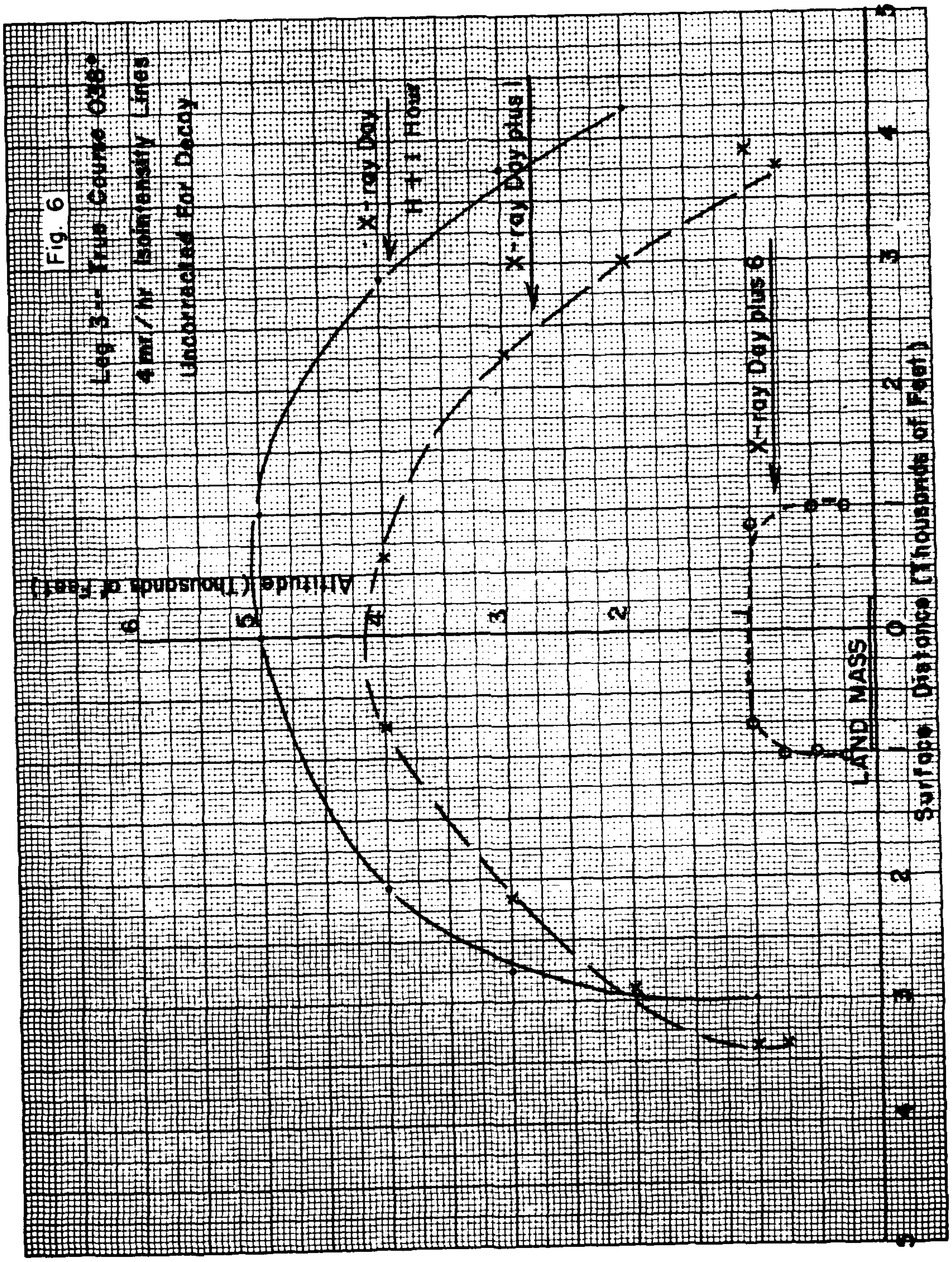


Fig. 6
Leg 3 -- True Course 038°
4 mr/hr Isointensity Lines
Uncorrected For Decay

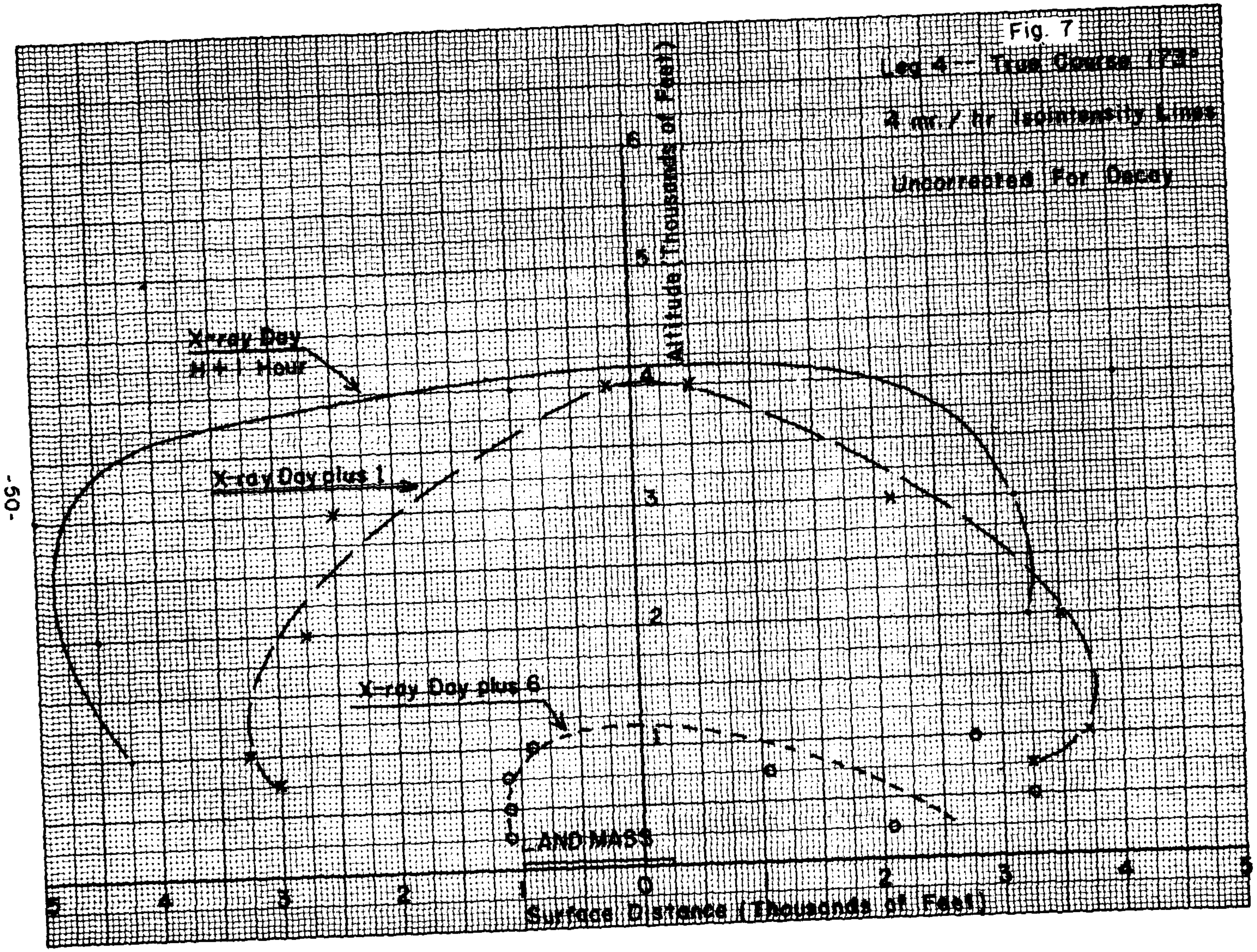

Leg 4 -- True Course 173°
2 mr./hr. Isointensity Lines
Uncorrected For Decay
Altitude (Thousands of Feet)
X-ray Day
H+1 Hour
X-ray Day plus 1
X-ray Day plus 6
LAND MASS
Surface Distance (Thousands of Feet)
5
4
3
2
1
0
1
2
3
4
5
6

Fig. 7

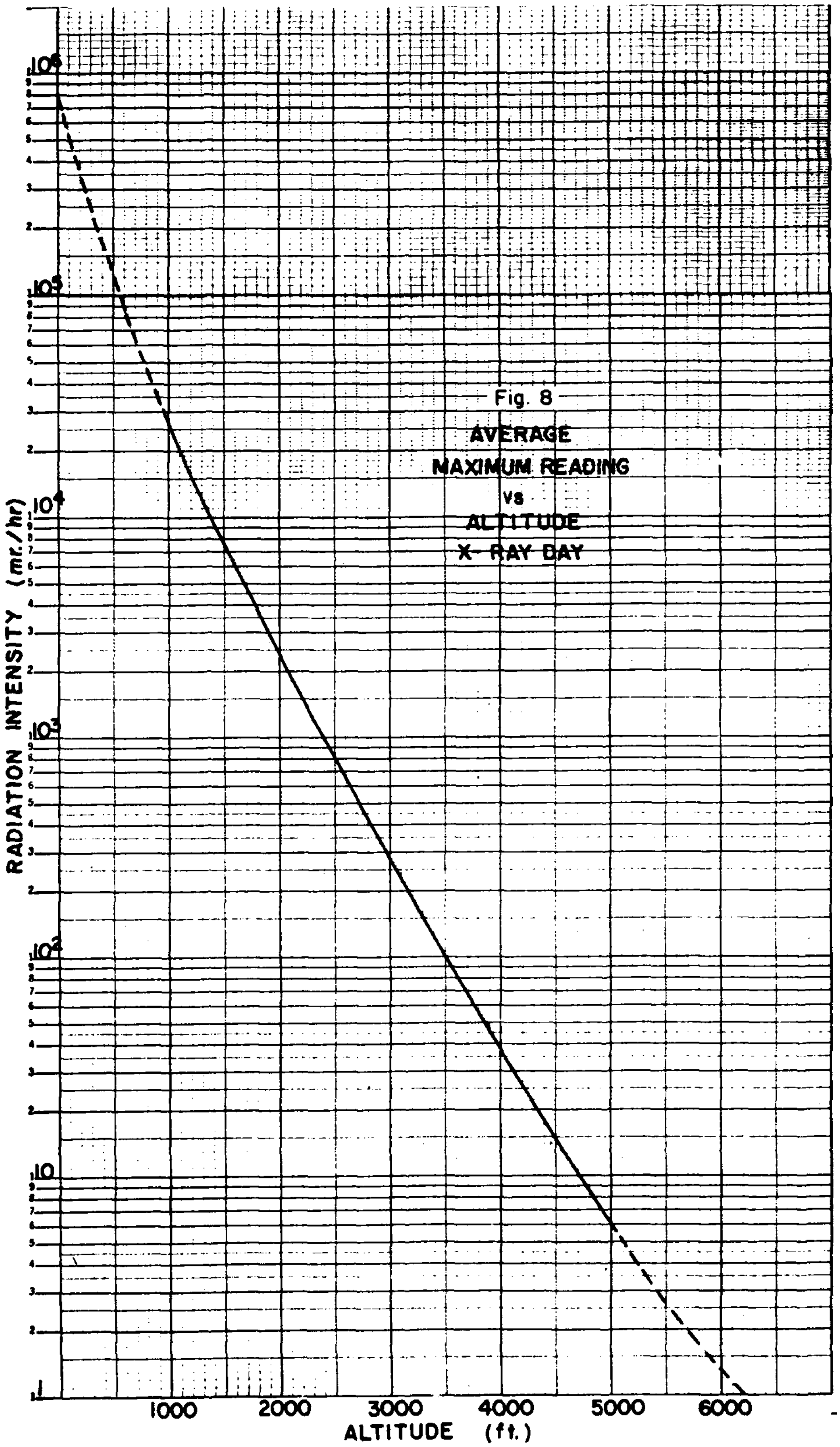


Fig. 8
AVERAGE
MAXIMUM READING
vs
ALTITUDE
X- RAY DAY
RADIATION INTENSITY (mr./hr)
ALTITUDE (ft.)
1000
2000
3000
4000
5000
6000
10⁶
10⁵
10⁴
10³
10²
10
1

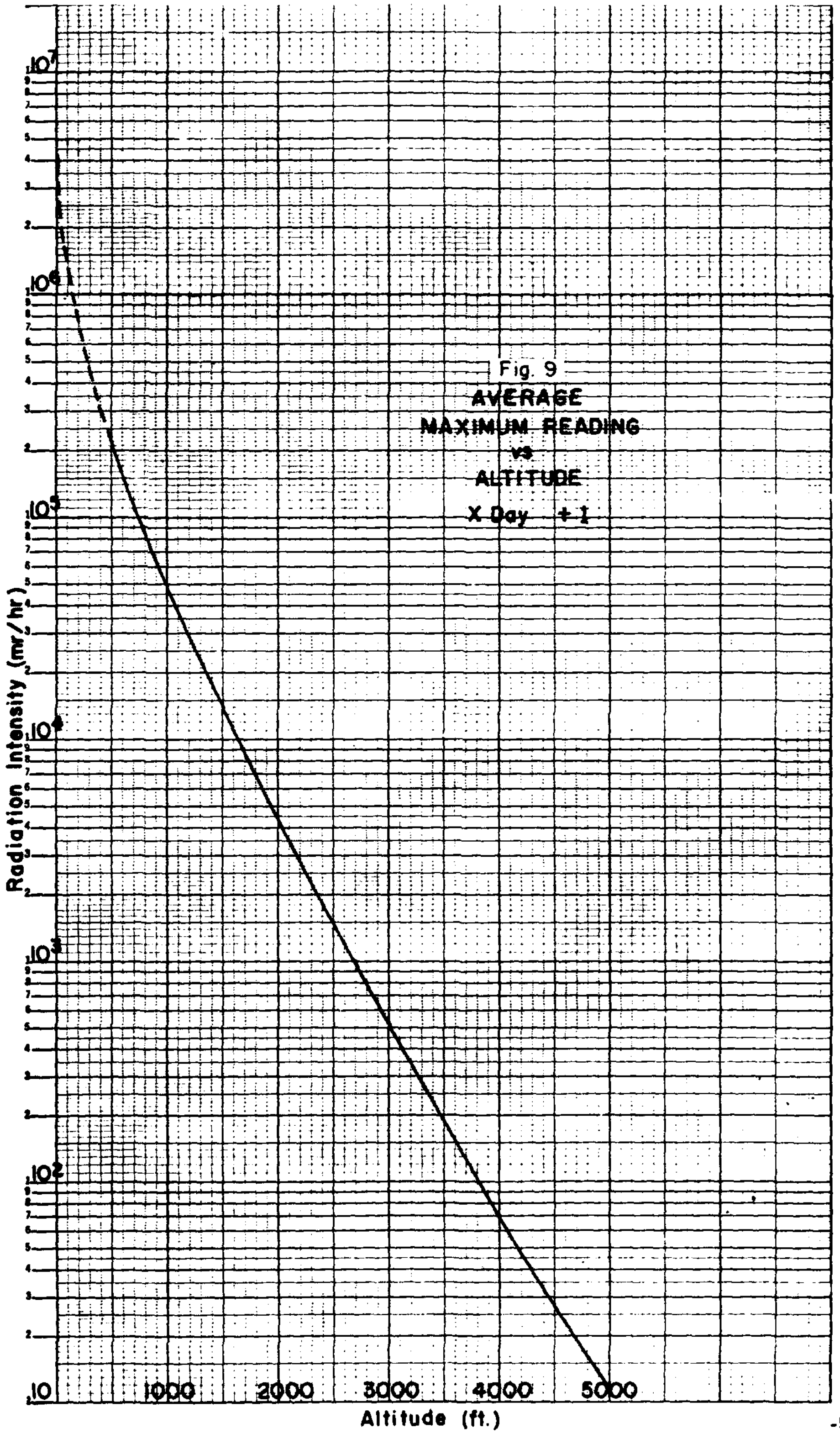


Fig. 9
AVERAGE
MAXIMUM READING
vs
ALTITUDE
X Day + 1
Radiation Intensity (mr/hr)
10
10^2
10^3
10^4
10^5
10^6
10^7
1000
2000
3000
4000
5000
Altitude (ft.)

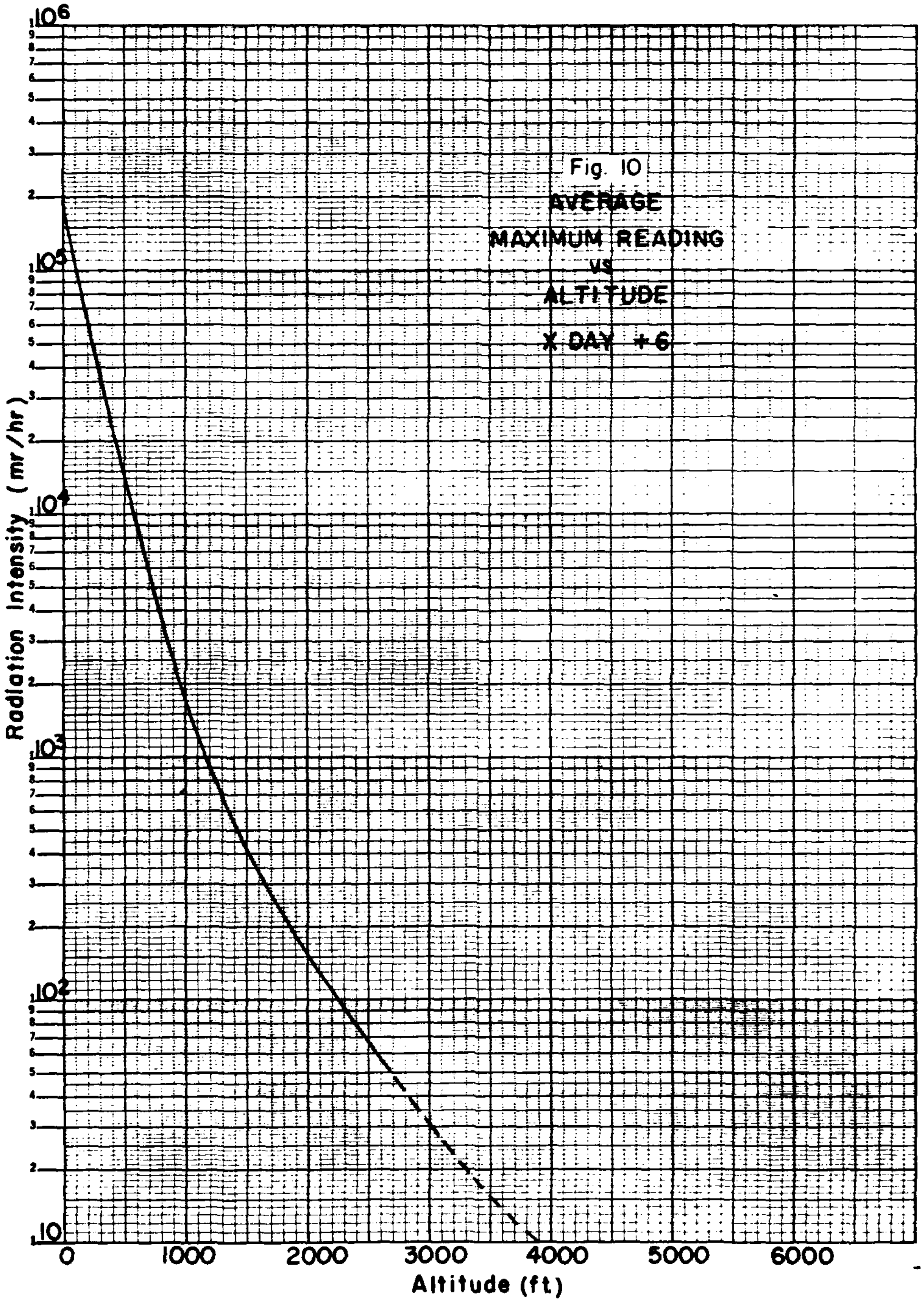


Fig. 10
AVERAGE
MAXIMUM READING
vs
ALTITUDE
X DAY +6
Radiation Intensity (mr/hr)
Altitude (ft.)
10^6
10^5
10^4
10^3
10^2
10
0
1000
2000
3000
4000
5000
6000

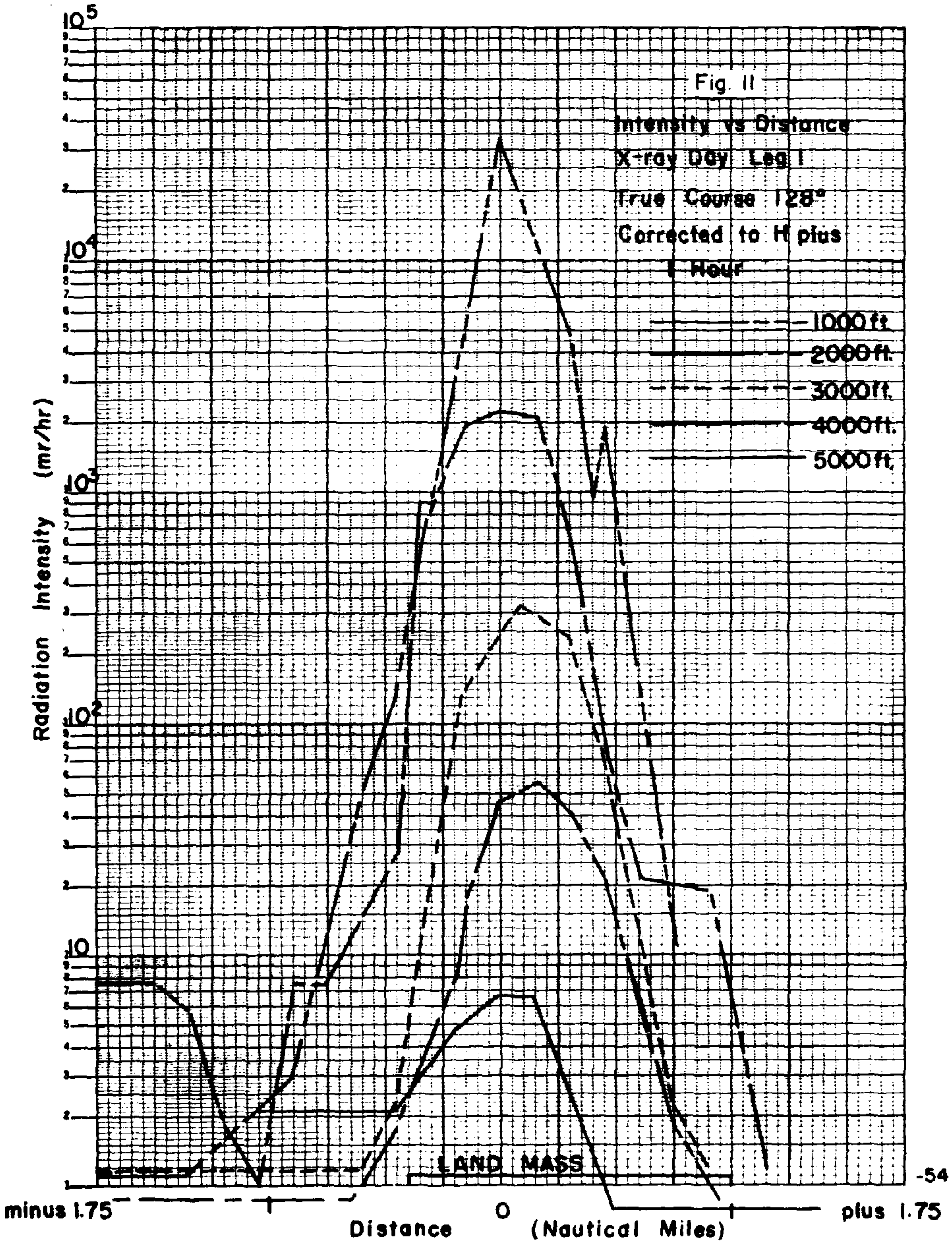


Fig. II
Intensity vs Distance
X-ray Day Leg I
True Course 128°
Corrected to H plus
1 Hour
1000 ft.
2000 ft.
3000 ft.
4000 ft.
5000 ft.
10^5
10^4
10^3
10^2
10
1
Radiation Intensity (mr/hr)
LAND MASS
minus 1.75
0
plus 1.75
Distance (Nautical Miles)

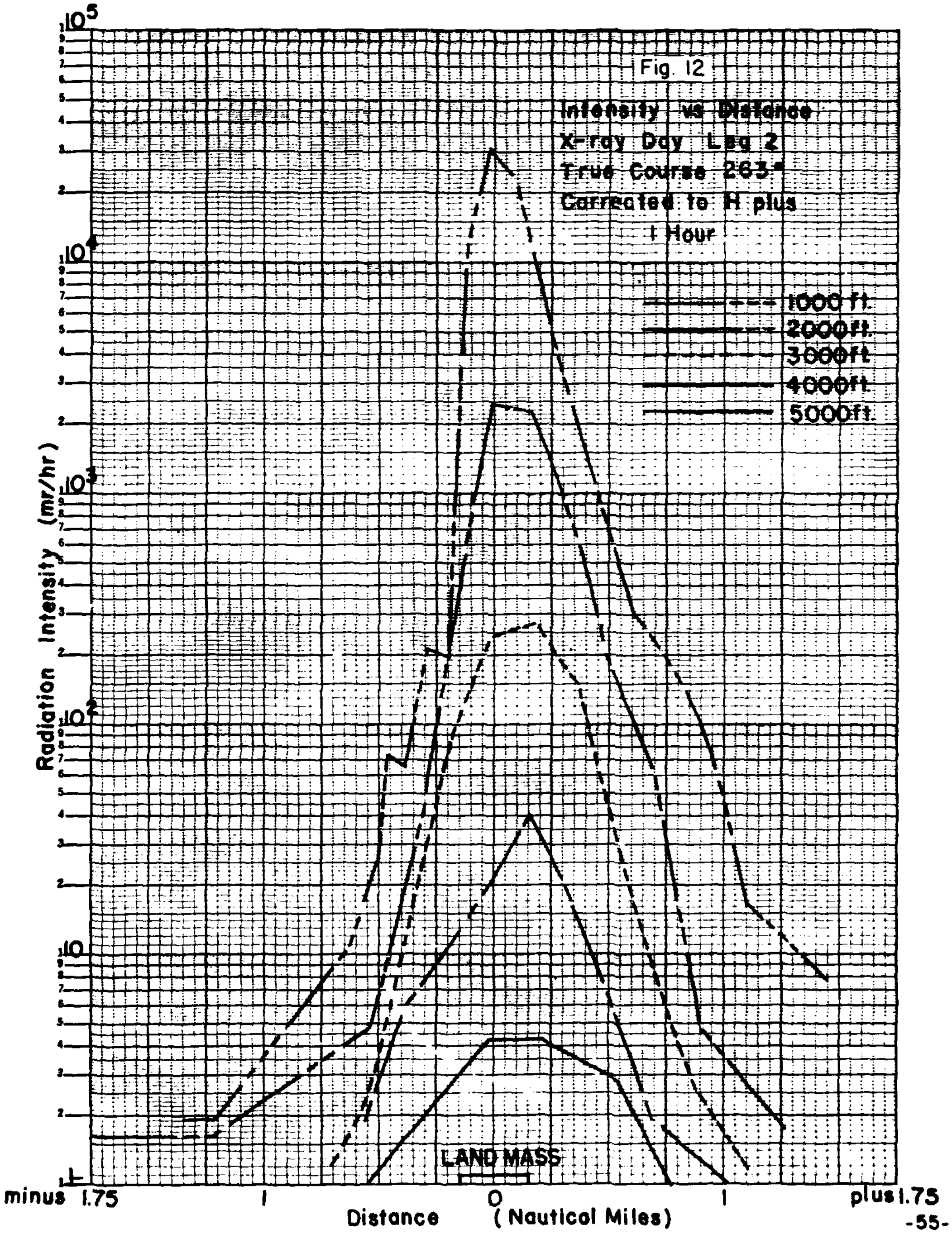


Fig. 12
Intensity vs Distance
X-ray Day Leg 2
True Course 263°
Corrected to H plus
1 Hour
1000 ft.
2000 ft.
3000 ft.
4000 ft.
5000 ft.
Radiation Intensity (mr/hr)
10^5
10^4
10^3
10^2
10
1
LAND MASS
minus 1.75
1
0
1
plus 1.75
Distance (Nautical Miles)

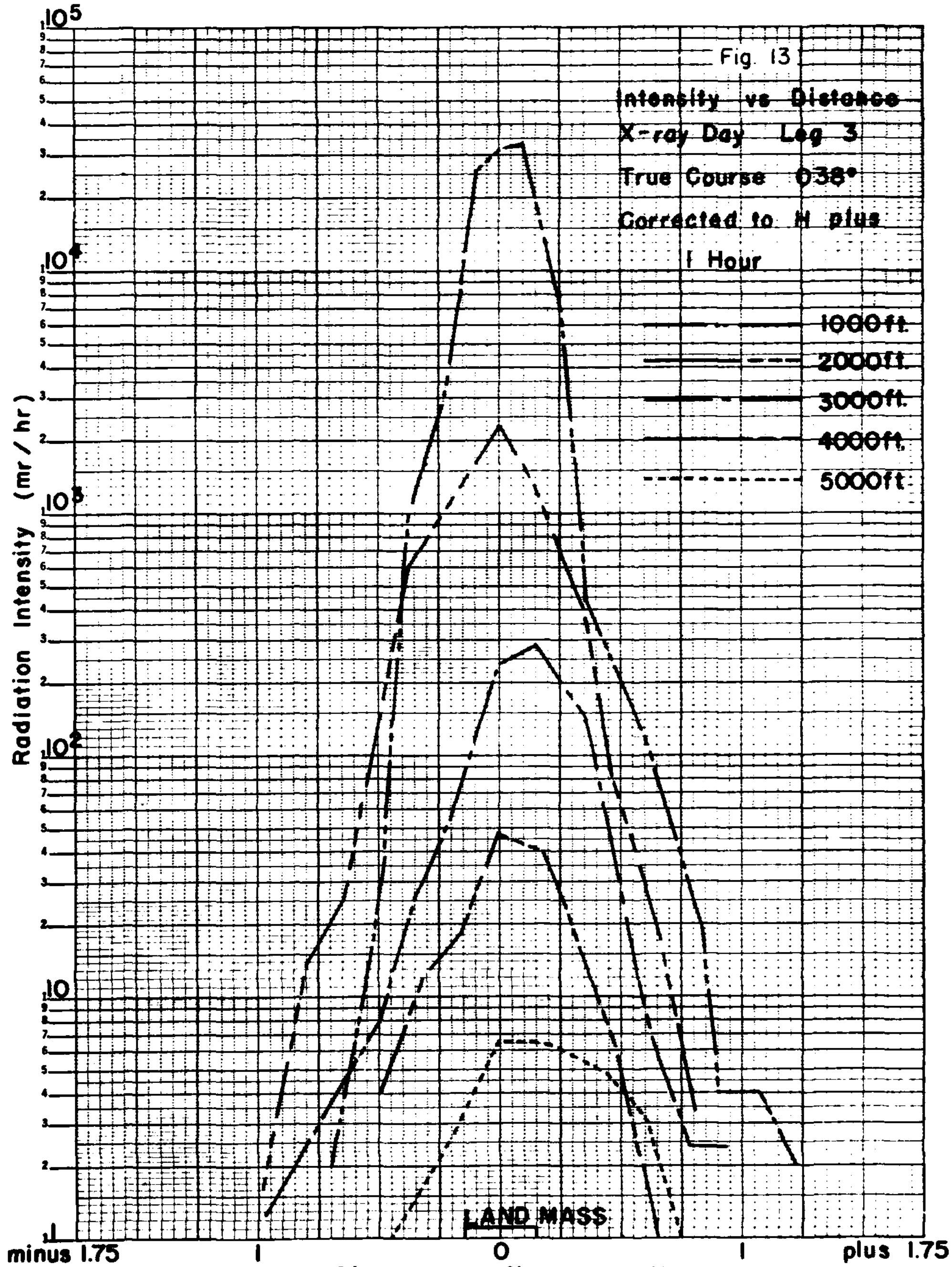


Fig. 13
Intensity vs Distance
X-ray Day Leg 3
True Course 038°
Corrected to H plus
1 Hour
1000ft.
2000ft.
3000ft.
4000ft.
5000ft.
Radiation Intensity (mr / hr)
LAND MASS
minus 1.75
1
0
1
plus 1.75
Distance (Nautical Miles)

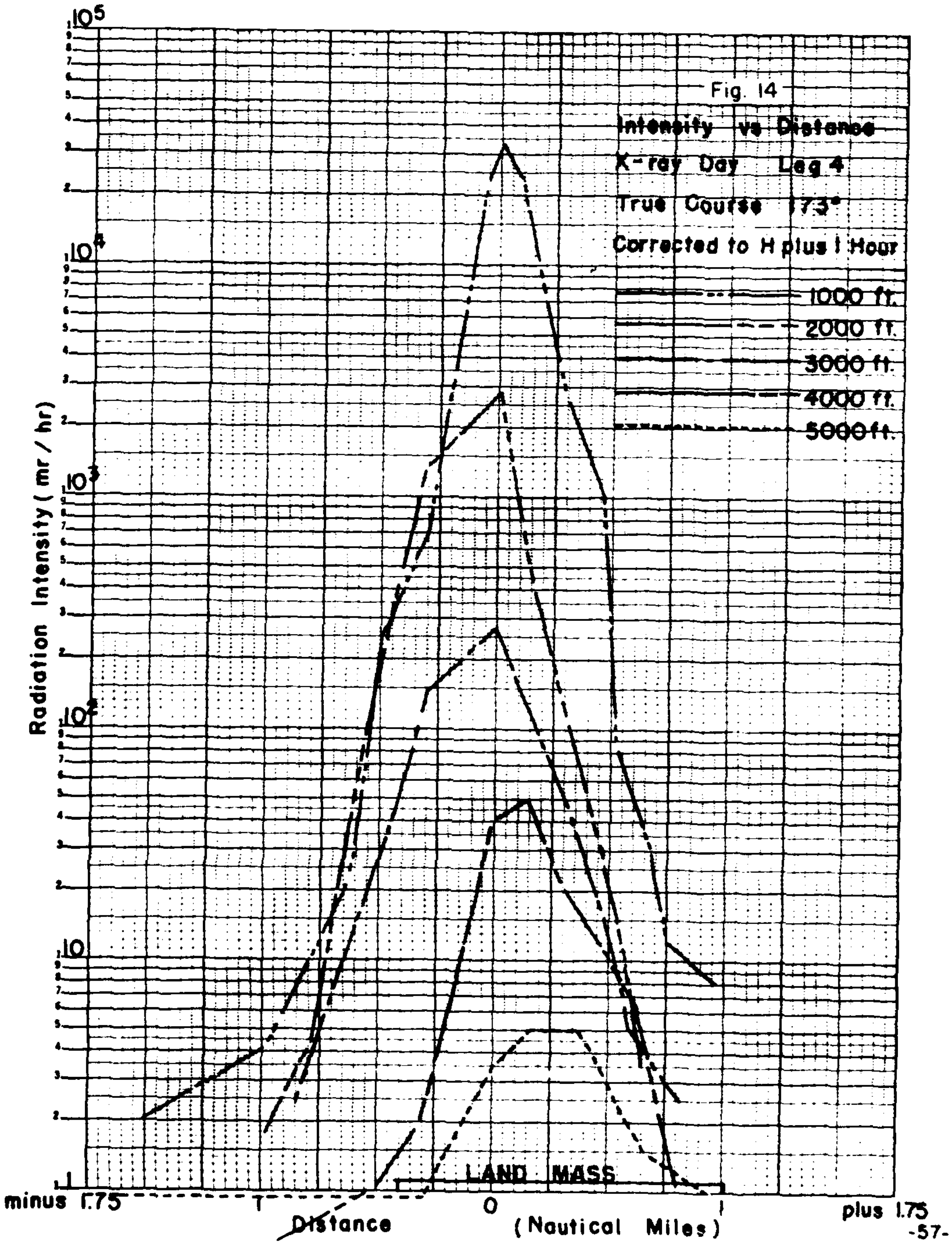


Fig. 14
Intensity vs Distance
X-ray Day Leg 4
True Course 173°
Corrected to H plus 1 Hour
1000 ft.
2000 ft.
3000 ft.
4000 ft.
5000 ft.
Radiation Intensity (mr / hr)
LAND MASS
minus 1.75
1
0
1
plus 1.75
Distance (Nautical Miles)

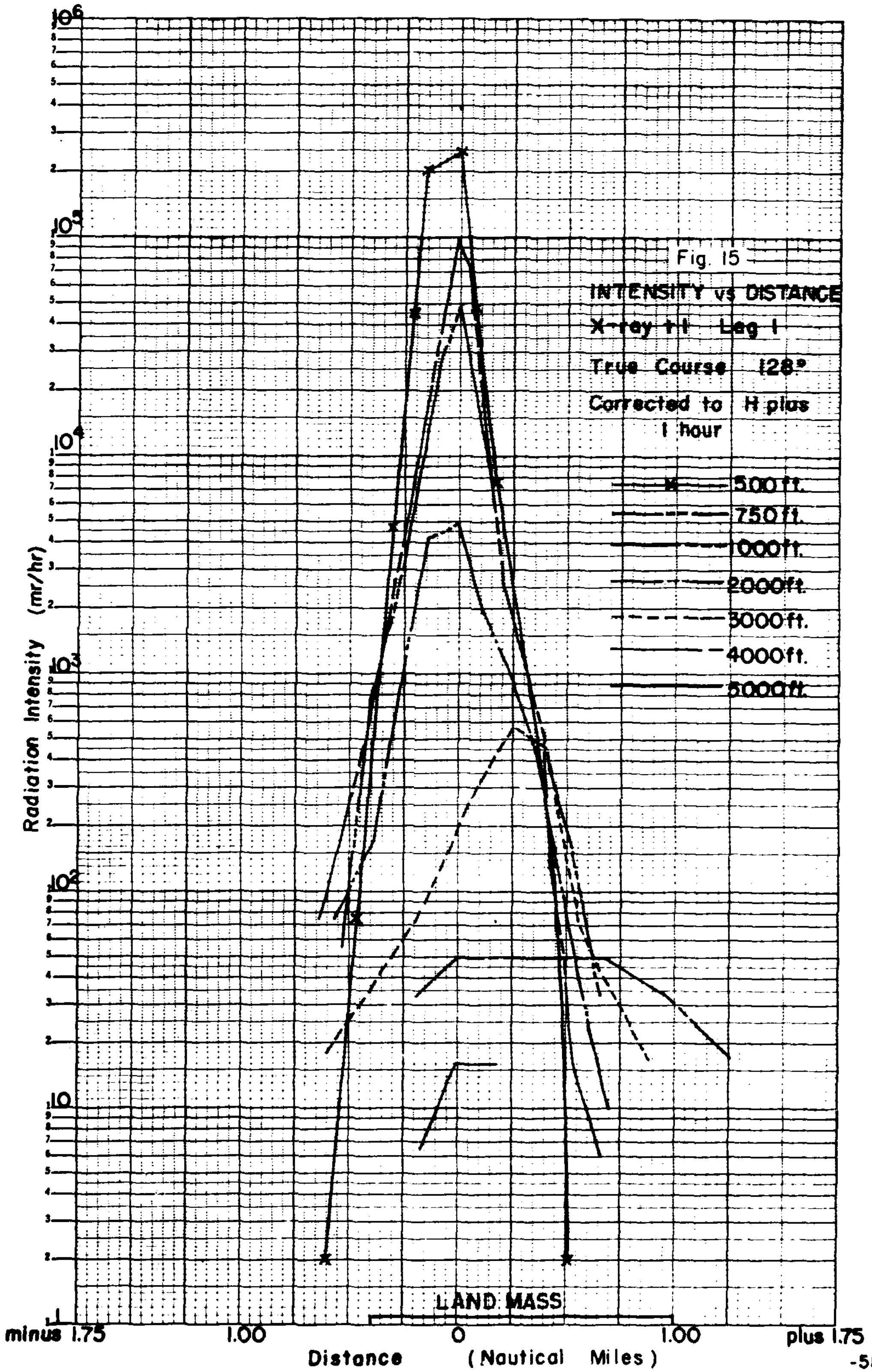


Fig. 15
INTENSITY vs DISTANCE
X-ray +1 Leg I
True Course 128°
Corrected to H plus
1 hour
500 ft.
750 ft.
1000 ft.
2000 ft.
3000 ft.
4000 ft.
5000 ft.
Radiation Intensity (mr/hr)
10^6
10^5
10^4
10^3
10^2
10
1
LAND MASS
minus 1.75
1.00
0
1.00
plus 1.75
Distance (Nautical Miles)

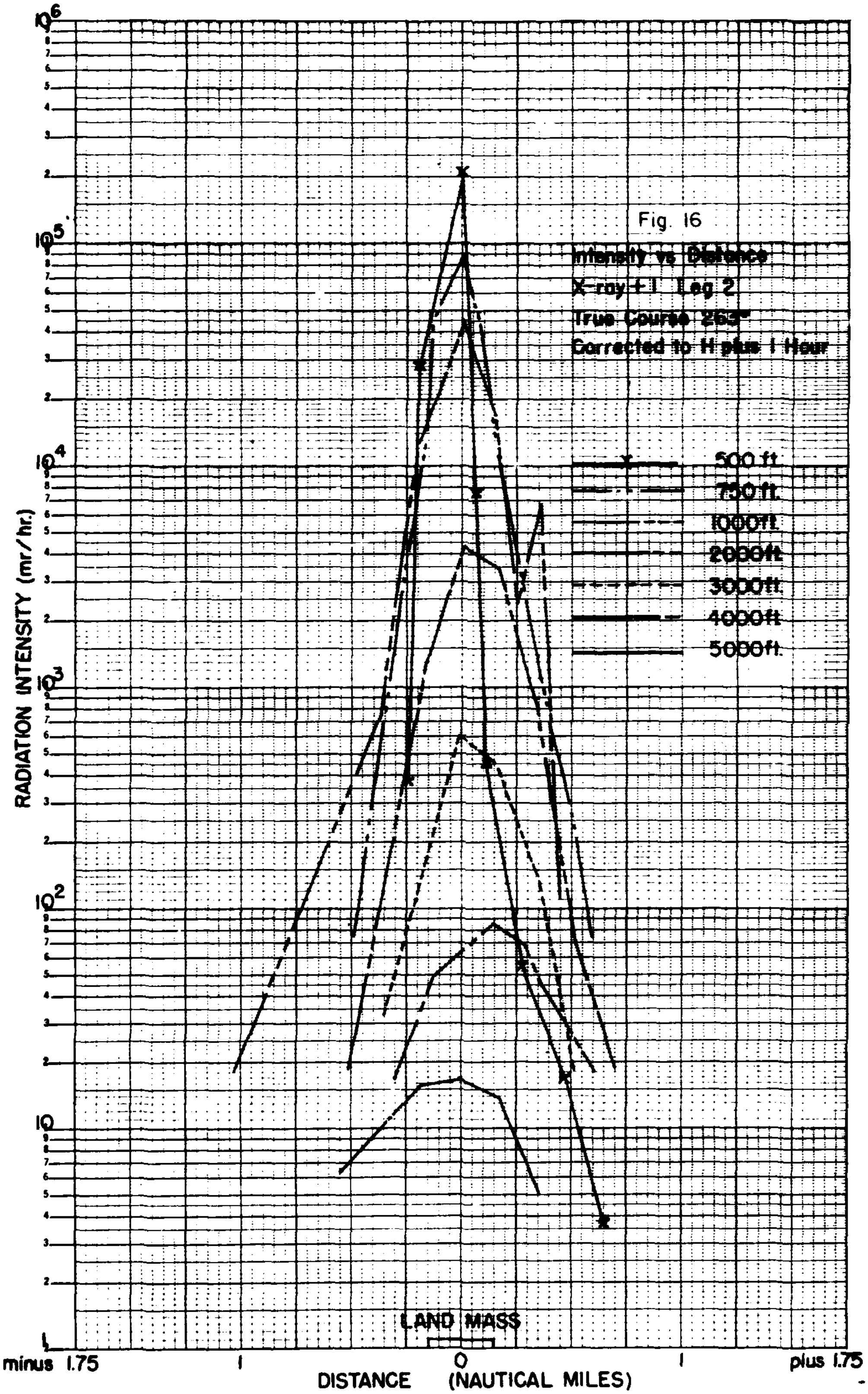


Fig. 16
Intensity vs Distance
X-ray +1 Leg 2
True Course 263°
Corrected to H plus 1 Hour
500 ft.
750 ft.
1000ft.
2000ft.
3000ft.
4000ft.
5000ft.
RADIATION INTENSITY (mr/hr.)
10^6
10^5
10^4
10^3
10^2
10
1
LAND MASS
minus 1.75
1
0
1
plus 1.75
DISTANCE (NAUTICAL MILES)

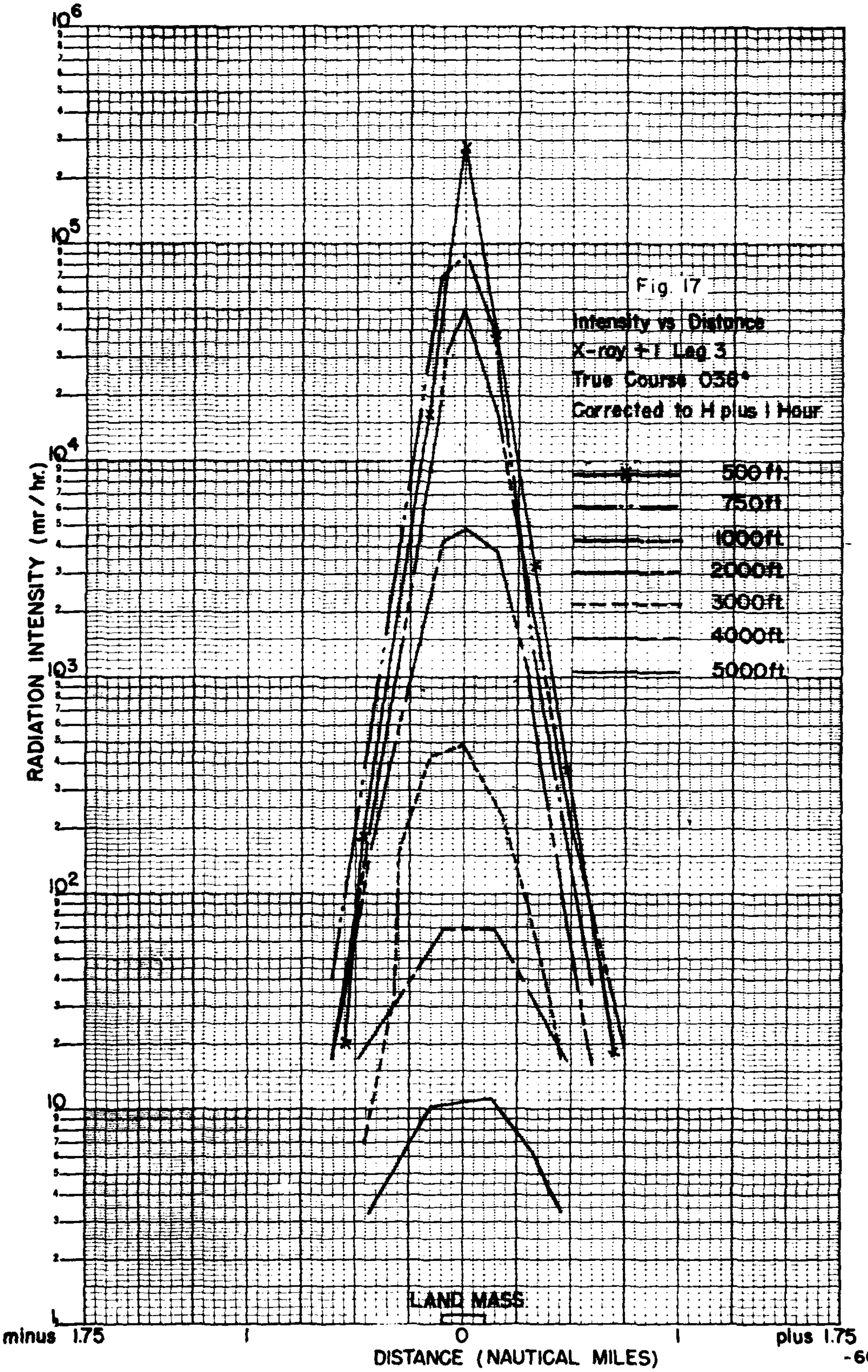


Fig. 17
Intensity vs Distance
X-ray +1 Leg 3
True Course 036°
Corrected to H plus 1 Hour
500 ft.
750 ft.
1000 ft.
2000 ft.
3000 ft.
4000 ft.
5000 ft.
RADIATION INTENSITY (mr / hr.)
10^6
10^5
10^4
10^3
10^2
10
1
LAND MASS
minus 1.75
1
0
1
plus 1.75
DISTANCE (NAUTICAL MILES)

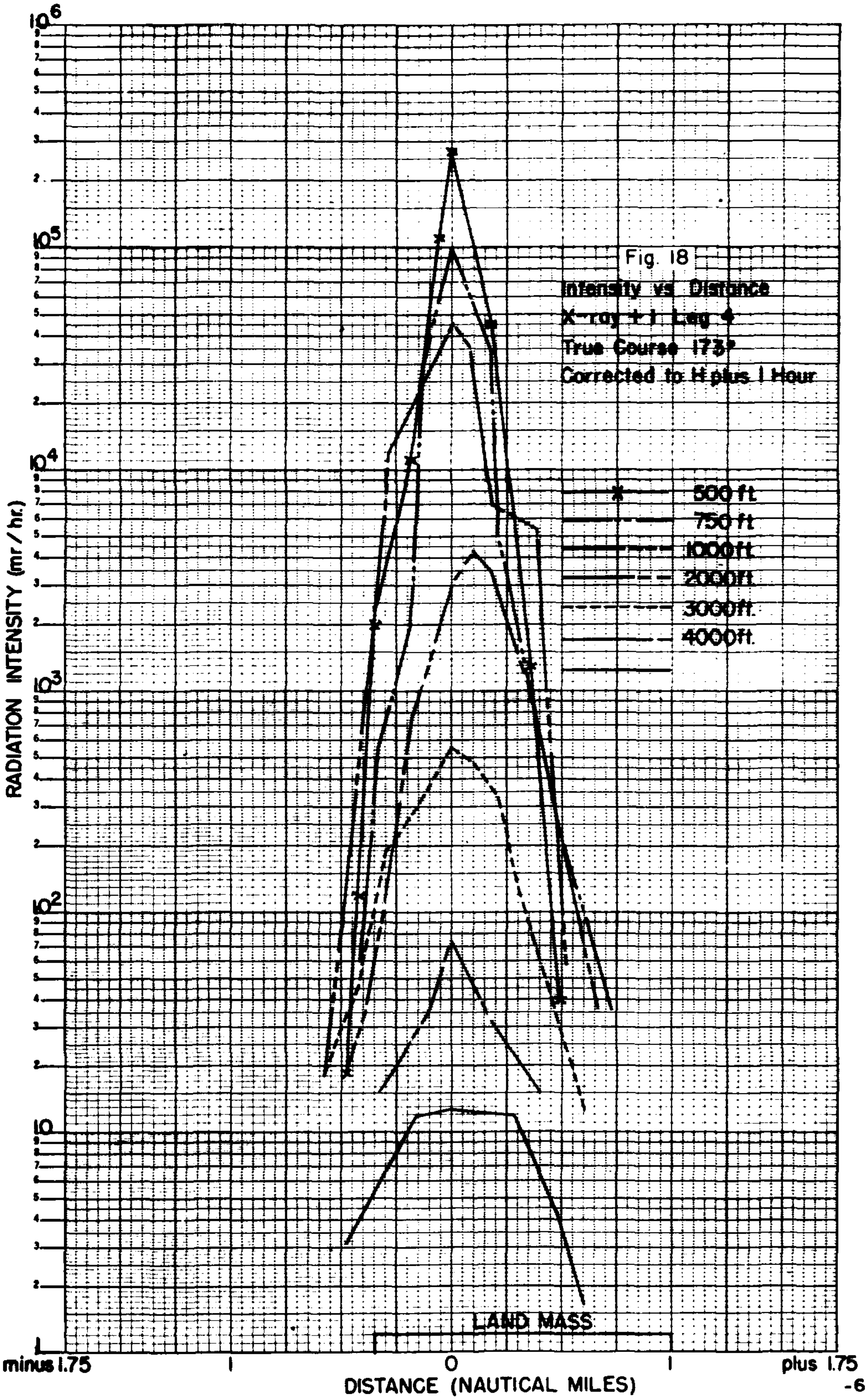
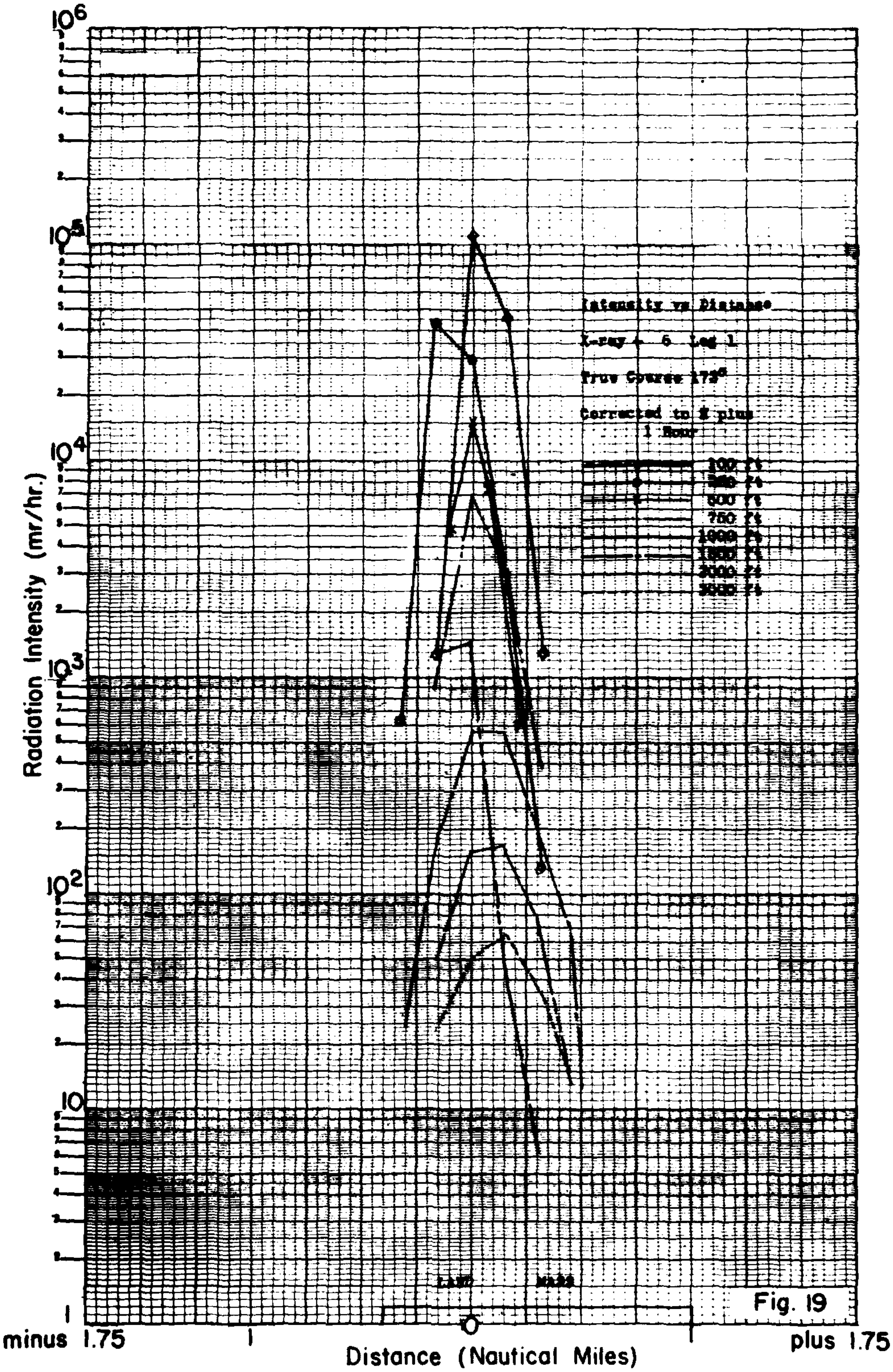


Fig. 18
Intensity vs Distance
X-ray + 1 Leg 4
True Course 173°
Corrected to H plus 1 Hour
500 ft
750 ft
1000ft
2000ft
3000ft
4000ft
RADIATION INTENSITY (mr / hr.)
DISTANCE (NAUTICAL MILES)
LAND MASS
minus 1.75
plus 1.75


Intensity vs Distance
X-ray - 6 Leg 1
True Course 173°
Corrected to H plus 1 Hour
100 ft
500 ft
750 ft
1000 ft
1500 ft
2000 ft
3000 ft
LAND MASS
Radiation Intensity (mr/hr.)
10^6
10^5
10^4
10^3
10^2
10
1
minus 1.75
1
0
plus 1.75
Distance (Nautical Miles)
Fig. 19

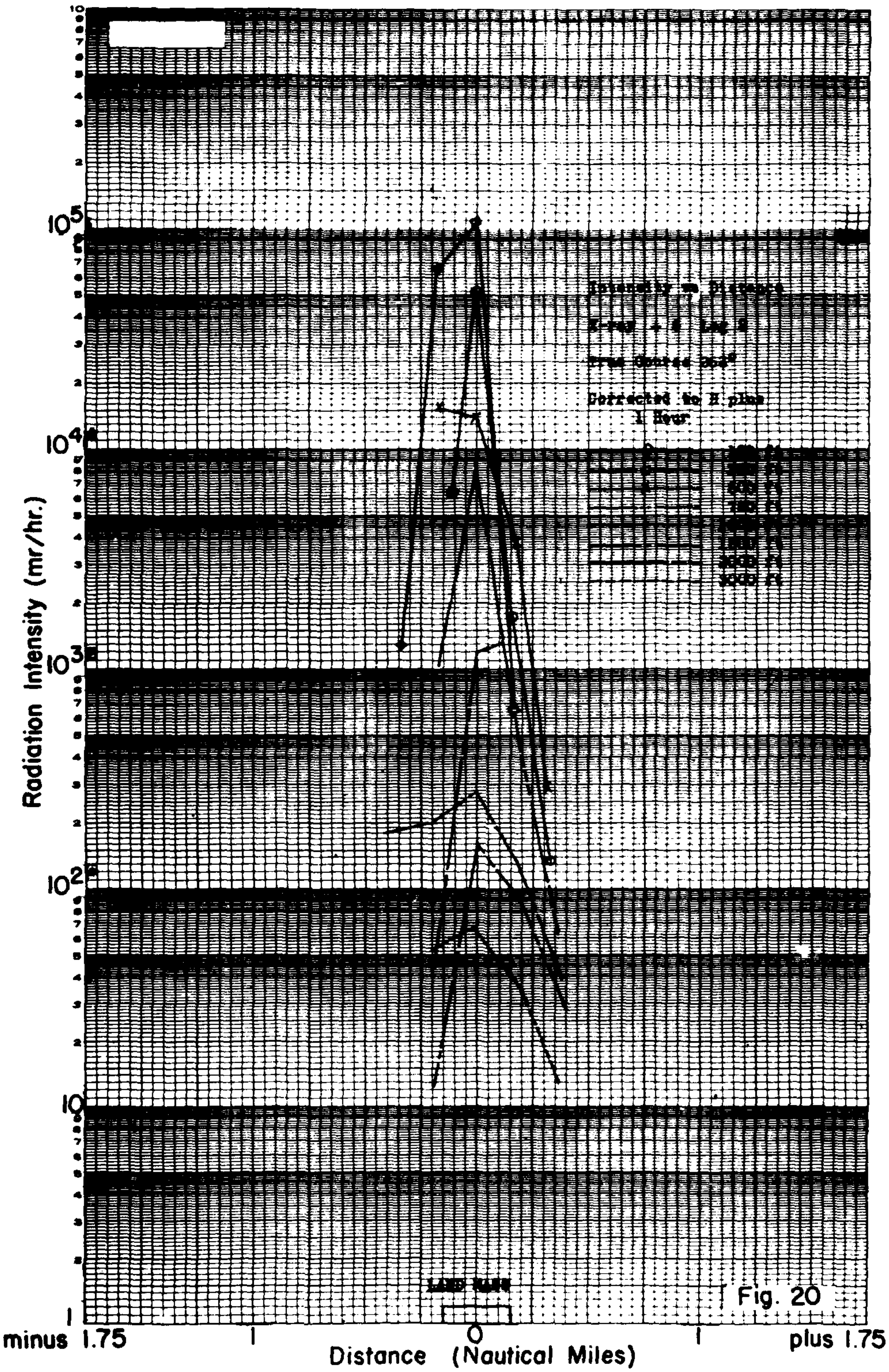

Radiation Intensity (mr/hr.)
10^5
10^4
10^3
10^2
10
1
Corrected to H plus
1 Hour
minus 1.75
1
0
1
plus 1.75
Distance (Nautical Miles)

Fig. 20

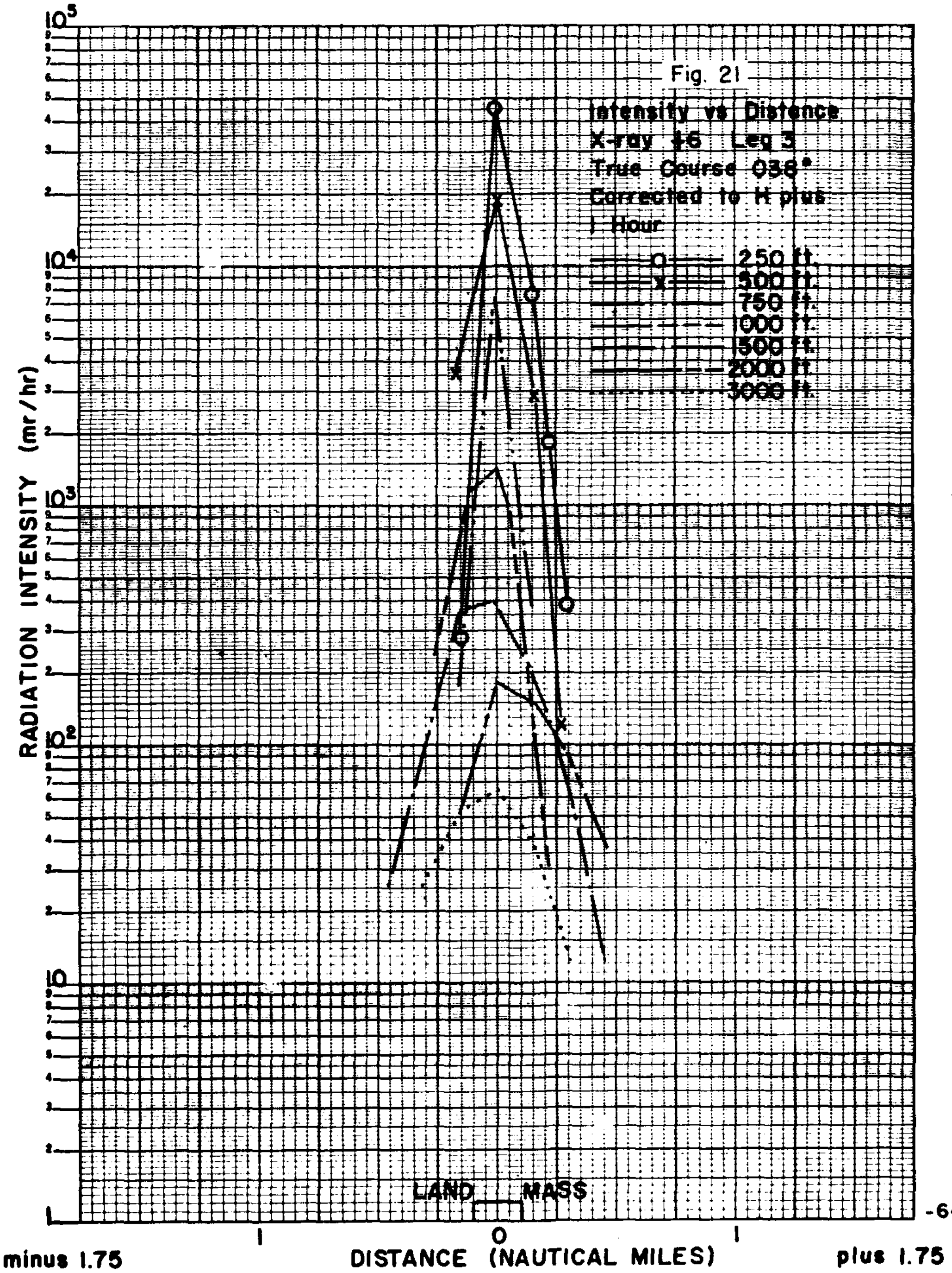


Fig. 21
Intensity vs Distance
X-ray #6 Leg 3
True Course 038°
Corrected to H plus
1 Hour
250 ft.
500 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
3000 ft.
RADIATION INTENSITY (mr/hr)
10^5
10^4
10^3
10^2
10
1
LAND MASS
minus 1.75
1
0
1
plus 1.75
DISTANCE (NAUTICAL MILES)

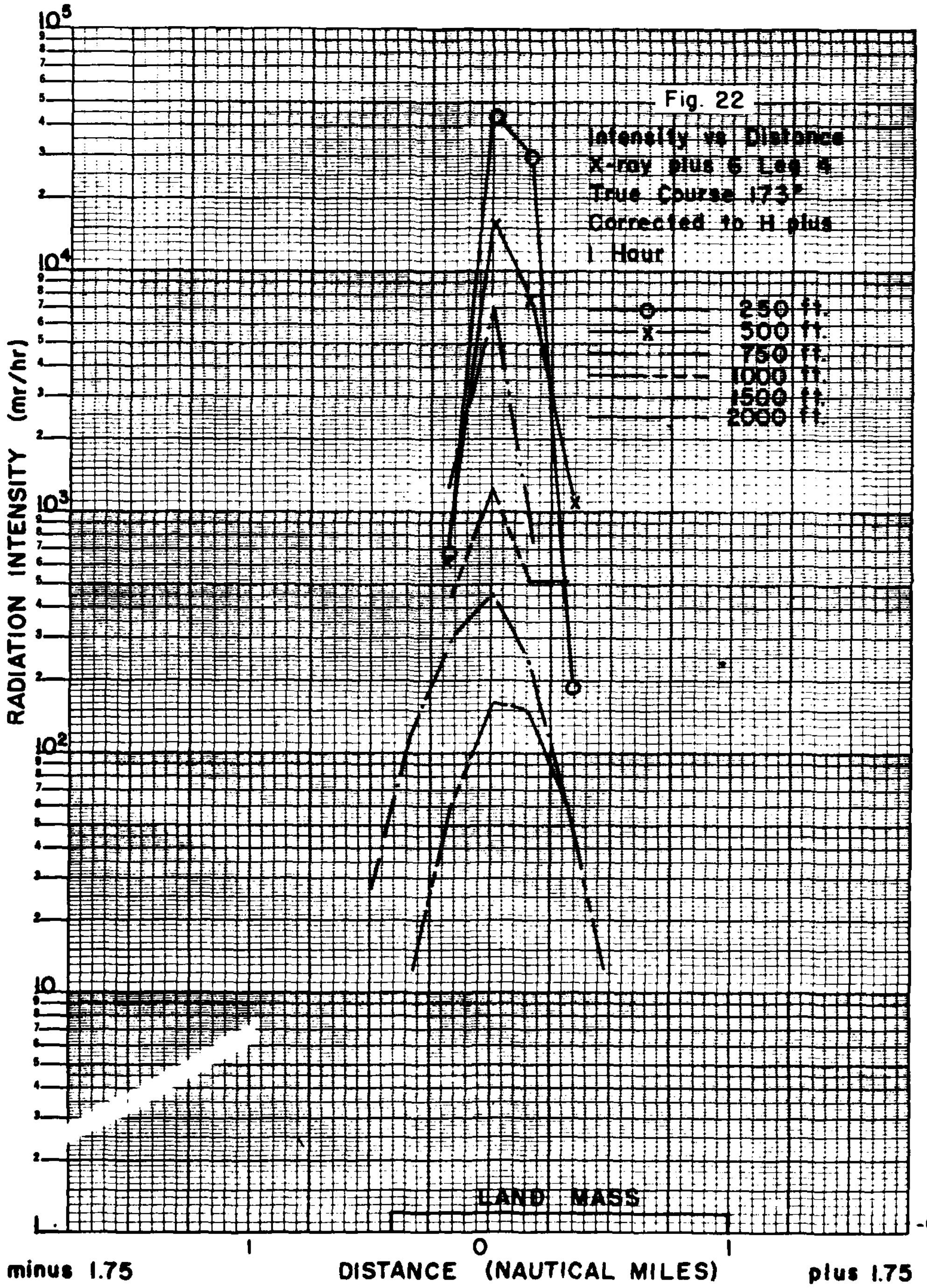


Fig. 22
Intensity vs. Distance
X-ray plus 6 Leg 4
True Course 173°
Corrected to H plus
1 Hour
250 ft.
500 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
RADIATION INTENSITY (mr/hr)
10^5
10^4
10^3
10^2
10
1
LAND MASS
minus 1.75
1
0
1
DISTANCE (NAUTICAL MILES)
plus 1.75

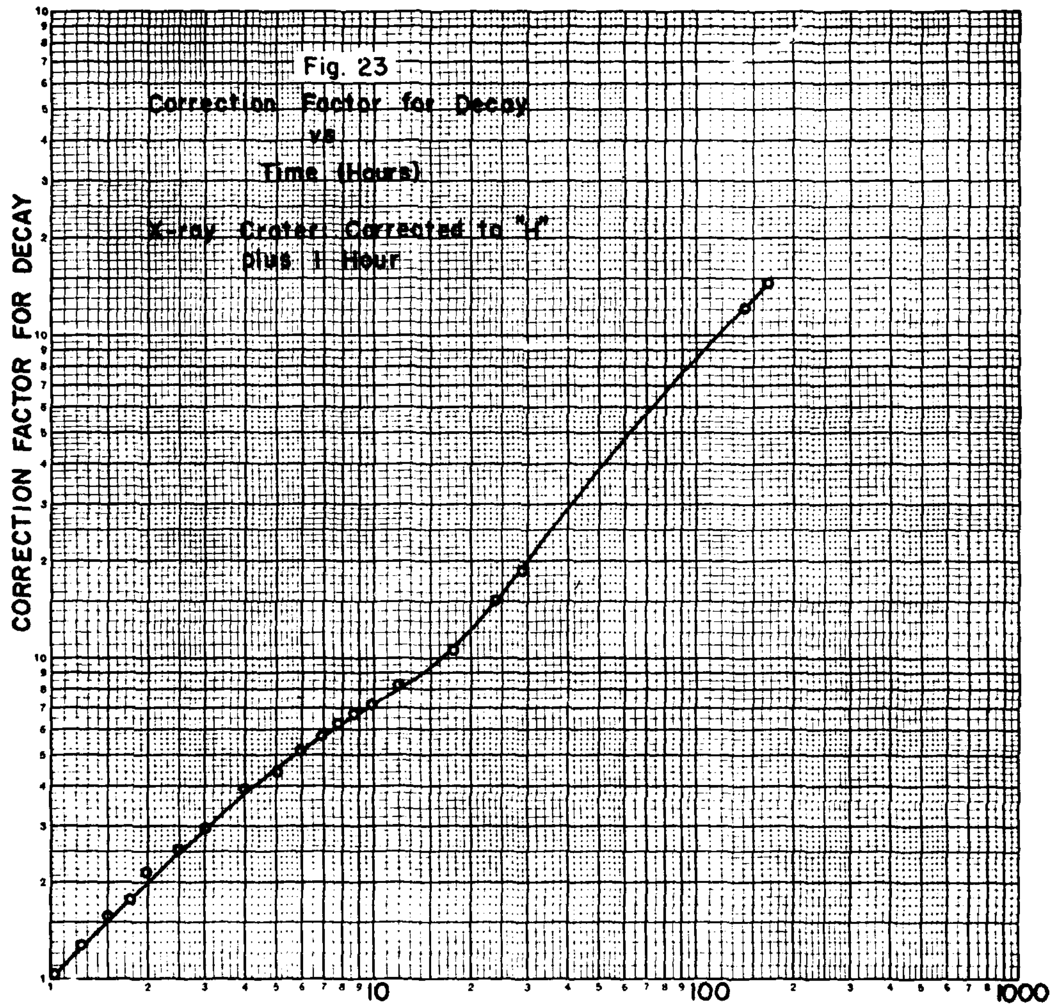


Fig. 23
Correction Factor for Decay
vs
Time (Hours)
X-ray Crater: Corrected to "H"
plus 1 Hour
CORRECTION FACTOR FOR DECAY
10
100
1000

TIME (Hours)

FIGURE 24

X-RAY CRATER

Intensity x Altitude^2 vs Altitude Values

Altitude	Average Maximum Intensity Corrected H + 1 hr	Altitude^2	IA^2
X-ray Day			
5000	6	2.5×10^7	1.5×10^8
4000	47.5	1.6×10^7	7.6×10^8
3000	276	9×10^6	2.5×10^9
2000	2400	4×10^6	9.6×10^9
1000	31,850	10^6	3.18×10^{10}
X-ray plus 1			
5000	11.6	2.5×10^7	2.9×10^8
4000	68.8	1.6×10^7	1.1×10^9
3000	546	9×10^6	4.9×10^9
2000	4880	4×10^6	1.85×10^{10}
1000	45,250	10^6	4.5×10^{10}
750	92,000	5.64×10^5	5.1×10^{10}
500	241,200	2.5×10^5	6.04×10^{10}
X-ray plus 6			
3000	30	9×10^6	2.7×10^8
2500	66	6.25×10^6	4.1×10^8
2000	160	4×10^6	6.4×10^8
1500	430	2.25×10^6	9.7×10^8
1000	1750	10^6	1.75×10^9
750	4800	5.6×10^5	2.7×10^9
500	15,000	2.5×10^4	3.8×10^9
250	50,000	6.25×10^4	3.1×10^9
100	110,000	10^4	1.1×10^9

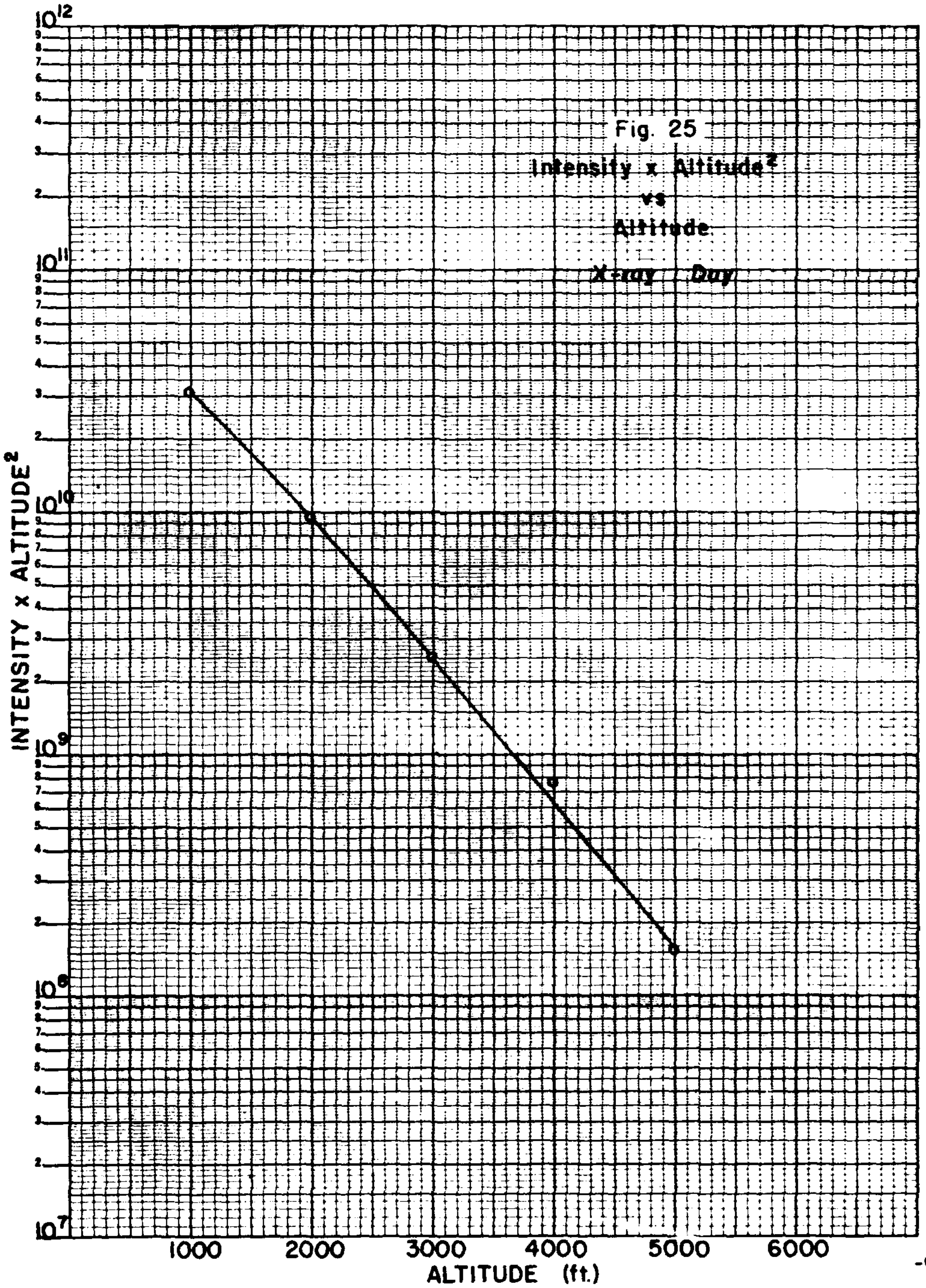


Fig. 25
Intensity x Altitude²
vs
Altitude
X-ray / Day
INTENSITY x ALTITUDE²
ALTITUDE (ft.)
1000
2000
3000
4000
5000
6000
10^12
10^11
10^10
10^9
10^8
10^7

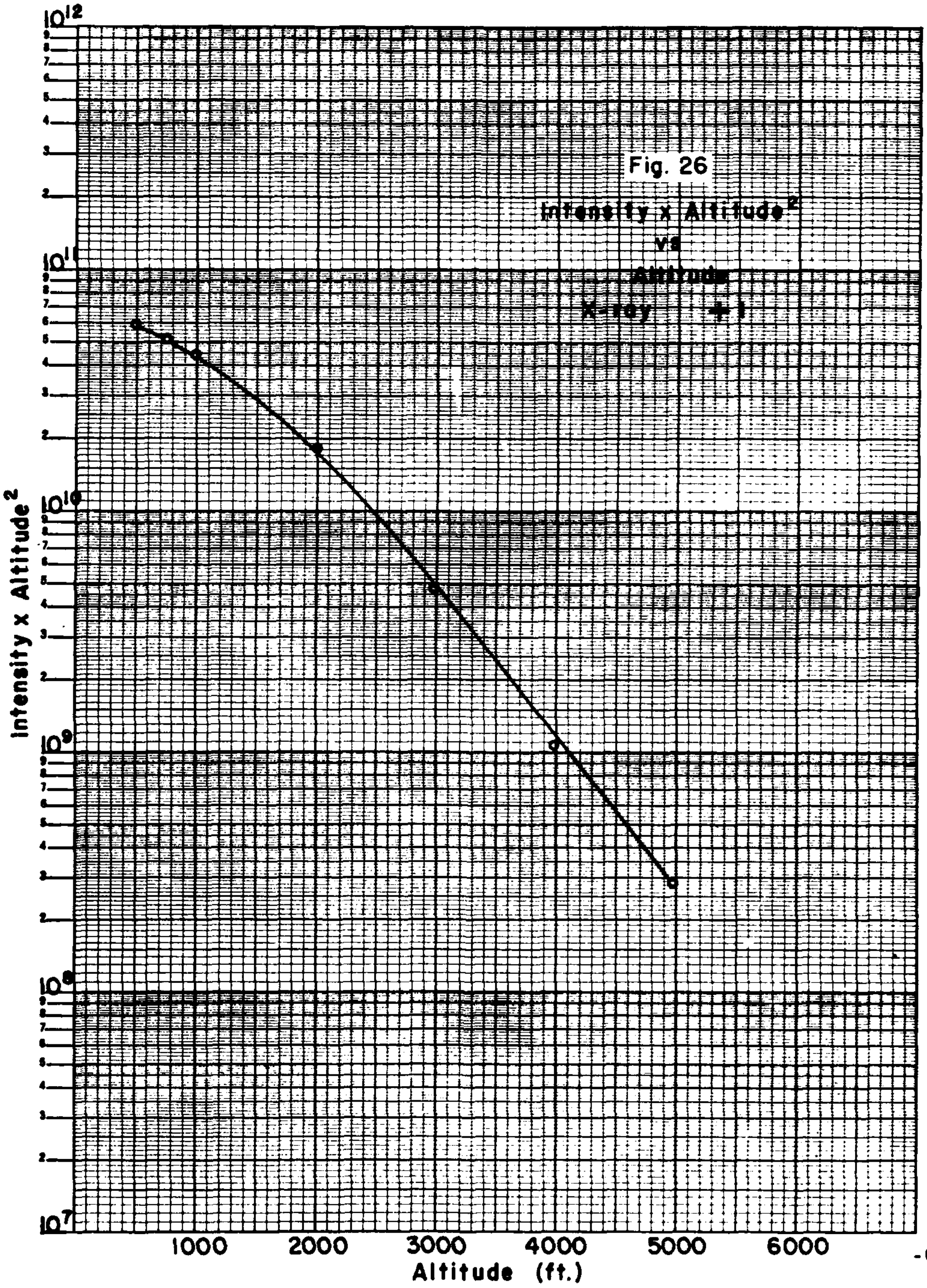


Fig. 26

Intensity x Altitude^2

vs

Altitude

X-ray +)

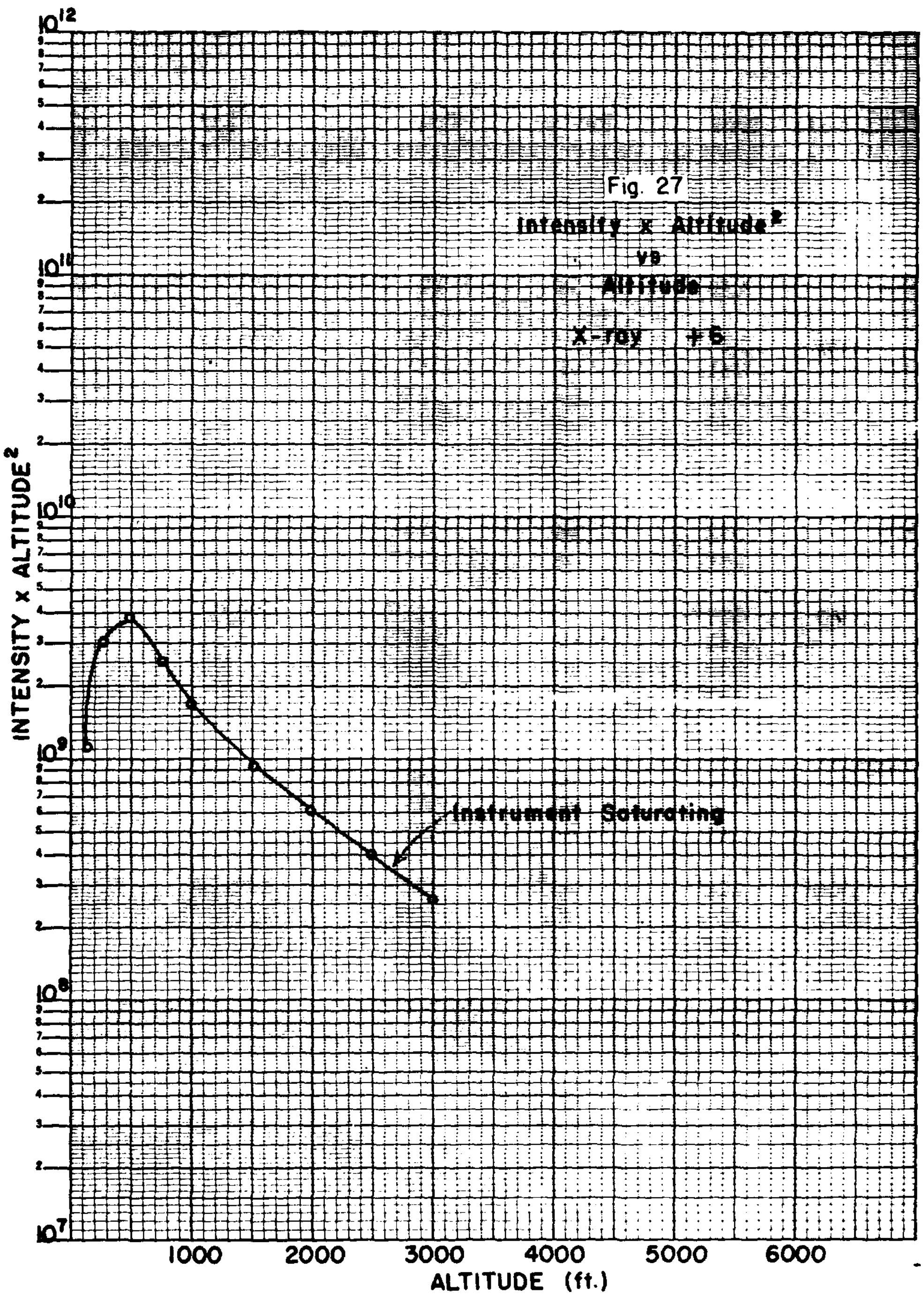


Fig. 27
Intensity x Altitude²
vs
Altitude
X-ray #6
Instrument Saturating
INTENSITY x ALTITUDE²
ALTITUDE (ft.)
1000
2000
3000
4000
5000
6000

FIGURE 28

NAVIGATOR'S DATA - X-RAY DAY

Altitude (Feet)	True Heading	Drift Correction	True Course	Wind Direction/Velocity	Ground Speed (knots)
5000	126°	-2°	128°	100/10	111
	261	-2	263		130
	042	+4	038		115
	169	-4	173		117
4000	126°	-2°	128°	100/10	111
	261	-2	263		127
	042	+4	038		115
	169	-4	173		117
2000	127°	-1°	128°	110/10	111
	261	-2	263		129
	042	+4	038		117
	169	-4	173		116
1000	127°	-1°	128°	120/9	111
	261	-2	263		127
	242	+4	038		118
	169	-4	173		115
3000	126°	-2°	128°	105/10	111
	261	-2	263		129
	042	+4	038		116
	169	-4	173		117
5000	126°	-2°	128°	100/10	111
6000	309	+1	308	110/10	127
7000	127	-1	128	120/10	105
8000	307	-1	308	130/10	125

FIGURE 29

NAVIGATOR'S DATA - X-RAY PLUS 1

Altitude (Feet)	True Heading	Drift Correction	True Course	Wind Direction/ Velocity	True Air Speed (knots)	Ground Speed (knots)
5000	125°	-3°	128°	090/9	120	110
	262	-1	263			128
	042	+4	038			110
	168	-5	173			113
4000	125°	-3°	128°	090/11	120	105
	262	-1	263			125
	042	+4	038			113
	168	-5	173			113
3000	125°	-3°	128°	090/12	120	106
	262	-1	263			130
	043	+5	038			110
	168	-5	173			115
2000	125°	-3°	128°	090/14	120	112
	262	-1	263			128
	042	+4	038			110
	168	-5	173			118
1000	123°	-5°	128°	090/14	120	109
	263	0	263			132
	043	+5	038			110
	166	-7	173			118
750	123°	-5°	128°	090/12	120	108
	263	0	263			130
	043	+5	038			109
	166	-7	173			118
500	123°	-5°	128°	090/10	124	112
	263	0	263			133
	043	+5	038			113
	166	-7	173			121

FIGURE 30

NAVIGATOR'S DATA - X-RAY PLUS 6

Altitude (Feet)	True Heading	Drift Correction	True Course	Indicated Air Speed (mi/hr)	Ground Speed (knots)
3000	121°	-7°	128°	135	106
	264	+1	263		139
	044	+6	038		105
	154	-9	173		120
2000	122°	-6°	128°	135	108
	263	0	263		137
	044	+6	038		107
	165	-8	173		120
1500	122°	-6°	128°	137	108
	263	0	263		137
	044	+6	038		107
	165	-8	173		120
1000	124°	-4°	128°	139	112
	265	+2	263		132
	039	+1	038		108
	169	-4	173		121
750	124°	-4°	128°	140	116
	265	+2	263		129
	039	+1	038		110
	169	-4	173		124
500	124°	-4°	128°	140	120
	265	+2	263		127
	039	+1	038		118
	169	-4	173		127
250	125°	-3°	128°		118
	264	+1	263		130
	038	0	038		110
	170	-3	173		128
100					118
					130
					110
					128

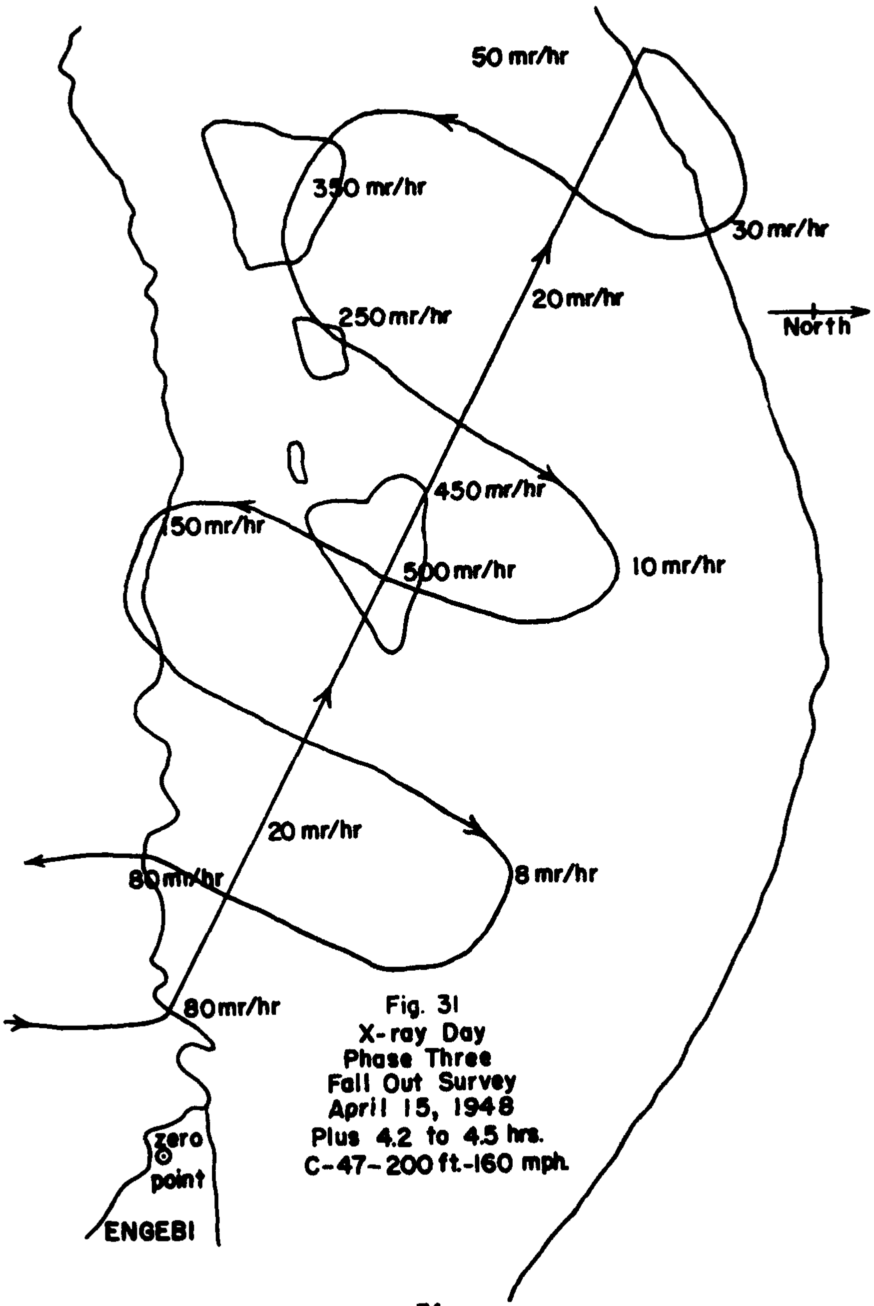


Fig. 31
X-ray Day
Phase Three
Fall Out Survey
April 15, 1948
Plus 4.2 to 4.5 hrs.
C-47-200 ft.-160 mph.

APPENDIX 2

YOKE CRATER CHARTS AND GRAPHS

CONTENTS

FIGURE 1

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - YOKE DAY

Altitude Feet		Leg	Reading	Plus Time (Hours)	Decay Factor	Corrected Value (mr/hr) to H Plus 6 hrs
4000		1	17	7.10	1.19	21.2
		2	18	7.25	1.20	21.6
		3	17	7.33	1.21	20.6
	Average		17.6	7.23	1.20	21.1
3000		1	87	7.40	1.24	108
		2	85	7.45	1.25	106
		3	85	7.50	1.26	107
	Average		85.5	7.45	1.25	106
2000		1	680	7.65	1.29	877
		2	700	7.70	1.30	910
		3	700	7.75	1.31	917
	Average		693	7.70	1.30	903
1500		1	1900	7.95	1.34	2540
		2	1900	8.00	1.35	2565
		3	2000	8.10	1.36	2720
	Average		1933	8.02	1.35	2610
1000		1	6000	8.16	1.37	8230
		2	5500	8.25	1.38	7600
		3	6000	8.30	1.39	8350
	Average		5833	8.25	1.38	8030
750		1	10,000	8.40	1.41	14,100
		2	12,000	8.45	1.42	17,050
		3	12,500	8.50	1.43	17,870
	Average		11,500	8.45	1.42	16,300
600		1	22,000	8.70	1.46	32,100
		2	18,000	8.75	1.47	26,500
		3	23,000	8.80	1.47	33,800
	Average		21,000	8.75	1.47	30,900

FIGURE 2

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - YOKE PLUS 1

Altitude Feet		Leg	Reading	Plus Time (Hours)	Decay Factor	Corrected Value (mr/hr) to H Plus 6 hrs
3000		1	32	26.1	5.80	185.5
		2	30	26.2	5.82	174.5
		3	33	26.3	5.85	177.0
	Average		31.3	26.2	5.82	176.0
2500		1	85	26.4	5.87	500.0
		2	80	26.5	5.90	473.0
		3	85	26.5	5.90	502.0
	Average		83.3	26.5	5.90	492.0
2000		1	195	26.6	5.92	1,155.0
		2	210	26.6	5.92	1,240.0
		3	210	26.7	5.95	1,250.0
	Average		205	26.6	5.92	1,210.0
1500		1	700	26.8	5.97	4,170.0
		2	700	26.9	6.00	4,200.0
		3	700	26.9	6.00	4,200.0
	Average		700	26.9	6.00	4,200.0
1000		1	2400	27.0	6.02	14,455.0
		2	2600	27.1	6.05	15,730.0
		3	2500	27.1	6.05	15,100.0
	Average		2500	27.1	6.05	15,100.0
750		1	4800	27.2	6.07	29,500.0
		2	4700	27.3	6.10	28,700.0
		3	4800	27.3	6.10	29,200.0
	Average		4766	27.3	6.10	28,700.0
500		1	8000	27.4	6.12	49,000.0
		2	8000	27.5	6.15	49,200.0
		3	7500	27.5	6.15	46,200.0
	Average		7833	27.5	6.15	48,200.0

FIGURE 2

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - YOKE PLUS 1

Altitude Feet		Leg	Reading	Plus Time (Hours)	Decay Factor	Corrected Value (mr/hr) to H Plus 6 hrs
250		1	25,000	27.6	6.17	154,000.0
		2	25,000	27.7	6.20	155,000.0
		3	25,000	27.7	6.20	155,000.0
	Average		25,000	27.7	6.20	155,000.0

FIGURE 3

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - YOKE PLUS 9

Altitude Feet		Leg	Reading	Plus Time (Hours)	Decay Factor	Corrected Value (mr/hr) to H plus 6 hrs
2500		1	0.2	218.5	200	40.0
		2	0.2			40.0
		3	0.2			40.0
	Average		0.2			40.0
2000		1	0.7		200	140
		2	0.8			160
		3	0.7			140
	Average		0.7			140
1500		1	2.8		200	560
		2	2.6			520
		3	2.6			520
	Average		2.7			540
1000		1	13.0		200	2600
		2	13.0			2600
		3	10.0			2000
	Average		12.0			2400
750		1	25	219.0	200	5000
		2	25			5000
		3	20			4000
	Average		23.3			4660
500		1	80		200	16,000
		2	60			12,000
		3	60			12,000
	Average		66.6			13,320
250		1	200		200	40,000
		2	160			32,000
		3	160			32,000
	Average		173			34,600

FIGURE 3

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - YOKE PLUS 9

Altitude Feet		Leg	Reading	Plus Time (Hours)	Decay Factor	Corrected Value (mr/hr) to H Plus 6 hrs
100		1	500		200	100,000
		2	400			80,000
		3	380	219.5		76,000
	Average		420			84,000
50		1	600		200	120,000
		2	600			120,000
	Average		600			120,000

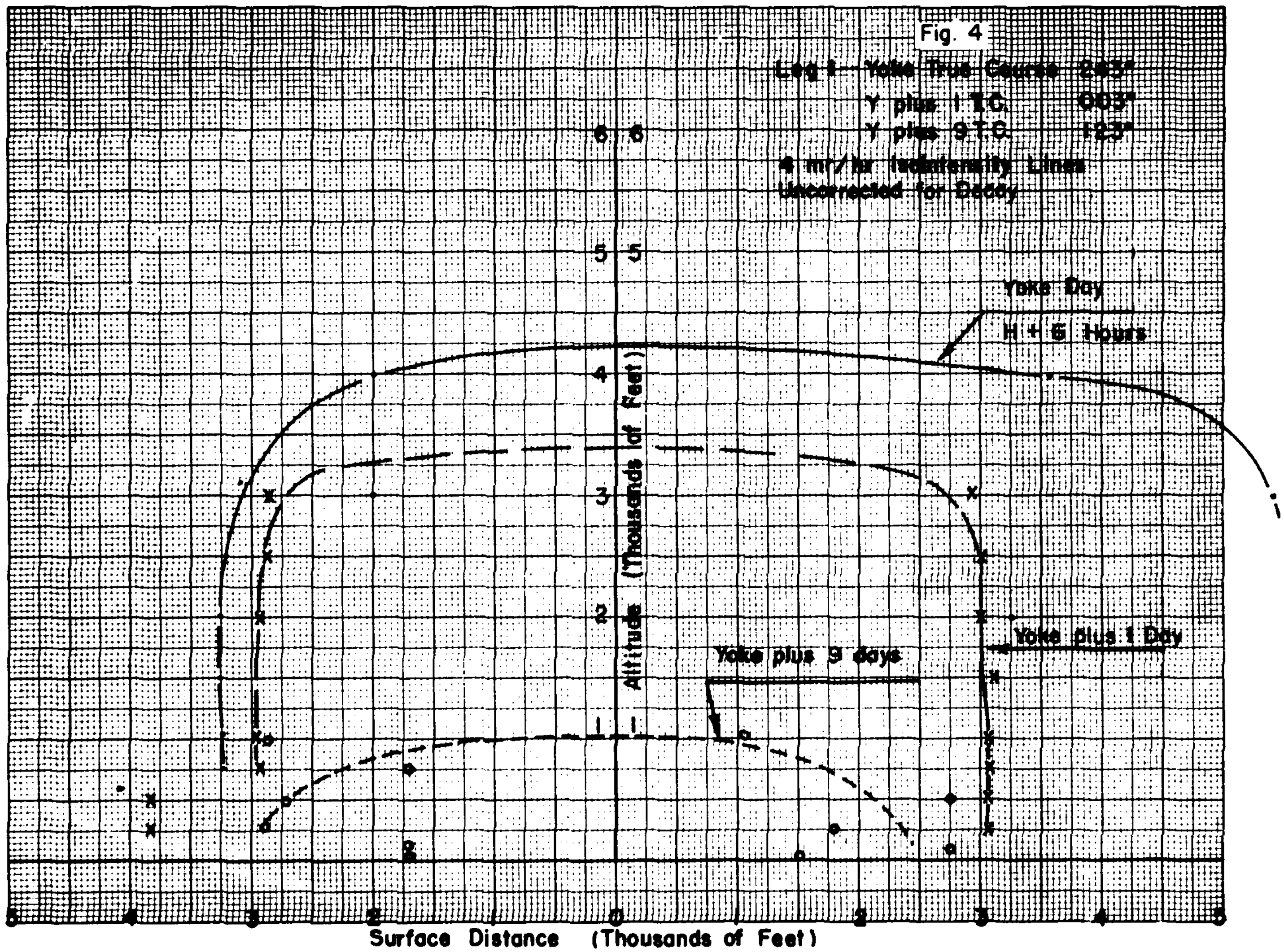


Fig. 4
Leg I — Yoke True Course 263°
Y plus 1 T.C. 003°
Y plus 9 T.C. 123°
4 mr/hr Isointensity Lines
Uncorrected for Decay
Yoke Day
H + 6 Hours
Yoke plus 1 Day
Yoke plus 9 days
Altitude (Thousands of Feet)
Surface Distance (Thousands of Feet)

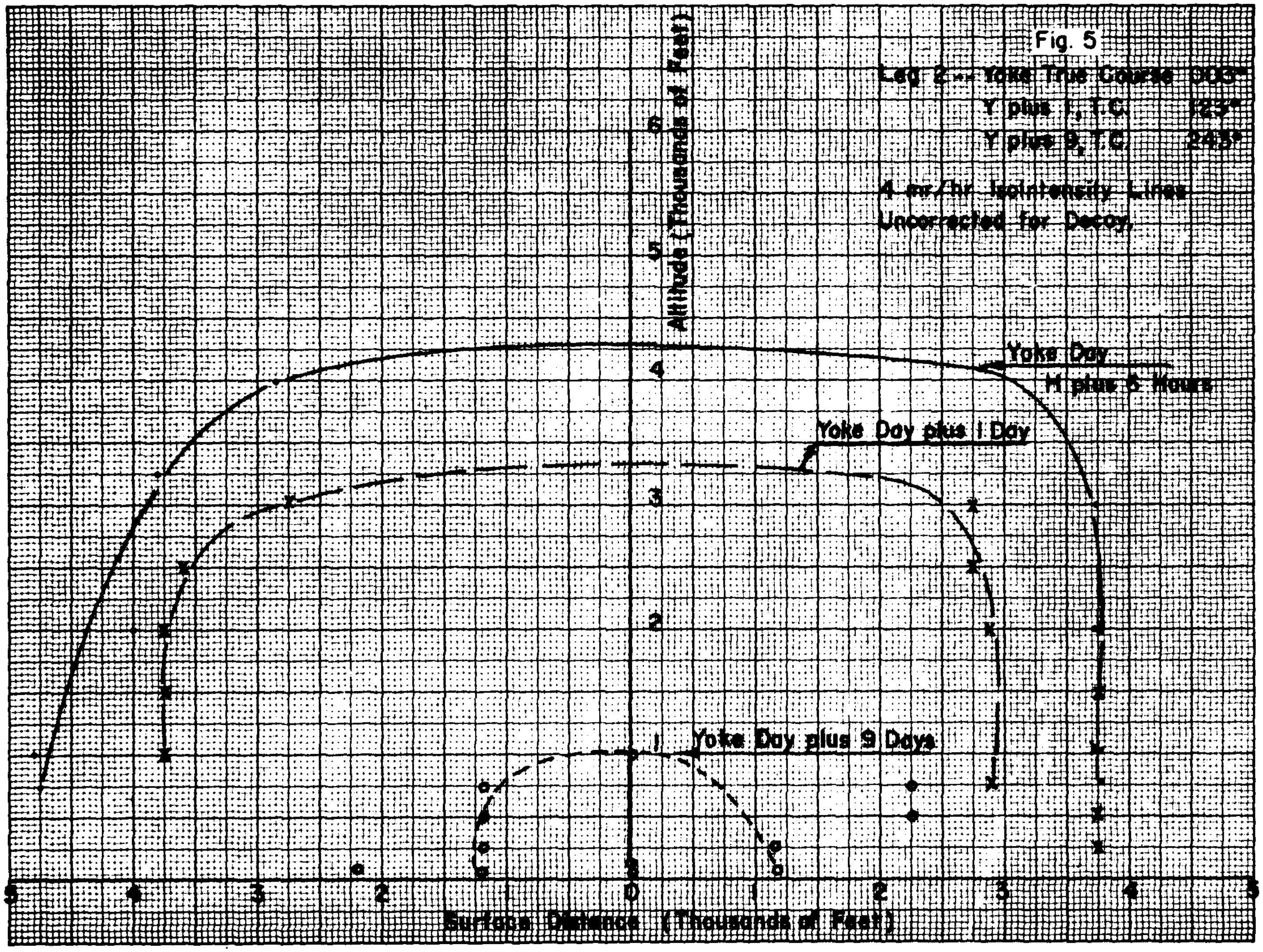

Leg 2 -- Yoke True Course 003°
Y plus 1, T.C. 123°
Y plus 9, T.C. 243°
4 mr/hr Isointensity Lines
Uncorrected for Decay
Yoke Day
H plus 6 Hours
Yoke Day plus 1 Day
Yoke Day plus 9 Days
Altitude (Thousands of Feet)
Surface Distance (Thousands of Feet)
5
4
3
2
1
0
1
2
3
4
5
6

Fig. 5

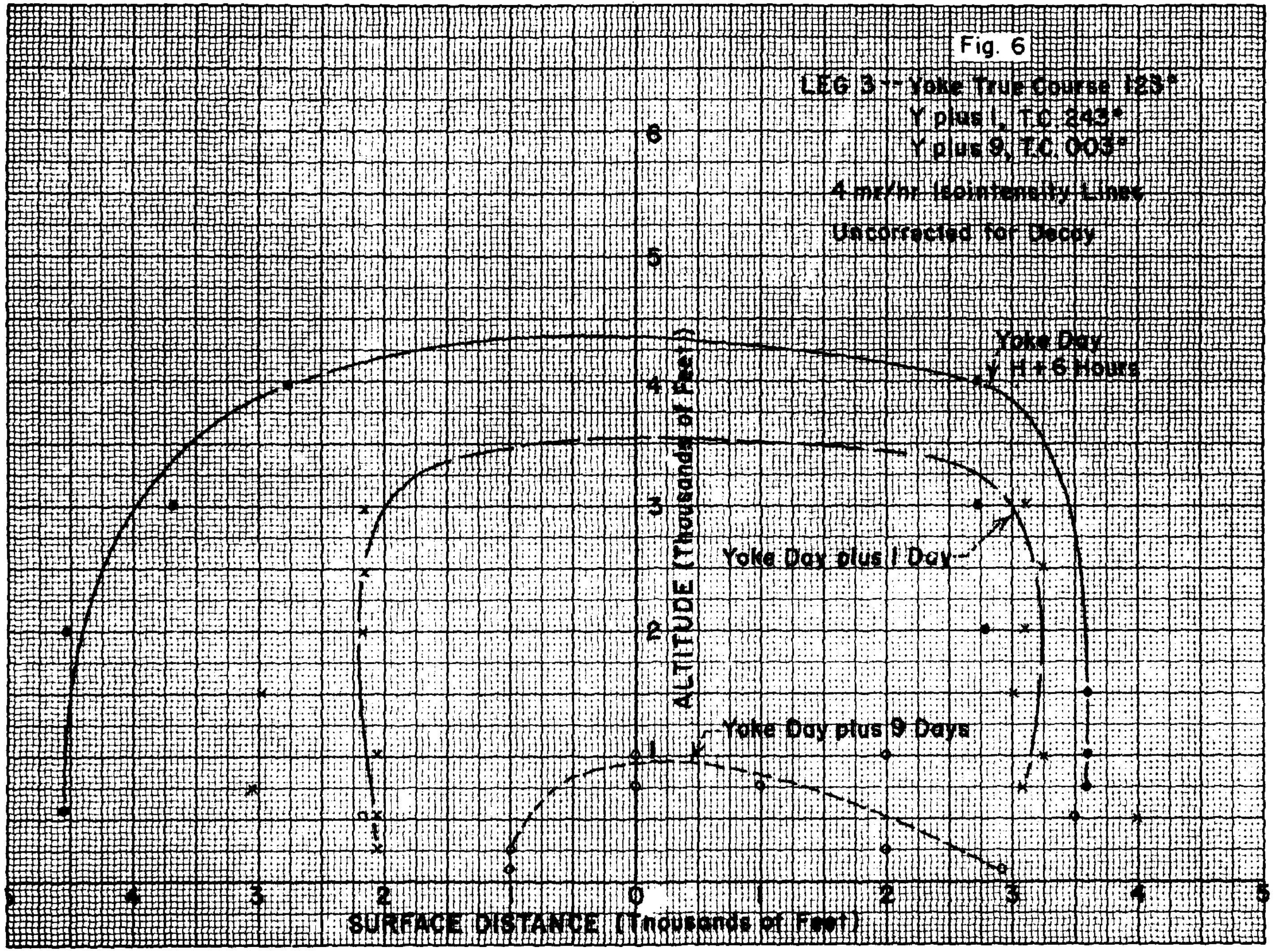


Fig. 6
LEG 3 -- Yoke True Course 123°
Y plus 1, T.C. 243°
Y plus 9, T.C. 003°
4 mr/hr Isointensity Lines
Uncorrected for Decay
Yoke Day
H + 6 Hours
Yoke Day plus 1 Day
Yoke Day plus 9 Days
ALTITUDE (Thousands of Feet)
SURFACE DISTANCE (Thousands of Feet)
1
2
3
4
5
6
5
4
3
2
1
0
1
2
3
4
5

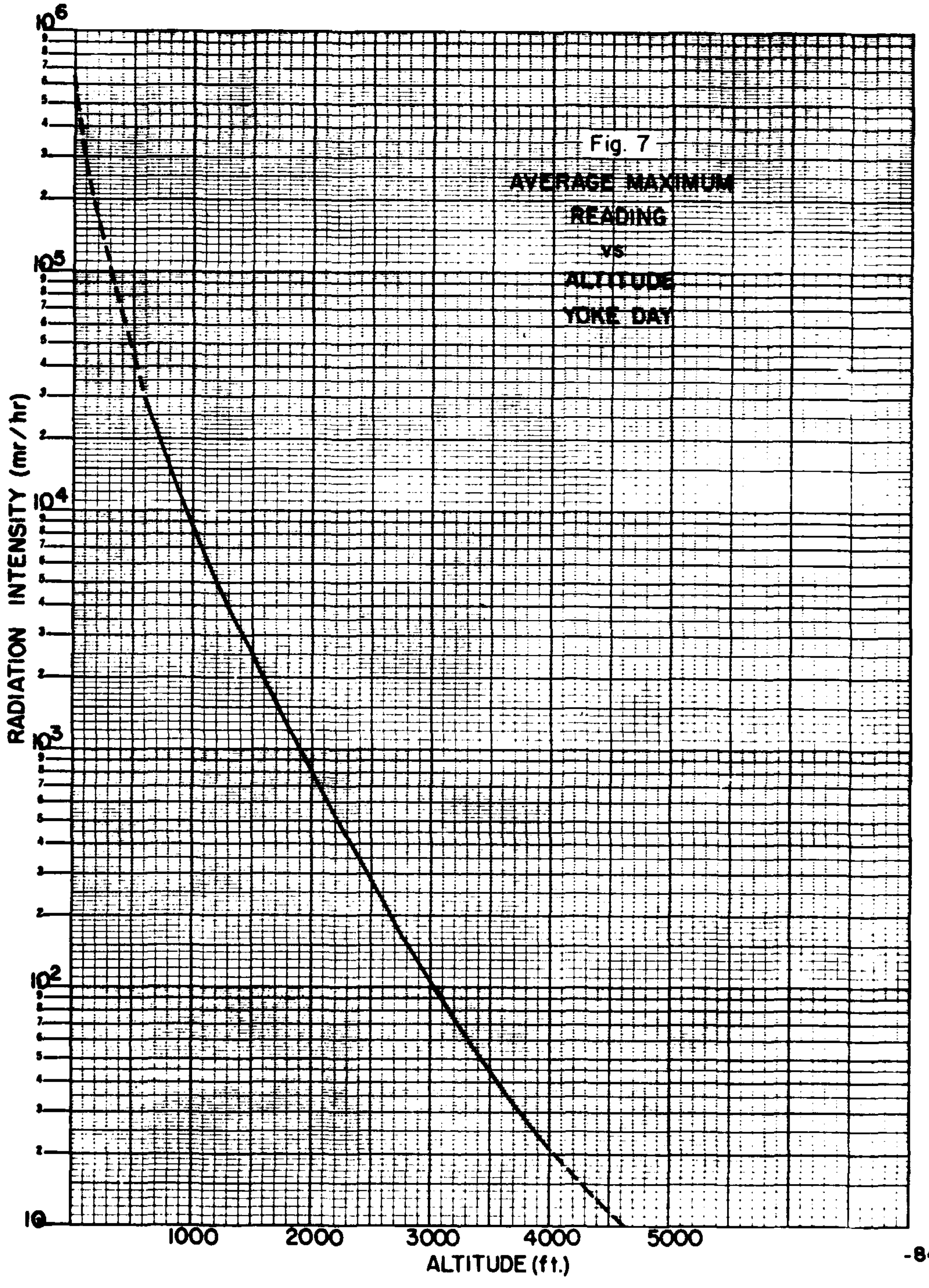


Fig. 7
AVERAGE MAXIMUM
READING
VS
ALTITUDE
YOKE DAY
RADIATION INTENSITY (mr/hr)
ALTITUDE (ft.)
1000
2000
3000
4000
5000

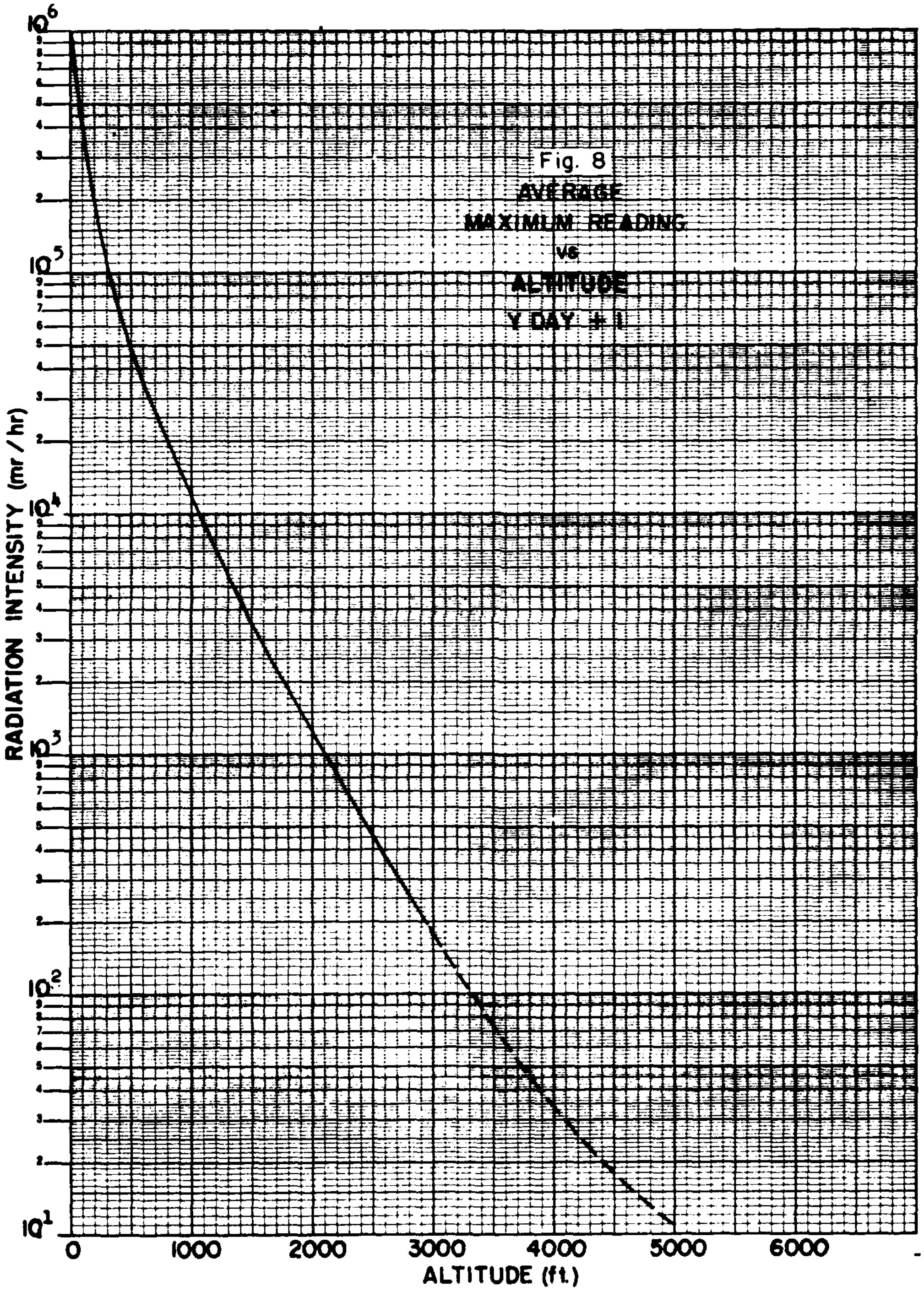


Fig. 8
AVERAGE
MAXIMUM READING
vs
ALTITUDE
Y DAY + 1
RADIATION INTENSITY (mr / hr)
10^6
10^5
10^4
10^3
10^2
10^1
0
1000
2000
3000
4000
5000
6000
ALTITUDE (ft.)

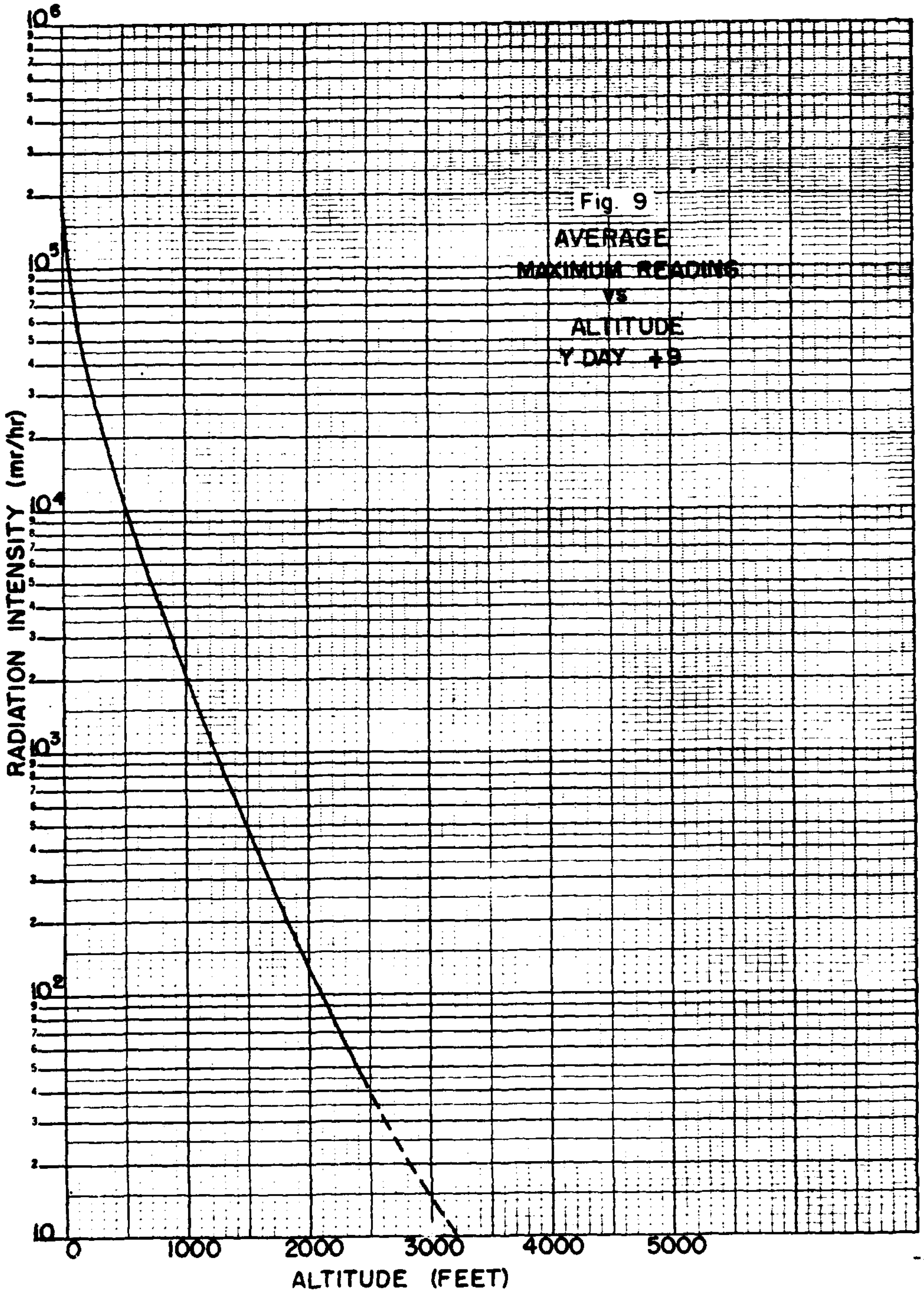


Fig. 9
AVERAGE
MAXIMUM READING
VS
ALTITUDE
Y DAY +9
RADIATION INTENSITY (mr/hr)
ALTITUDE (FEET)
10
10²
10³
10⁴
10⁵
10⁶
0
1000
2000
3000
4000
5000

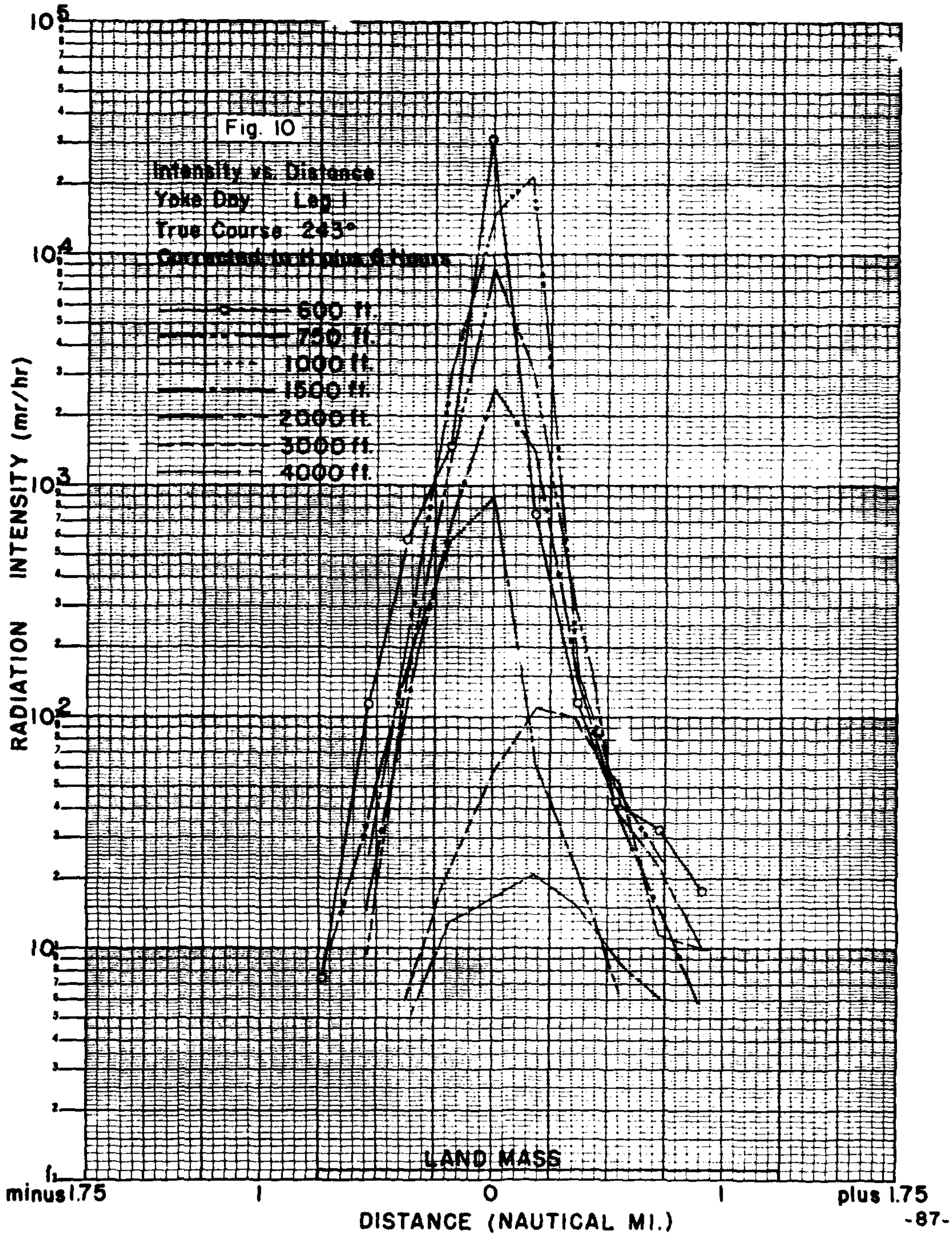


Fig. 10
Intensity vs. Distance
Yoke Day Leg I
True Course 243°
Corrected to H plus 6 Hours
600 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
3000 ft.
4000 ft.
RADIATION INTENSITY (mr/hr)
LAND MASS
minus 1.75
1
0
1
plus 1.75
DISTANCE (NAUTICAL MI.)

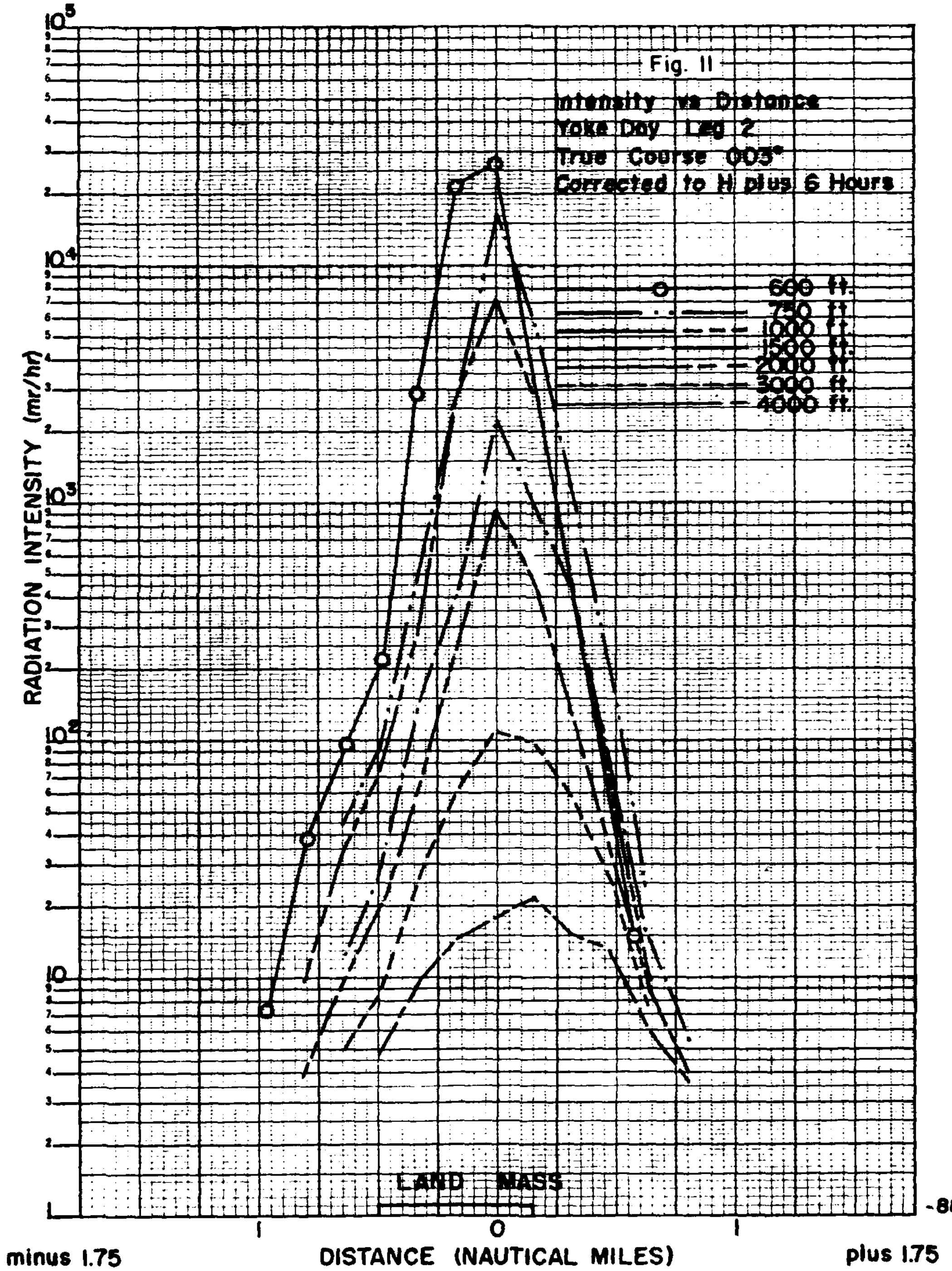


Fig. 11
Intensity vs Distance
Yoke Day Leg 2
True Course 003°
Corrected to H plus 6 Hours
600 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
3000 ft.
4000 ft.
RADIATION INTENSITY (mr/hr)
10^5
10^4
10^3
10^2
10
1
LAND MASS
1
0
1
minus 1.75
DISTANCE (NAUTICAL MILES)
plus 1.75

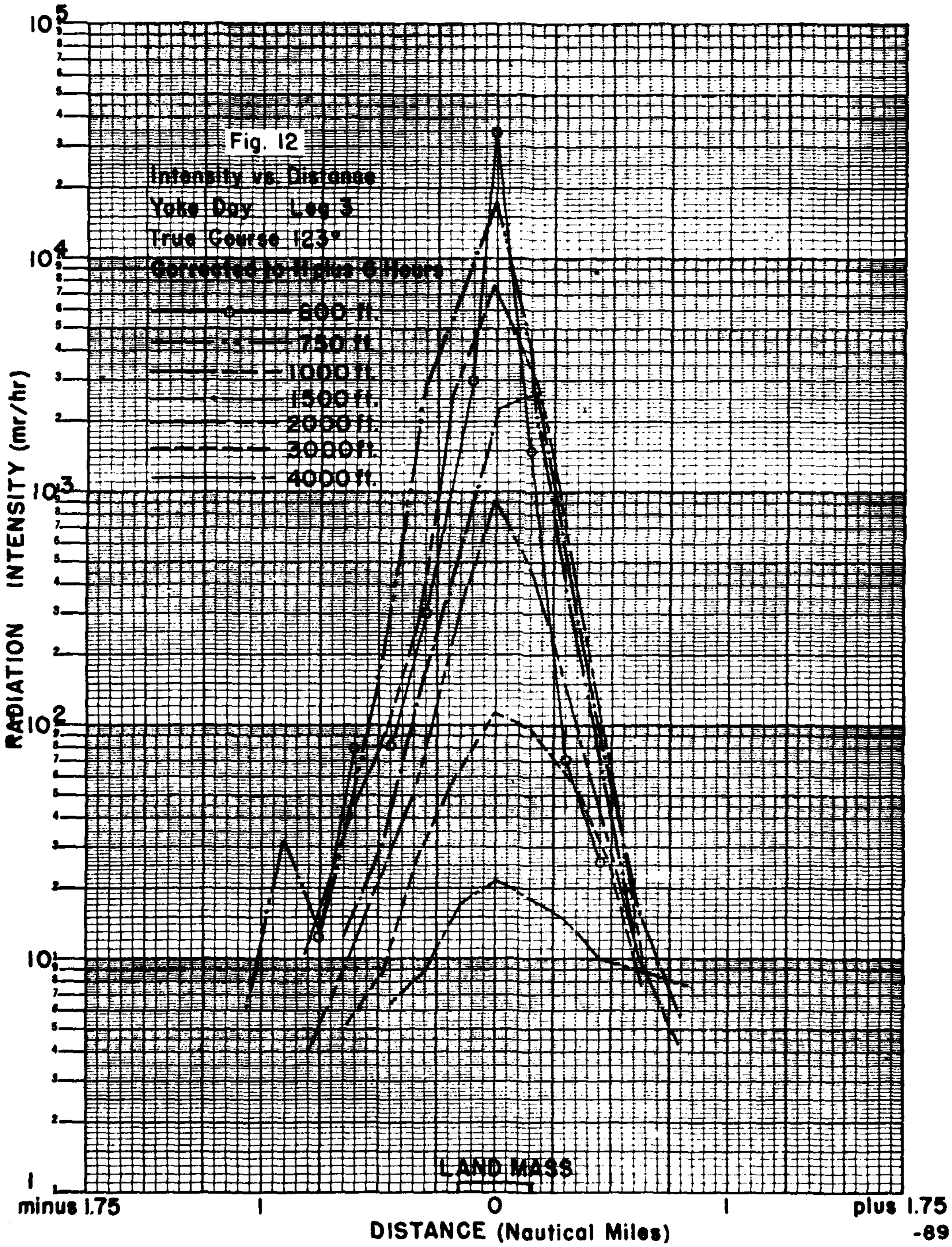


Fig. 12
Intensity vs. Distance
Yoke Day Leg 3
True Course 123°
600 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
3000 ft.
4000 ft.
RADIATION INTENSITY (mr/hr)
10^5
10^4
10^3
10^2
10
1
LAND MASS
minus 1.75
1
0
1
plus 1.75
DISTANCE (Nautical Miles)

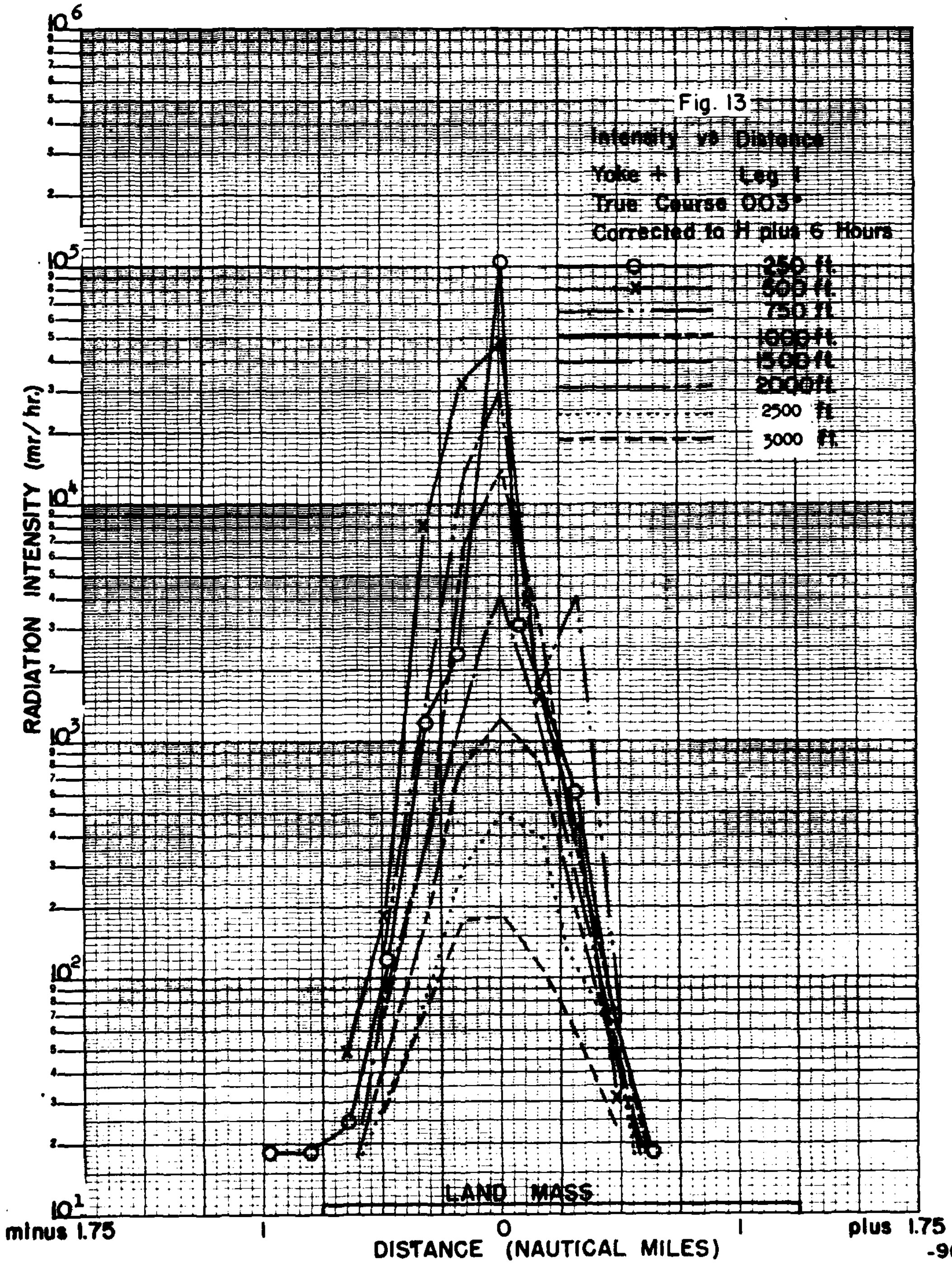


Fig. 13
Intensity vs Distance
Yoke + 1 Leg 1
True Course 003°
Corrected to H plus 6 Hours
250 ft.
500 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
2500 ft.
3000 ft.
RADIATION INTENSITY (mr/hr.)
10^6
10^5
10^4
10^3
10^2
10^1
LAND MASS
minus 1.75
1
0
1
plus 1.75
DISTANCE (NAUTICAL MILES)

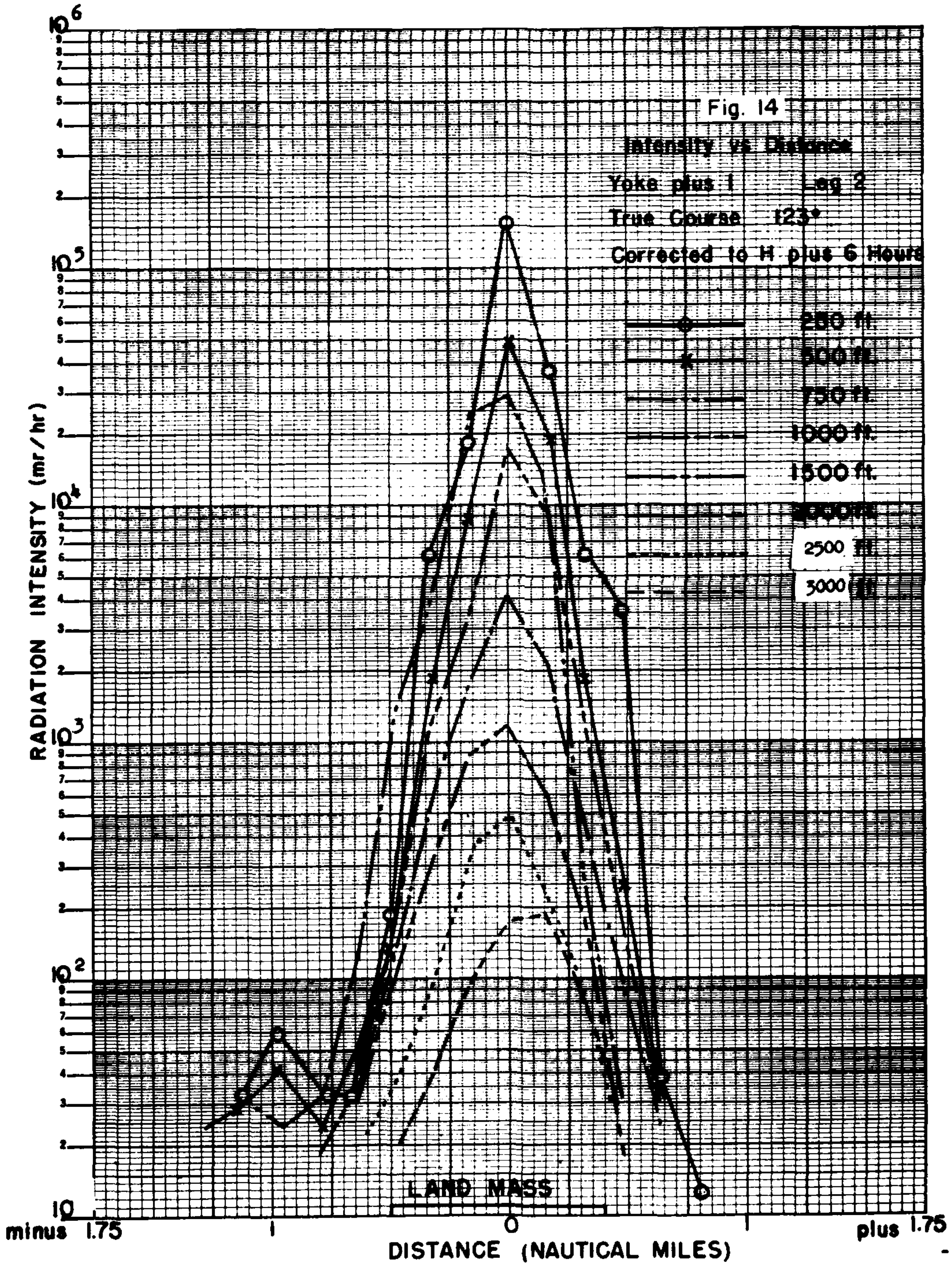


Fig. 14
Intensity vs Distance
Yoke plus 1 Leg 2
True Course 123°
Corrected to H plus 6 Hours
250 ft.
500 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
2500 ft.
3000 ft.
LAND MASS
RADIATION INTENSITY (mr/hr)
DISTANCE (NAUTICAL MILES)
minus 1.75
1
0
1
plus 1.75

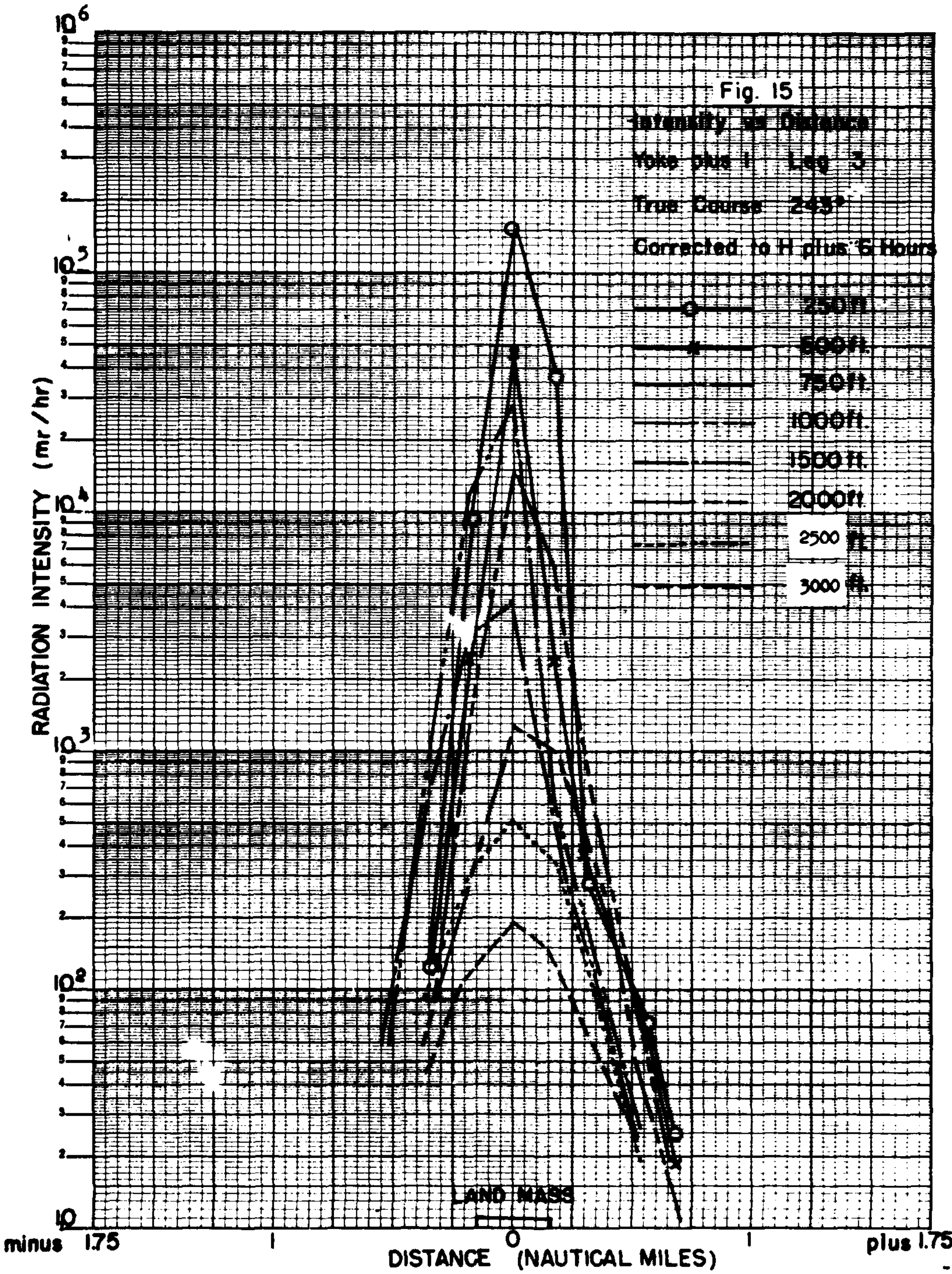


Fig. 15
Yoke plus 1 Leg 3
True Course 243°
Corrected to H plus 6 Hours
250ft.
500ft.
750ft.
1000ft.
1500 ft.
2000ft.
2500 ft.
3000 ft.
RADIATION INTENSITY (mr/hr)
LAND MASS
minus 1.75
1
0
1
plus 1.75
DISTANCE (NAUTICAL MILES)

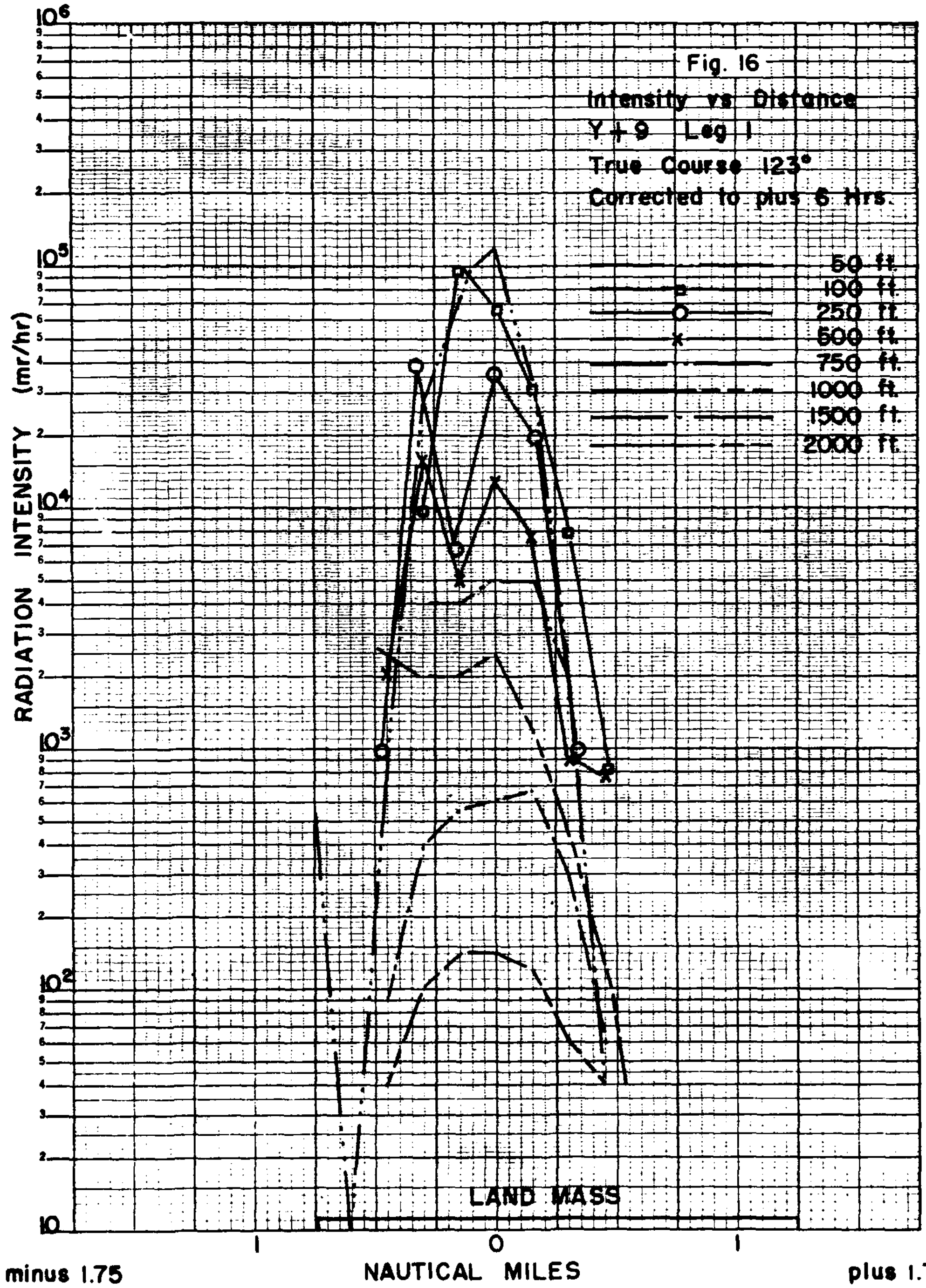


Fig. 16
Intensity vs Distance
Y+9 Leg I
True Course 123°
Corrected to plus 6 Hrs.
50 ft.
100 ft.
250 ft.
500 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
RADIATION INTENSITY (mr/hr)
LAND MASS
NAUTICAL MILES
minus 1.75
plus 1.75

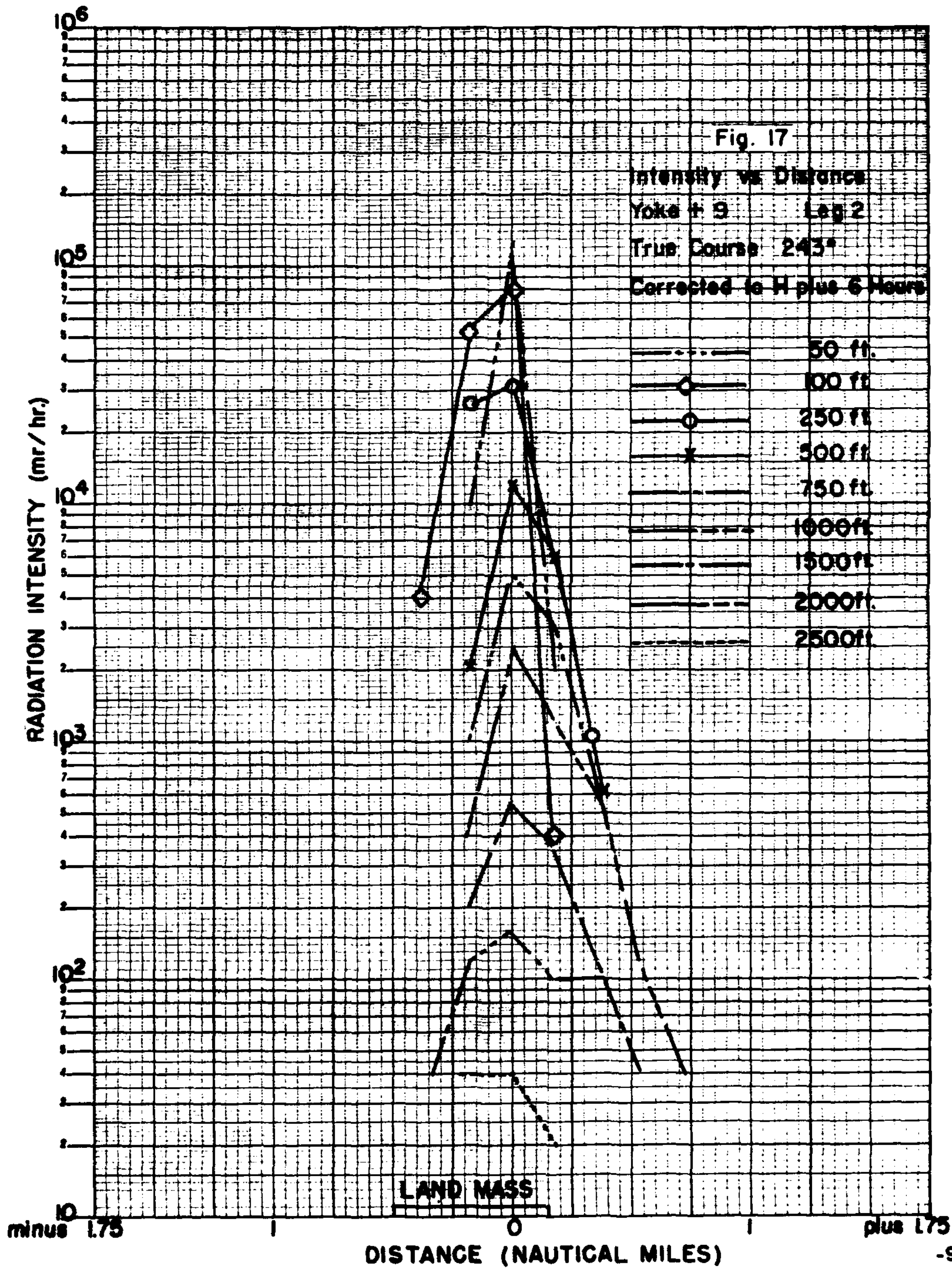


Fig. 17
Intensity vs. Distance
Yoke + 9 Leg 2
True Course 243°
Corrected to H plus 6 Hours
50 ft.
100 ft.
250 ft.
500 ft.
750 ft.
1000ft.
1500ft.
2000ft.
2500ft.
RADIATION INTENSITY (mr/hr.)
10^6
10^5
10^4
10^3
10^2
10
LAND MASS
minus 1.75
1
0
1
plus 1.75
DISTANCE (NAUTICAL MILES)

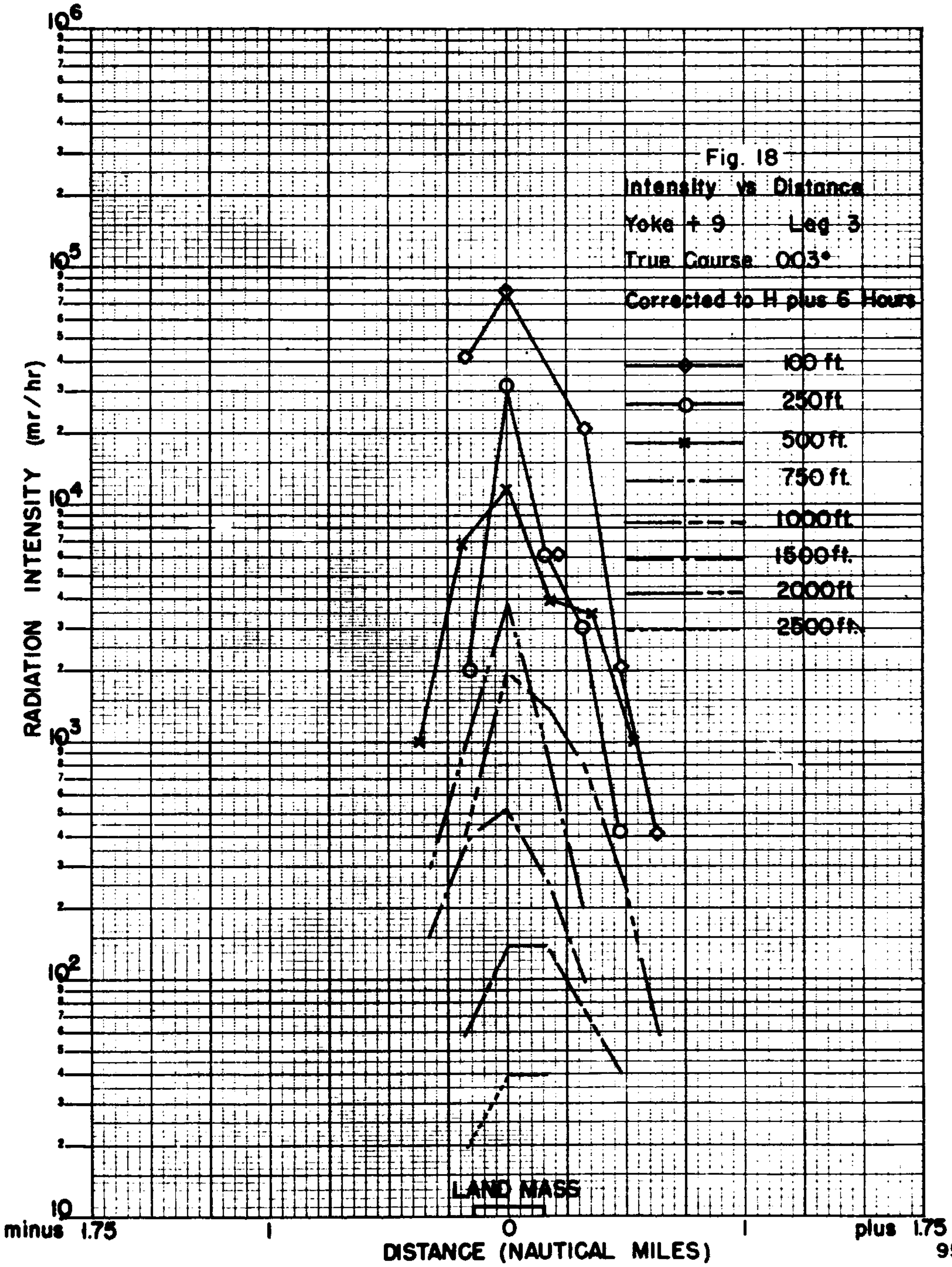


Fig. 18
Intensity vs Distance
Yoke + 9 Leg 3
True Course 003°
Corrected to H plus 6 Hours
100 ft.
250 ft.
500 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
2500 ft.
RADIATION INTENSITY (mr/hr)
10^6
10^5
10^4
10^3
10^2
10
LAND MASS
minus 1.75
1
0
1
plus 1.75
DISTANCE (NAUTICAL MILES)

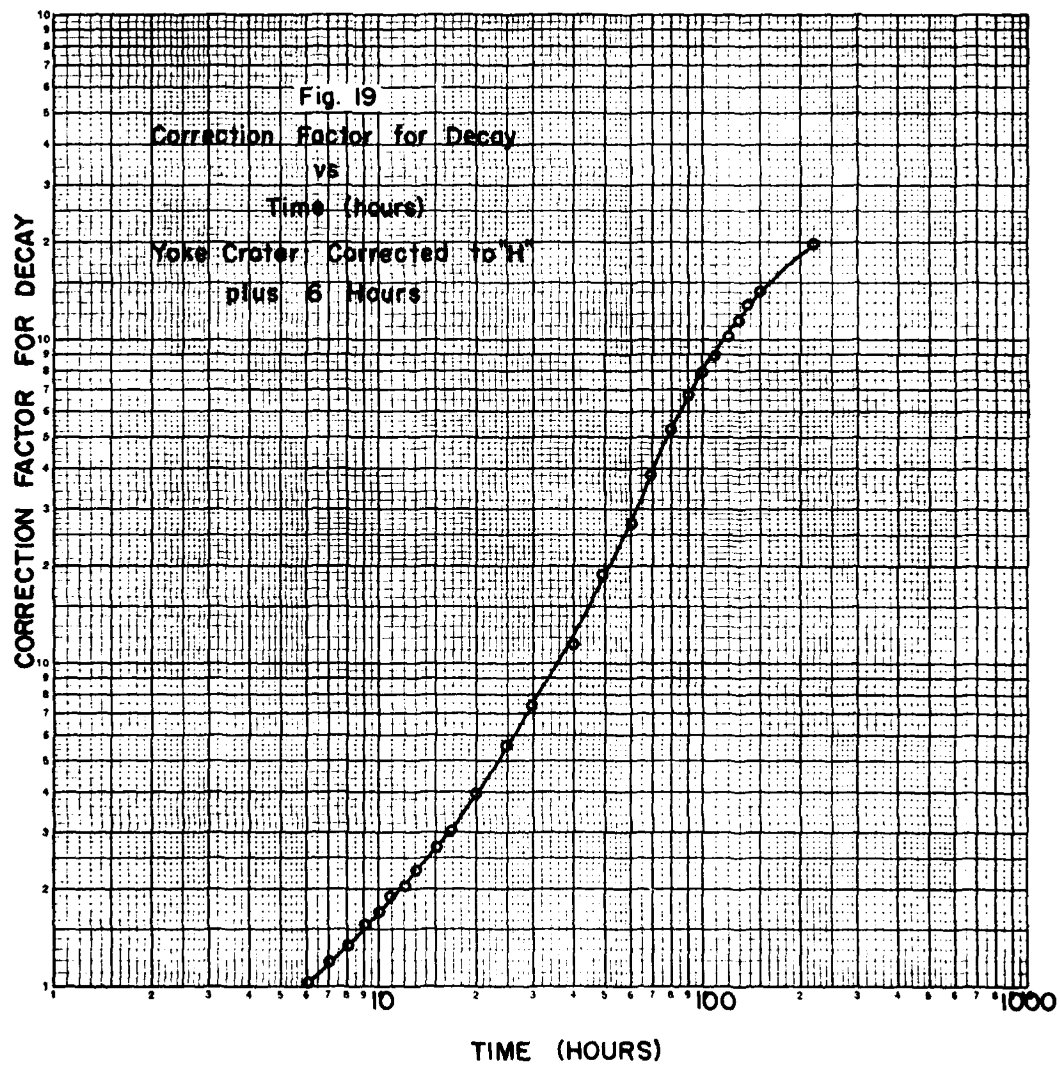


Fig. 19
Correction Factor for Decay
vs
Time (hours)
Yoke Crater Corrected to "H" plus 6 Hours
CORRECTION FACTOR FOR DECAY
10
100
1000
TIME (HOURS)

FIGURE 20

YOKE CRATER

Intensity x Altitude^2 vs Altitude Values

Altitude	Average Maximum Intensity Corrected to H + 6 hrs	Altitude^2	IA^2
Yoke Day			
4000	21.1	1.6×10^7	3.98×10^8
3000	106.	9×10^6	9.54×10^8
2000	903	4×10^6	3.61×10^9
1500	2610	2.25×10^6	5.84×10^9
1000	8030	10^6	8.03×10^9
750	16,300	5.6×10^5	9.04×10^9
600	30,900	3.6×10^5	1.45×10^{10}
Yoke plus 1			
3000	176.	9×10^6	1.58×10^9
2500	492	6.25×10^6	3.07×10^9
2000	1,210	4×10^6	4.84×10^9
1500	4,200	2.25×10^6	9.46×10^9
1000	15,100	10^6	1.51×10^{10}
750	28,700	5.6×10^5	1.63×10^{10}
500	48,200	2.5×10^5	1.21×10^{10}
250	150,000	6.25×10^4	9.38×10^9
Yoke Plus 9			
2500	40	6.25×10^6	2.5×10^8
2000	140	4×10^6	5.6×10^8
1500	540	2.25×10^6	1.2×10^9
1000	2400	10^6	2.4×10^9
750	4660	5.6×10^5	2.6×10^9
500	13,320	2.5×10^5	3.3×10^9
250	34,600	6.25×10^4	2.1×10^9
100	84,000	10^4	8.4×10^8
50	120,000	2.5×10^3	3×10^8

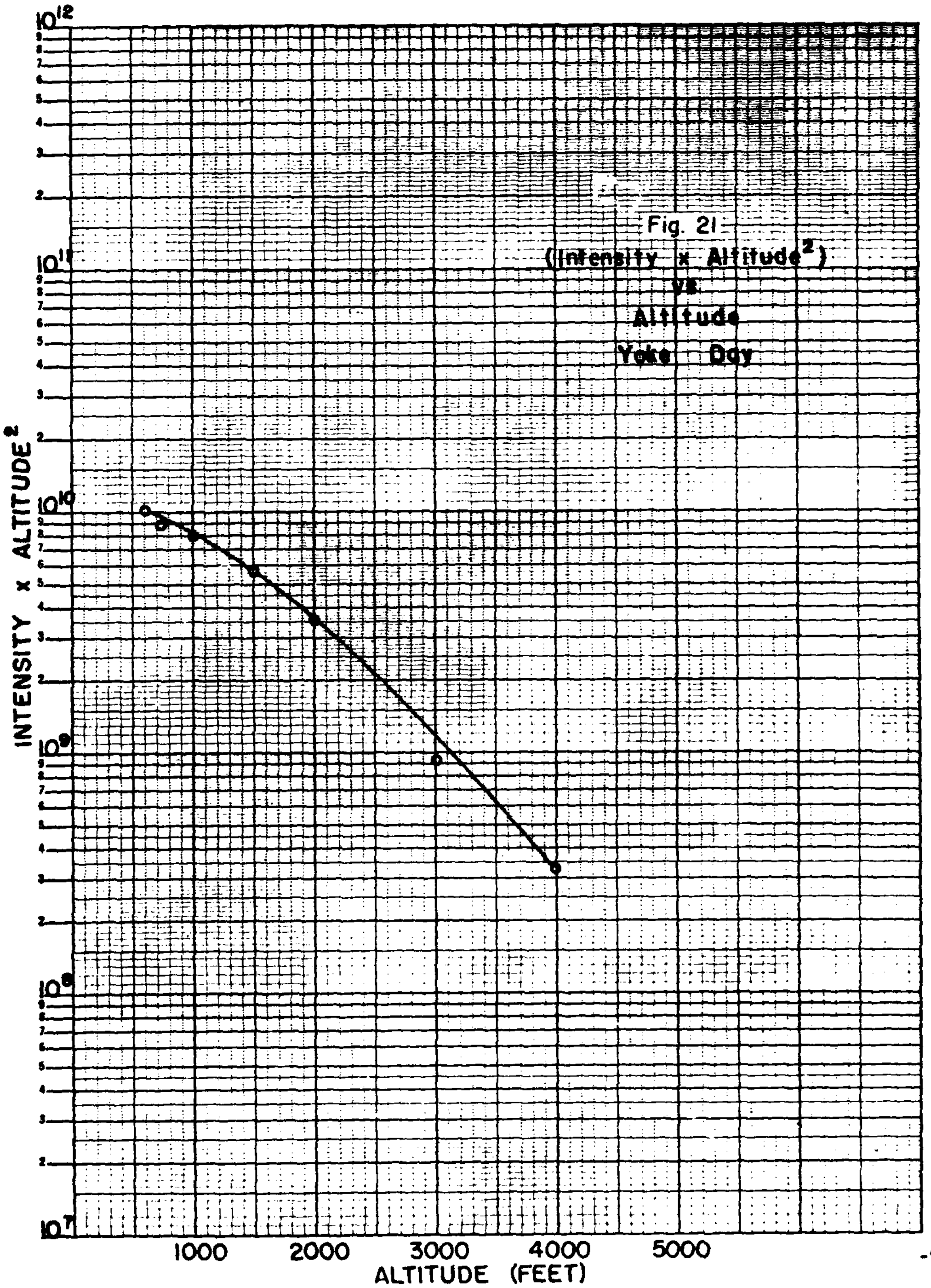


Fig. 21
(Intensity x Altitude^2)
vs
Altitude
Yoke Day
INTENSITY x ALTITUDE^2
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
1000
2000
3000
4000
5000
ALTITUDE (FEET)

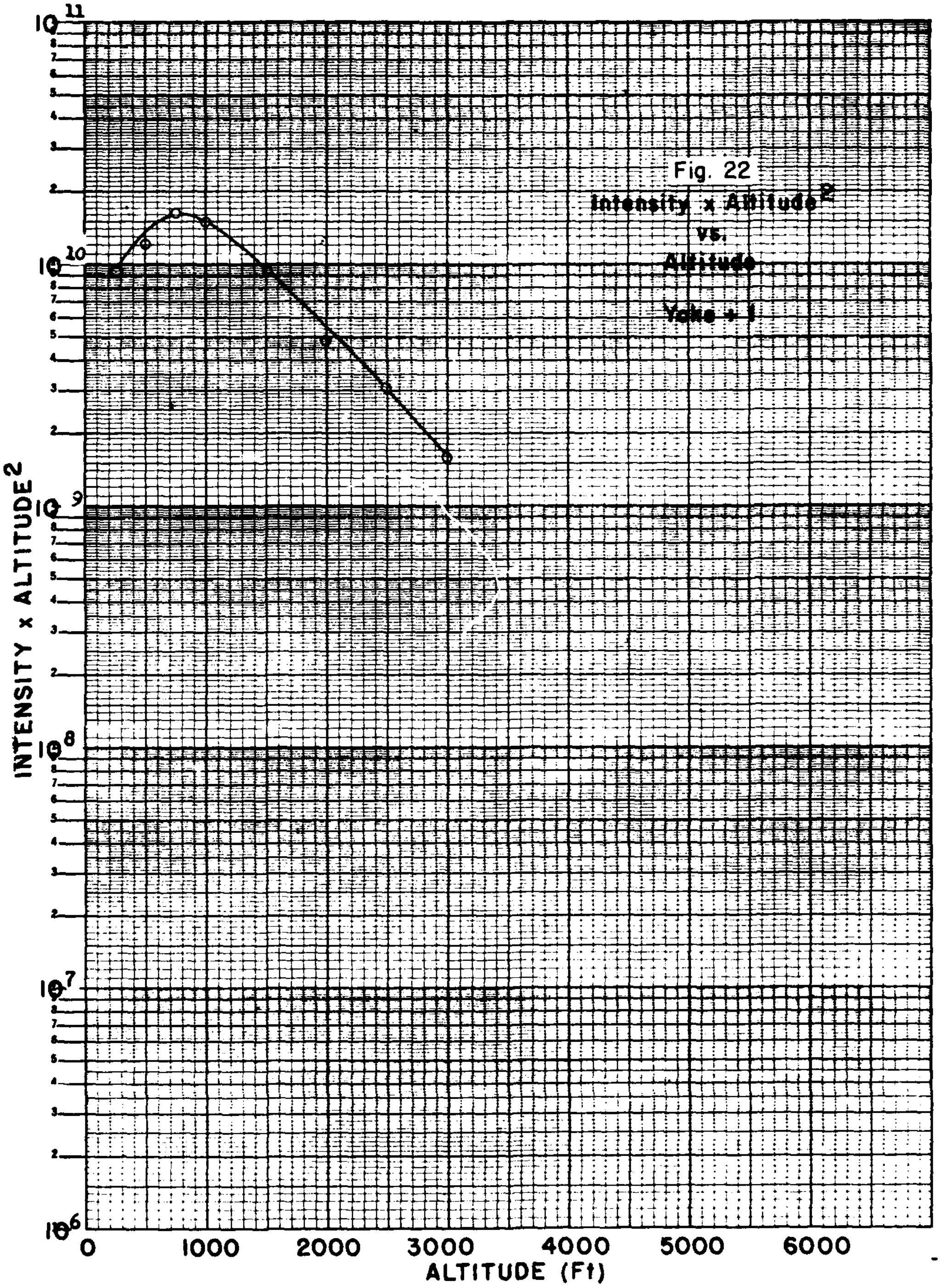


Fig. 22
Intensity x Altitude^2
vs.
Altitude
Yoke + 1
INTENSITY x ALTITUDE^2
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
0
1000
2000
3000
4000
5000
6000
ALTITUDE (Ft)

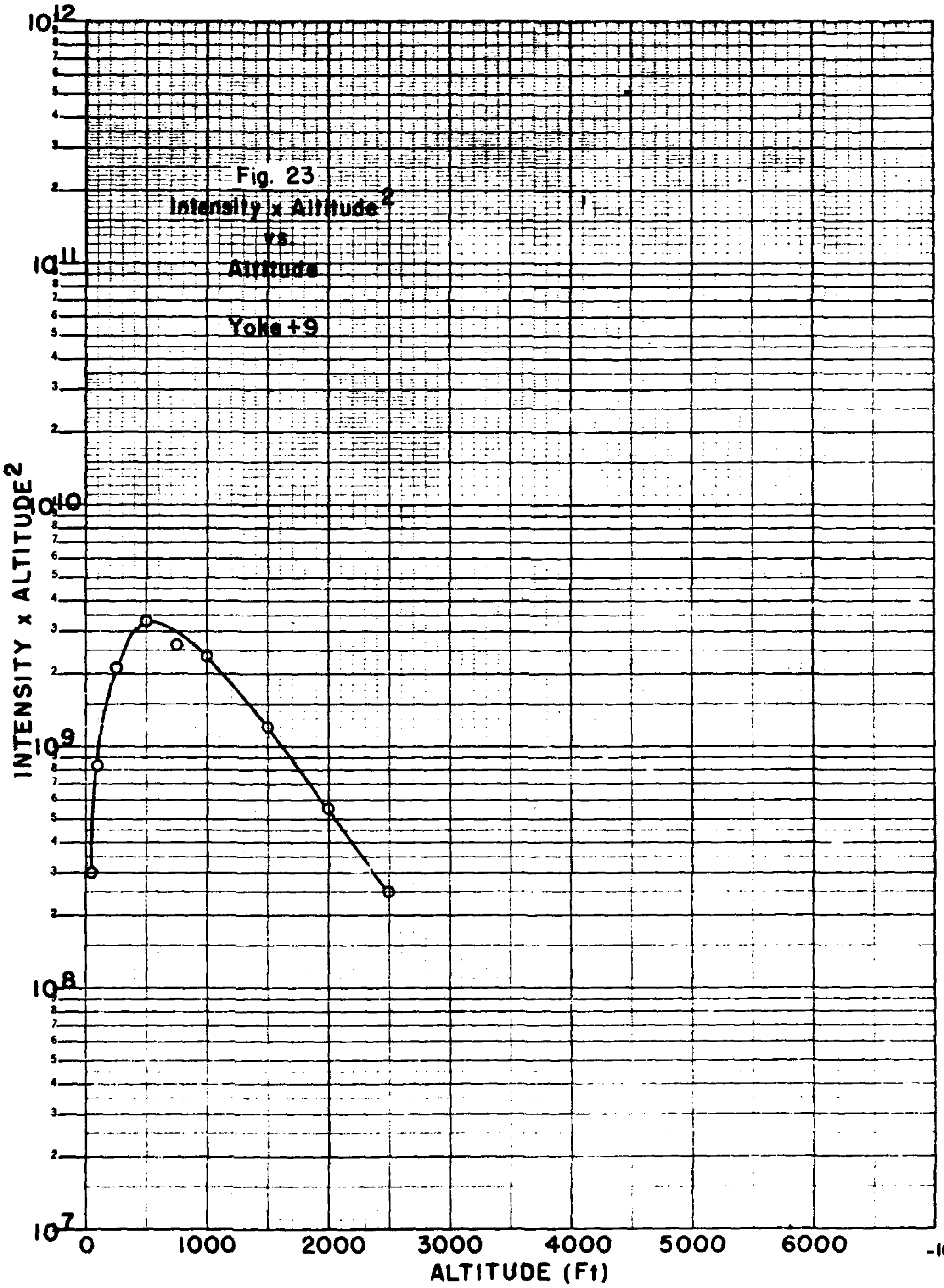


Fig. 23
Intensity x Altitude^2
vs.
Altitude
Yoke +9
INTENSITY x ALTITUDE^2
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
0
1000
2000
3000
4000
5000
6000
ALTITUDE (Ft)

FIGURE 24

NAVIGATOR'S DATA - YOKE DAY

Altitude (feet)	True Heading	Drift Correction	True Course	Wind Direction/ Velocity	Ground Speed (knots)
4000	240°	-3°	243°	090/16	134
	010	+7	003		118
	119	-4	123		106
3000	240°	-3°	243°	090/15	133
	010	+7	003		116
	119	-4	123		106
2000	241°	-2°	243°	080/14	134
	009	+6	003		116
	118	-5	123		109
1000	241°	-2°	243°	080/14	130
	008	+5	003		117
	120	-3	123		112
750	241°	-2°	243°	080/12	131
	008	+5	003		118
	119	-4	123		111
600	241°	-2°	243°	080/12	131
	008	+5	003		117
	119	-4	123		111
1500			243°		130
			003		117
			123		110

FIGURE 25

NAVIGATOR'S DATA - YOKE PLUS 1 DAY

Altitude (feet)	True Heading	Drift Correction	True Course	Wind Direction/ Velocity	Ground Speed (knots)
3000	008°	+5°	003°	080/12	120
	120	-3	123		110
	240	-3	243		130
2500	008°	+5°	003°	080/11	118
	119	-4	123		112
	242	-1	243		131
2000	008°	+5°	003°	080/10	118
	120	-3	123		113
	242	-1	243		130
1500	008°	+5°	003°	080/10	118
	120	-3	123		113
	242	-1	243		130
1000	007°	+4°	003°	090/8	120
	121	-2	123		114
	241	-2	243		128
750	007°	+4°	003°	090/7	121
	121	-2	123		115
	241	-2	243		129
500	007°	+4°	003°	090/8	121
	121	-2	123		115
	241	-2	243		129
250			003°		120
			123		114
			243		128

FIGURE 26

NAVIGATOR'S DATA - YOKE PLUS 9 DAY

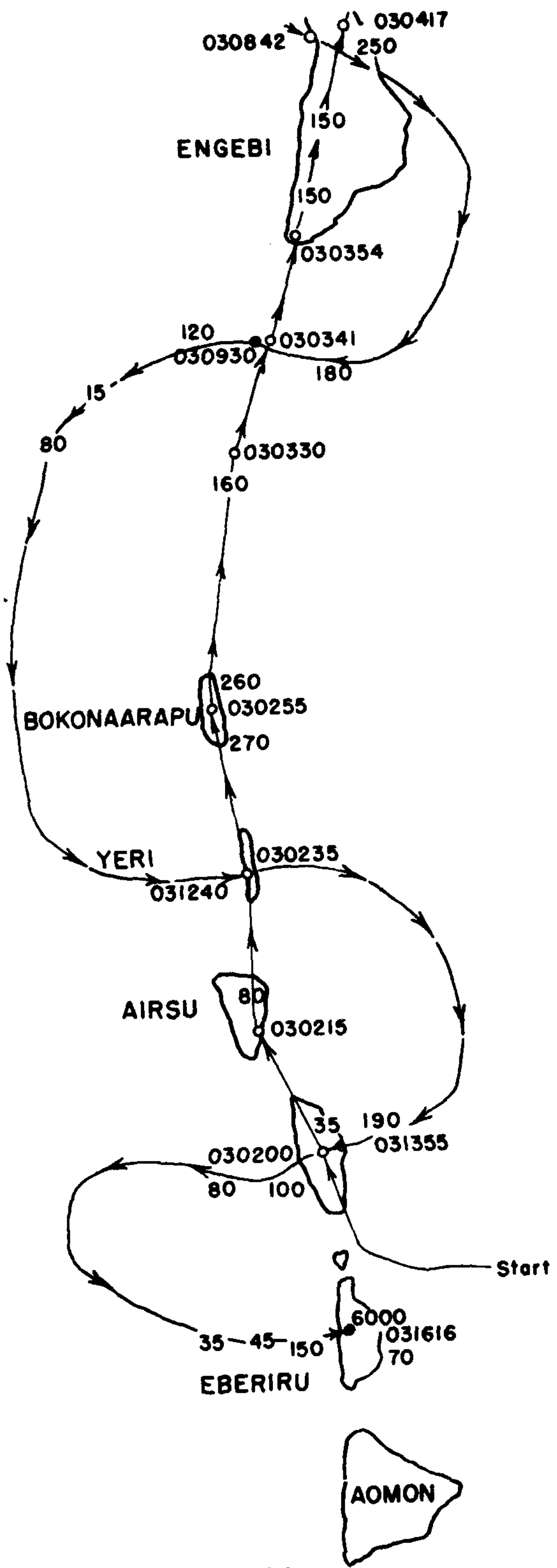
Altitude (feet)	True Heading	Drift Correction	True Course	Ground Speed (knots)	
2500	120°	-3°	123°		No run on this leg
	242	-1	243	130	1st leg
	007	+4	003	118	2nd leg
2000	120°	-3°	123°	112	
	242	-1	243	129	
	007	+4	003	117	
1500			123°	112	
			243	129	
			003	117	
1000			123°	114	
			243	130	
			003	117	
750			123°	112	
			243	130	
			003	117	
500			123°	112	
			243	129	
			003	117	
250			123°	114	
			243	131	
			003	118	
100			123°	112	
			123	129	
			003	117	
50			123°	112	
			243	129	
			003		No run
100	126°	-3°	129°	115	Engebi X-ray plus 24
	256	-1	257	132	
	049	+3	046	120	

Fig. 27

YOKE DAY
PHASE THREE
FALL-OUT SURVEY

May 1, 1948

C-47 200 ft. ALT.
160 mph Const. Air Speed



APPENDIX 3

ZEBRA CRATER CHARTS AND GRAPHS

CONTENTS

FIGURE 1

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - ZEBRA DAY

Altitude (feet)	Leg	Reading	Plus Time (hours)	Decay Factor	Corrected Value (mr/hr) to H Plus 2 hrs
6000	1	1	2.35	1.06	1.06
5000	1	3	2.45		3.18
	2	3	2.60		3.18
	3	2.5	2.66		2.65
	Average	2.8	2.60		3.18
4000	1	10.5	2.70	1.07	11.2
	2	10.5	2.77		11.2
	3	10.5	2.82		11.2
	Average	10.5	2.77		11.2
3000	1	60	2.90	1.08	64.8
	2	60	2.95		64.8
	3	55	3.05		59.4
	Average	58	2.98		62.7
2000	1	340	3.11	1.095	367
	2	340	3.16		367
	3	340	3.24	1.10	374
	Average	340	3.17		367
1500	1	1200	3.32		1320
	2	1100	3.38		1155
	3	1200	3.45	1.11	1330
	Average	1180	3.38		1300
1000	1	3900	3.50		4330
	2	3700	3.60		4110
	3	3900	3.65		4330
	Average	3833	3.57		4250

FIGURE 1

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - ZEBRA DAY
(Continued)

Altitude (feet)		Leg	Reading	Plus Time (hours)	Decay Factor	Corrected Value (mr/hr) to H Plus 2 hrs
750		1	6000	3.70	1.12	6555
		2	6000	3.77		6555
		3	7000	3.83		7840
	Average		6333	3.77		7010
500		1	14,000	3.90		15,700
		2	14,000	3.98	1.13	15,850
		3	14,000	4.03		15,850
	Average		14,000	3.97		15,850
400		1	21,000	4.08		23,700
		2	20,000	4.15		22,600
		3	20,000	4.20	1.14	22,800
	Average		20,333	4.14		22,700

FIGURE 2

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - ZEBRA PLUS 1

Altitude (feet)		Leg	Reading	Plus Time (hours)	Decay Factor	Corrected Value (mr/hr) to H Plus 2 hrs
5000		1	0.5	26.33	7.6	3.8
4000		1	1.8	26.45	7.64	13.6
		2	1.8	26.55	7.7	14.55
		3	2.0	26.62	7.7	15.4
	Average		1.9	26.53	7.68	14.6
3000		1	10.0	26.67	7.75	77.5
		2	13.0	26.75	7.79	101.0
		3	12.0	26.80	7.81	93.7
	Average		11.7	26.74	7.78	91.0
2000		1	85.0	26.84	7.83	665.0
		2	80.0	26.90	7.86	629.0
		3	80.0	27.02	7.92	633.0
	Average		81.7	26.92	7.88	644.0
1500		1	250	27.08	7.94	1,985.0
		2	240	27.12	7.96	1,910.0
		3	240	27.20	8.00	1,920.0
	Average		243.3	27.13	7.97	1,925.0
1000		1	1000	27.28	8.03	8,030.0
		2	1200	27.35	8.06	9,670.0
		3	1200	27.40	8.08	9,700.0
	Average		1133.3	27.34	8.05	9,100.0
750		1	2100	27.43	8.10	17,000.0
		2	2300	27.50	8.13	18,700.0
		3	2400	27.60	8.18	19,600.0
	Average		2266.7	27.51	8.14	18,430.0

FIGURE 2

MAXIMUM READINGS

C-47 RADIOLOGICAL SURVEY - ZEBRA PLUS 1
(Continued)

Altitude (feet)	Leg	Reading	Plus Time (hours)	Decay Factor	Corrected Value (mr/hr) to H Plus 2 hrs
500	1	5000	27.65	8.20	410,000.0
	2	5000	27.70	8.24	412,000.0
	3	4800	27.77	8.25	397,000.0
	Average	4933	27.37	8.22	405,000.0
250	1	12,000	27.82	8.27	993,000.0
	2		27.87	8.30	954,000.0
	3		27.92	8.34	1,000,000.0
	Average		27.87	8.30	990,000.0
150	1	20,000	28.10	8.44	1,677,000.0
	2	22,000	28.00	8.38	1,845,000.0
	3	20,000	28.05	8.36	1,670,000.0
	Average	20,700	28.05	8.38	1,735,000.0

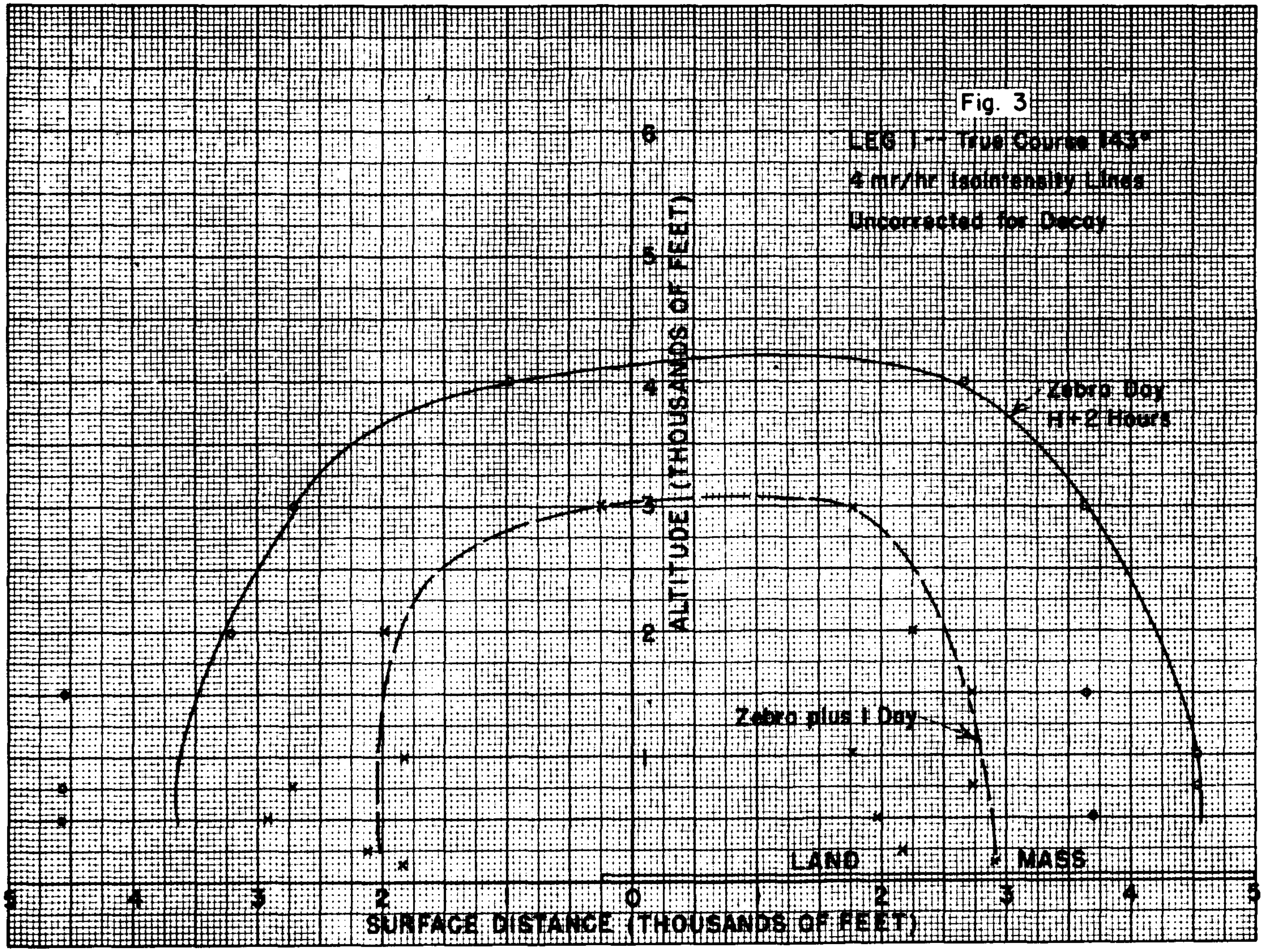


Fig. 3
LEG I -- True Course 143°
4 mr/hr Isointensity Lines
Uncorrected for Decay
Zebra Day
H+2 Hours
Zebra plus 1 Day
LAND
MASS
ALTITUDE (THOUSANDS OF FEET)
SURFACE DISTANCE (THOUSANDS OF FEET)

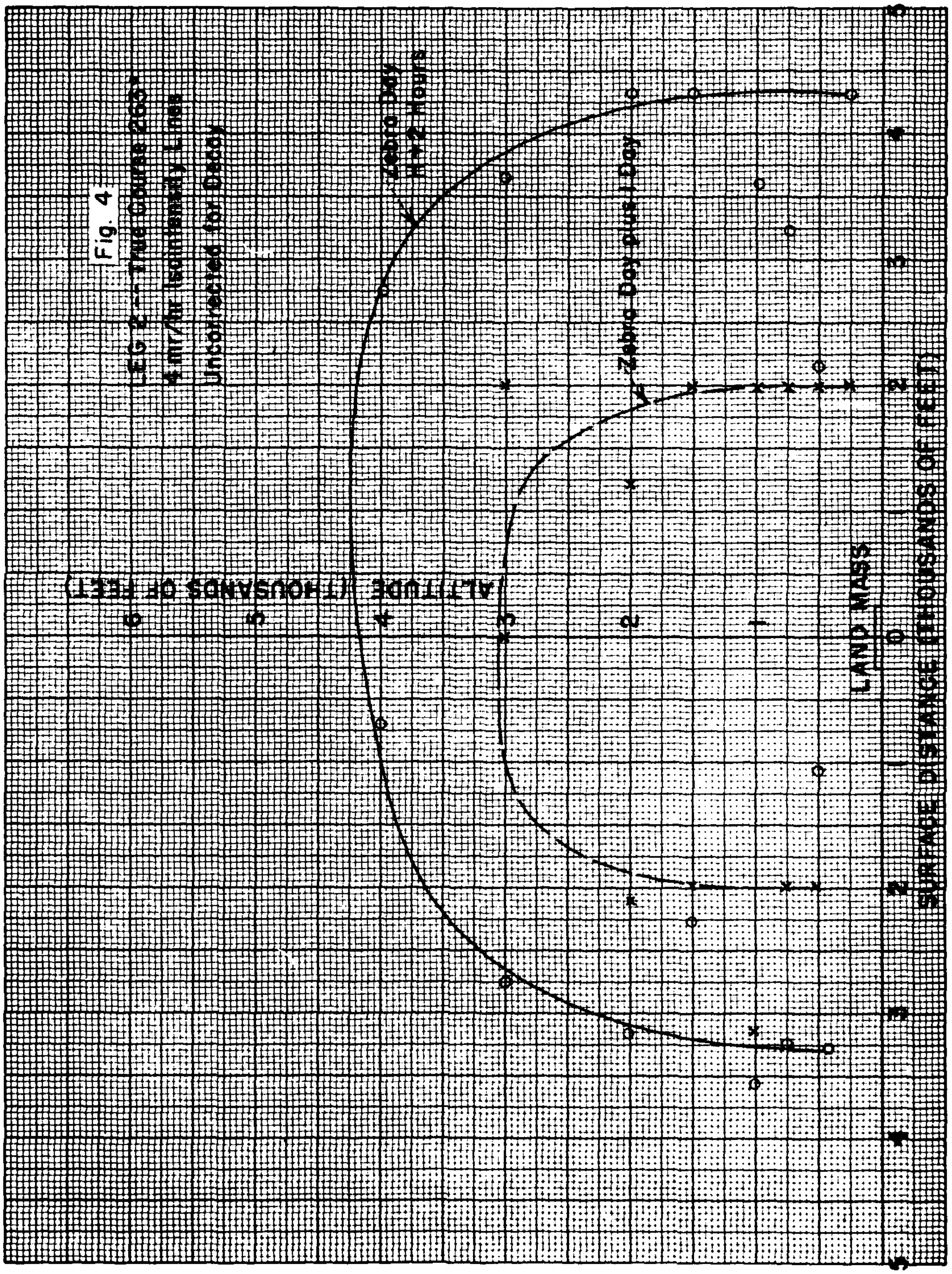


Fig. 4
LEG 2 -- True Course 265°
4 mr/hr Isointensity Lines
Uncorrected for Decay
Zebra Day
H+2 Hours
Zebra Day plus 1 Day
ALTITUDE (THOUSANDS OF FEET)
6
5
4
3
2
1
LAND MASS
SURFACE DISTANCE (THOUSANDS OF FEET)
5
4
3
2
1
0
1
2
3
4
5

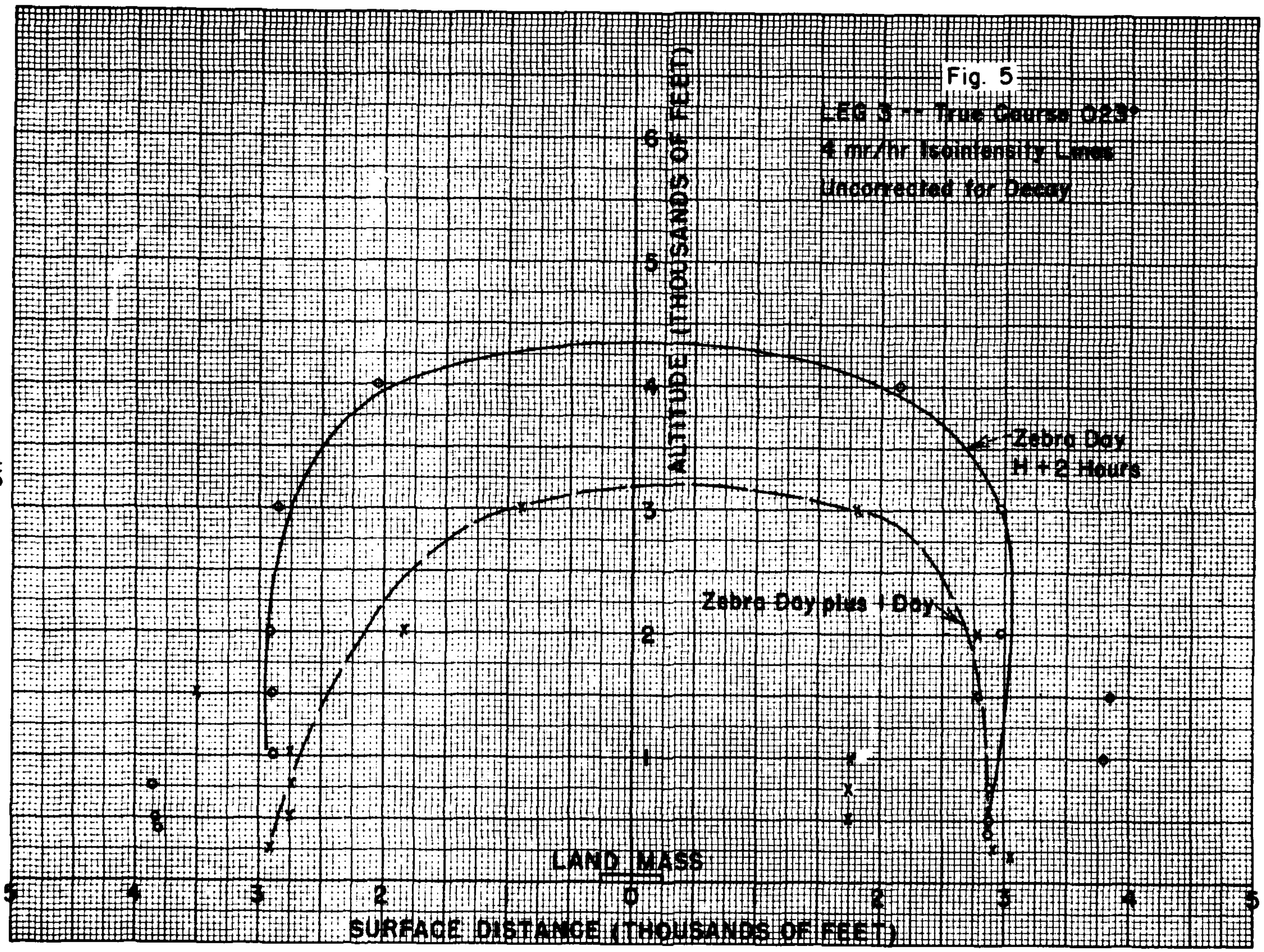


Fig. 5
LEG 3 -- True Course 023°
4 mr/hr Isointensity Lines
Uncorrected for Decay
Zebra Day
H + 2 Hours
Zebra Day plus 1 Day
ALTITUDE (THOUSANDS OF FEET)
6
5
4
3
2
1
LAND MASS
5
4
3
2
0
2
3
4
5
SURFACE DISTANCE (THOUSANDS OF FEET)

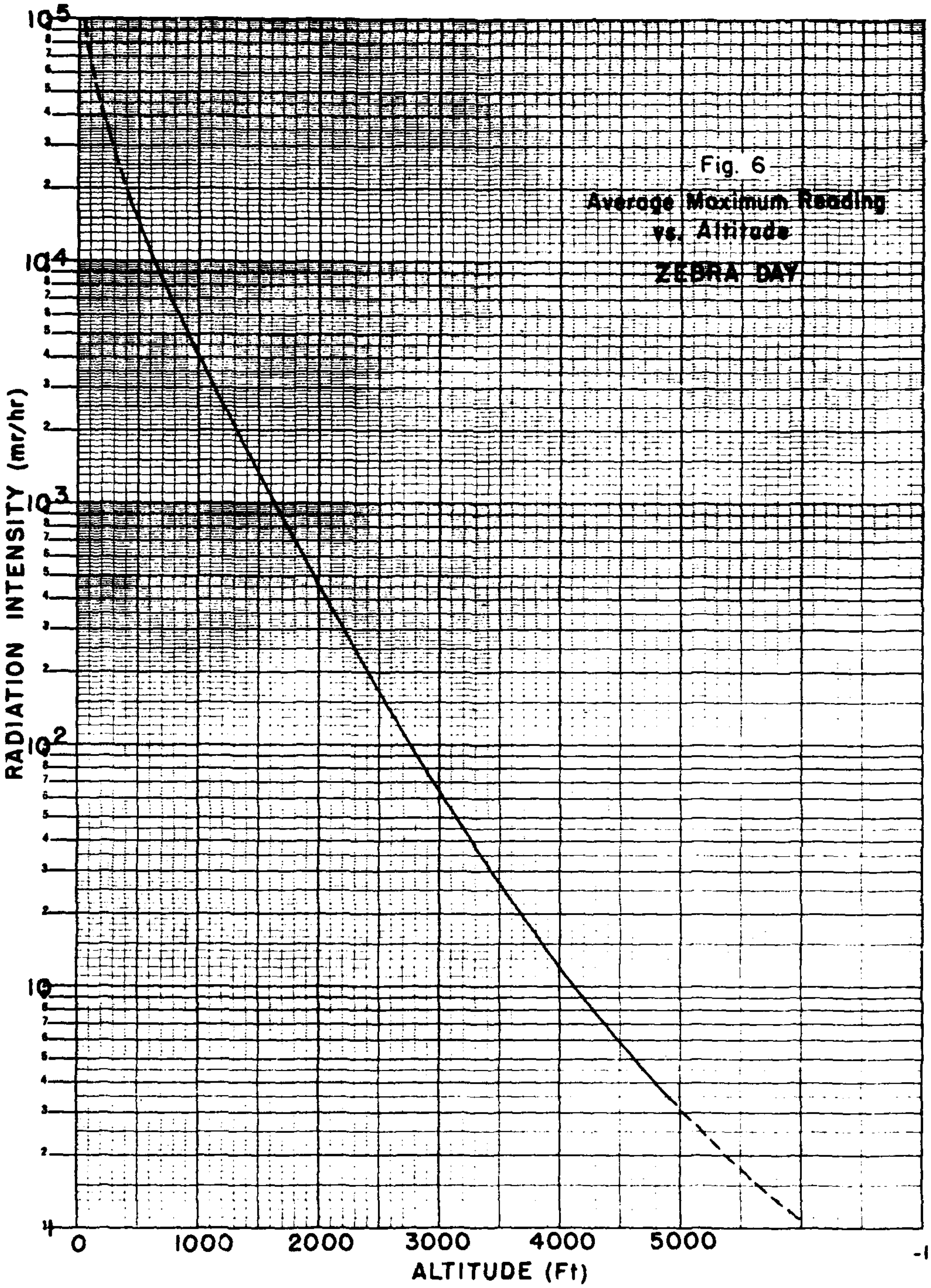


Fig. 6
Average Maximum Reading
vs. Altitude
ZEBRA DAY
RADIATION INTENSITY (mr/hr)
ALTITUDE (Ft)
0
1000
2000
3000
4000
5000
10^5
10^4
10^3
10^2
10
1

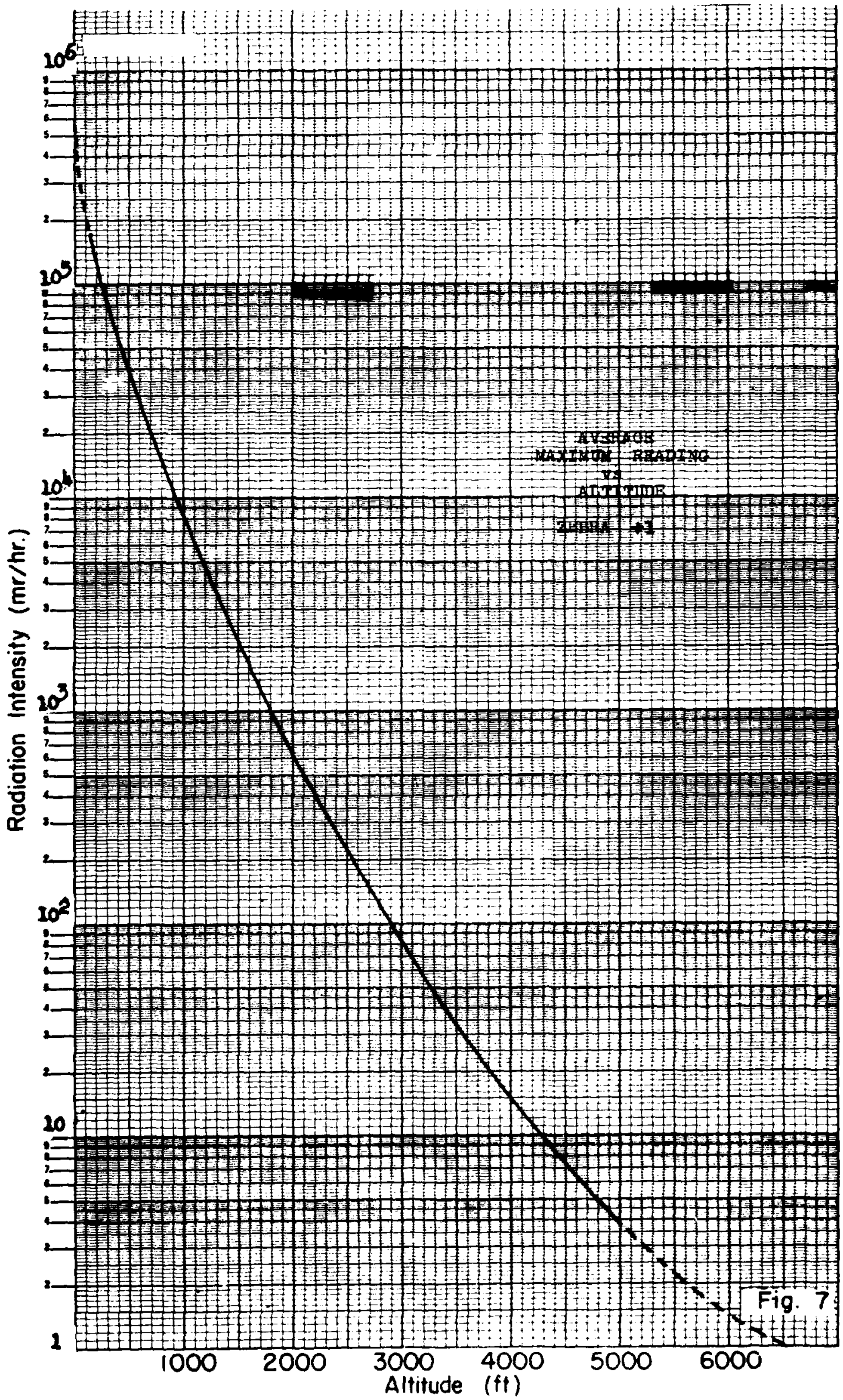

AVERAGE
MAXIMUM READING
vs
ALTITUDE
ZEBRA #1
Radiation Intensity (mr/hr.)
Altitude (ft)
1
10
10^2
10^3
10^4
10^5
10^6
1000
2000
3000
4000
5000
6000

Fig. 7

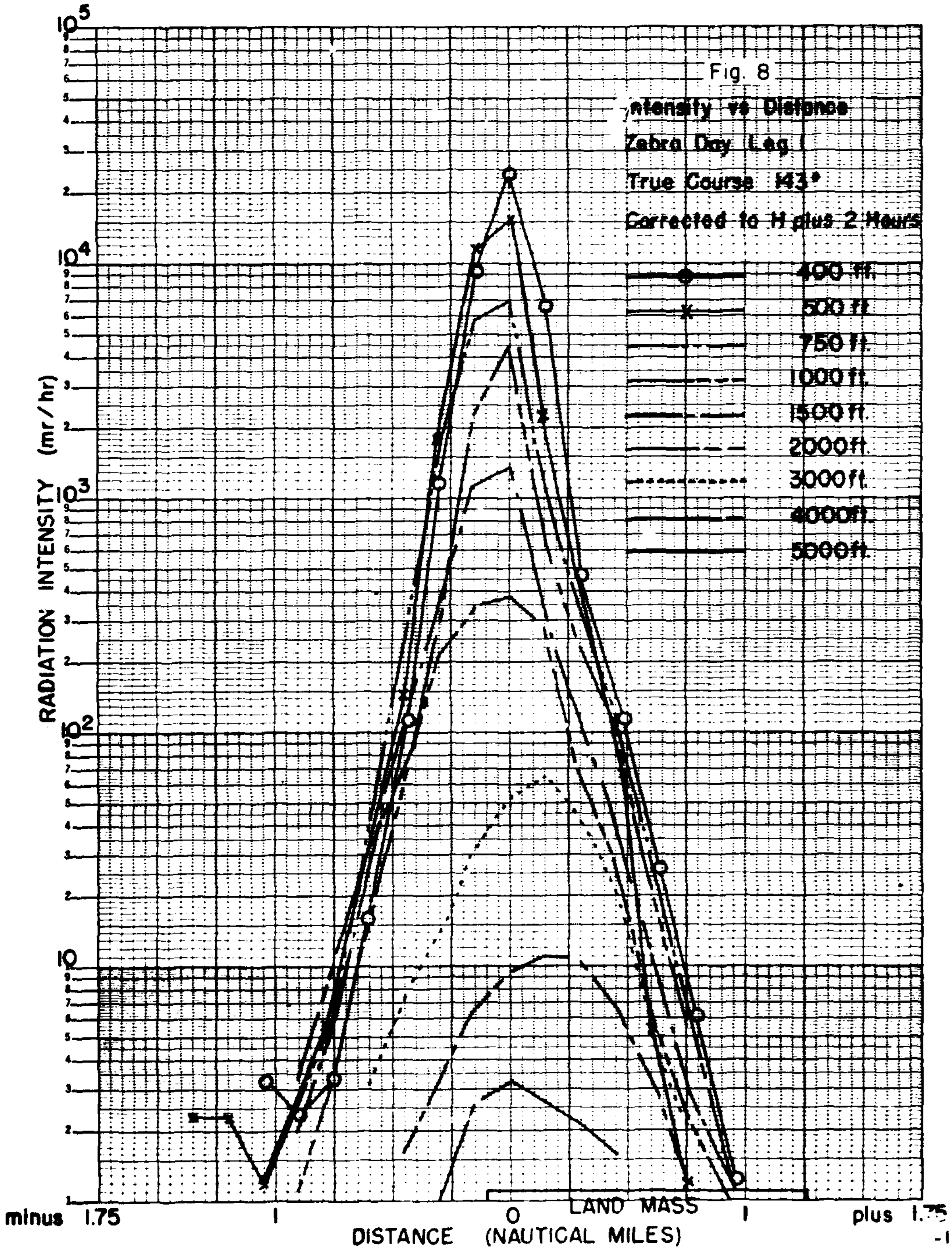


Fig. 8
Intensity vs Distance
Zebra Day Leg I
True Course 143°
Corrected to H plus 2 Hours
400 ft.
500 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
3000 ft.
4000 ft.
5000 ft.
RADIATION INTENSITY (mr/hr)
10^5
10^4
10^3
10^2
10
LAND MASS
minus 1.75
1
0
1
plus 1.75
DISTANCE (NAUTICAL MILES)

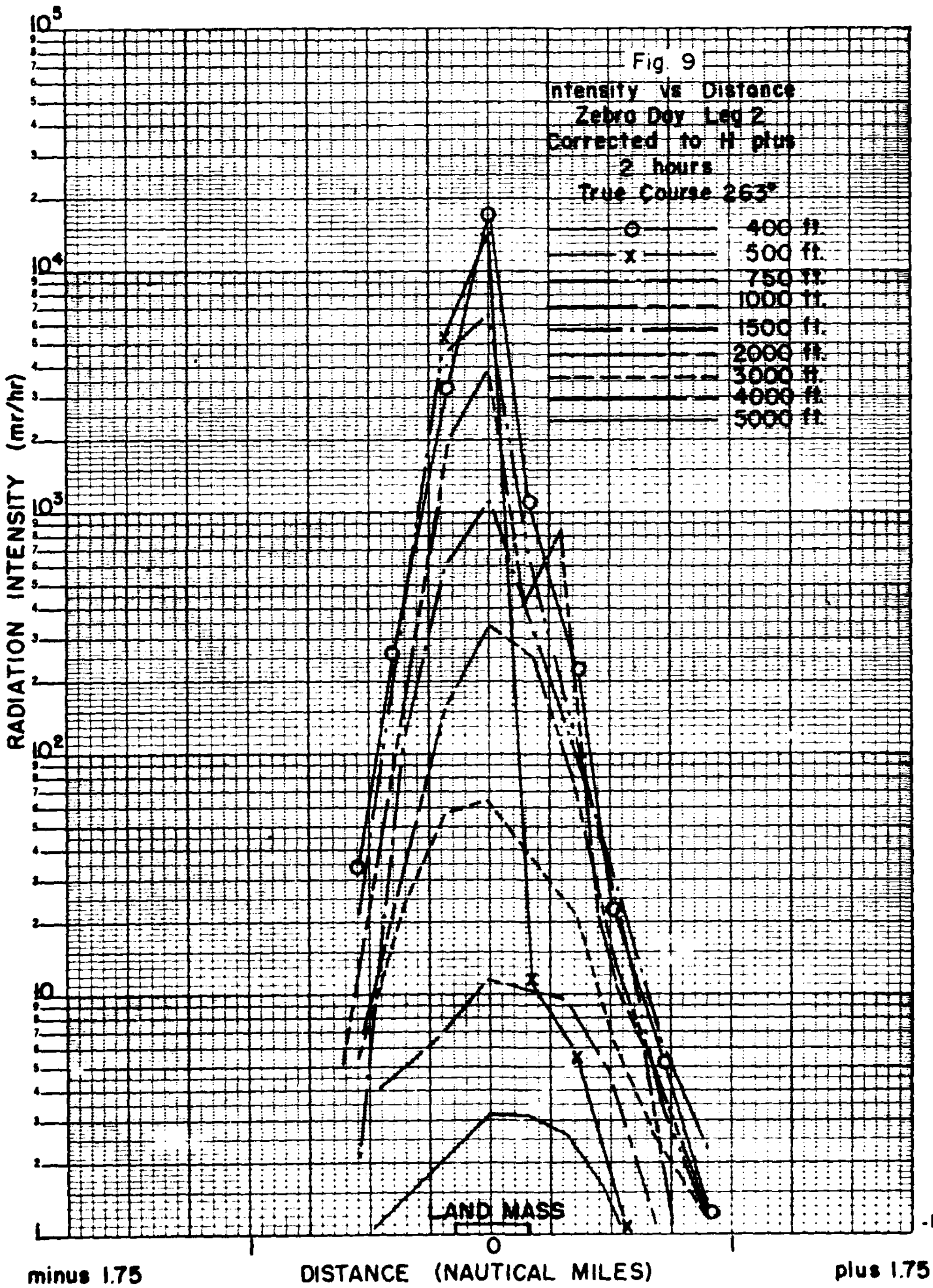


Fig. 9
Intensity vs Distance
Zebra Day Leg 2
Corrected to H plus
2 hours
True Course 263°
400 ft.
500 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
3000 ft.
4000 ft.
5000 ft.
RADIATION INTENSITY (mr/hr)
10^5
10^4
10^3
10^2
10
1
LAND MASS
0
minus 1.75
DISTANCE (NAUTICAL MILES)
plus 1.75

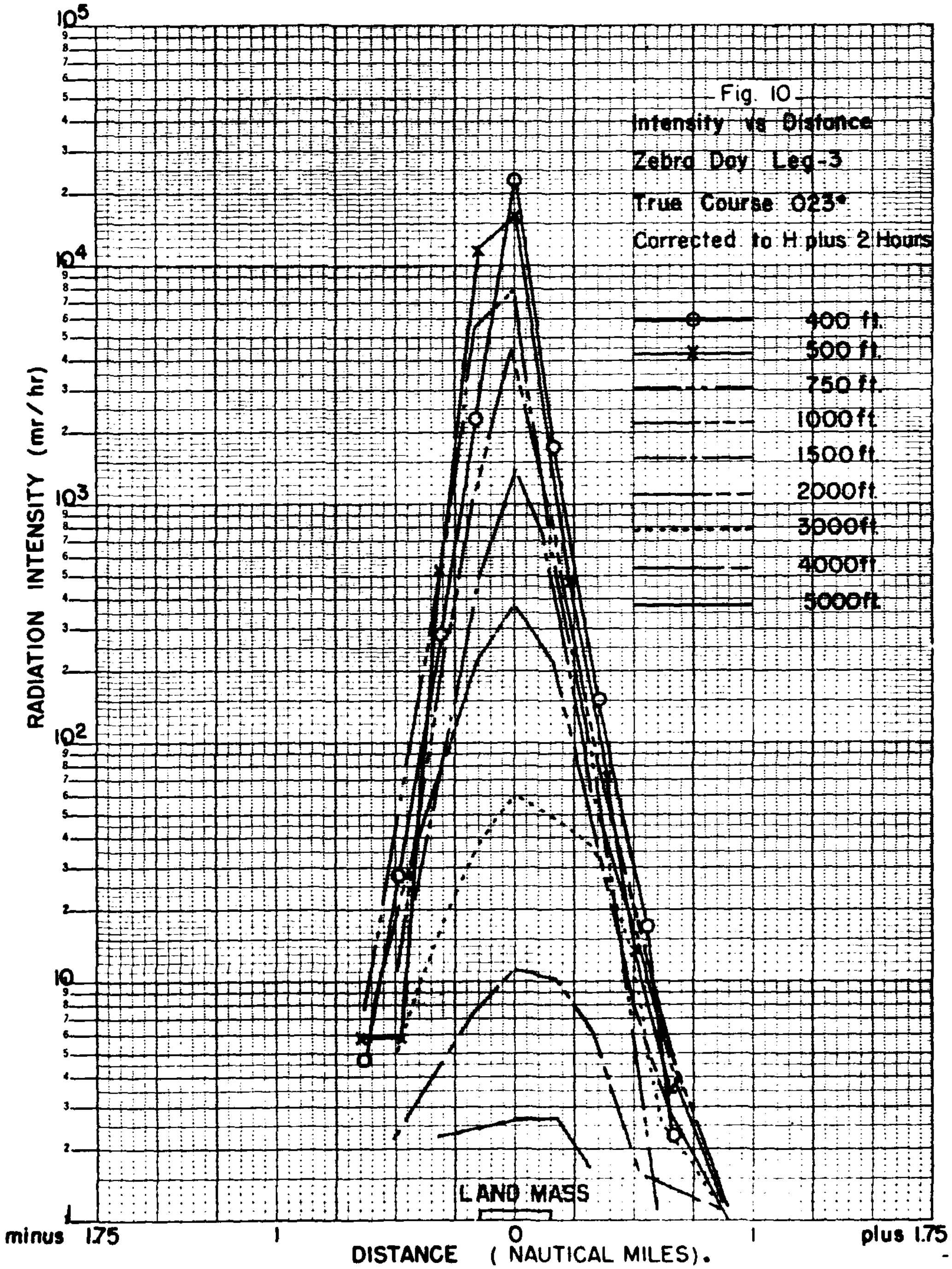
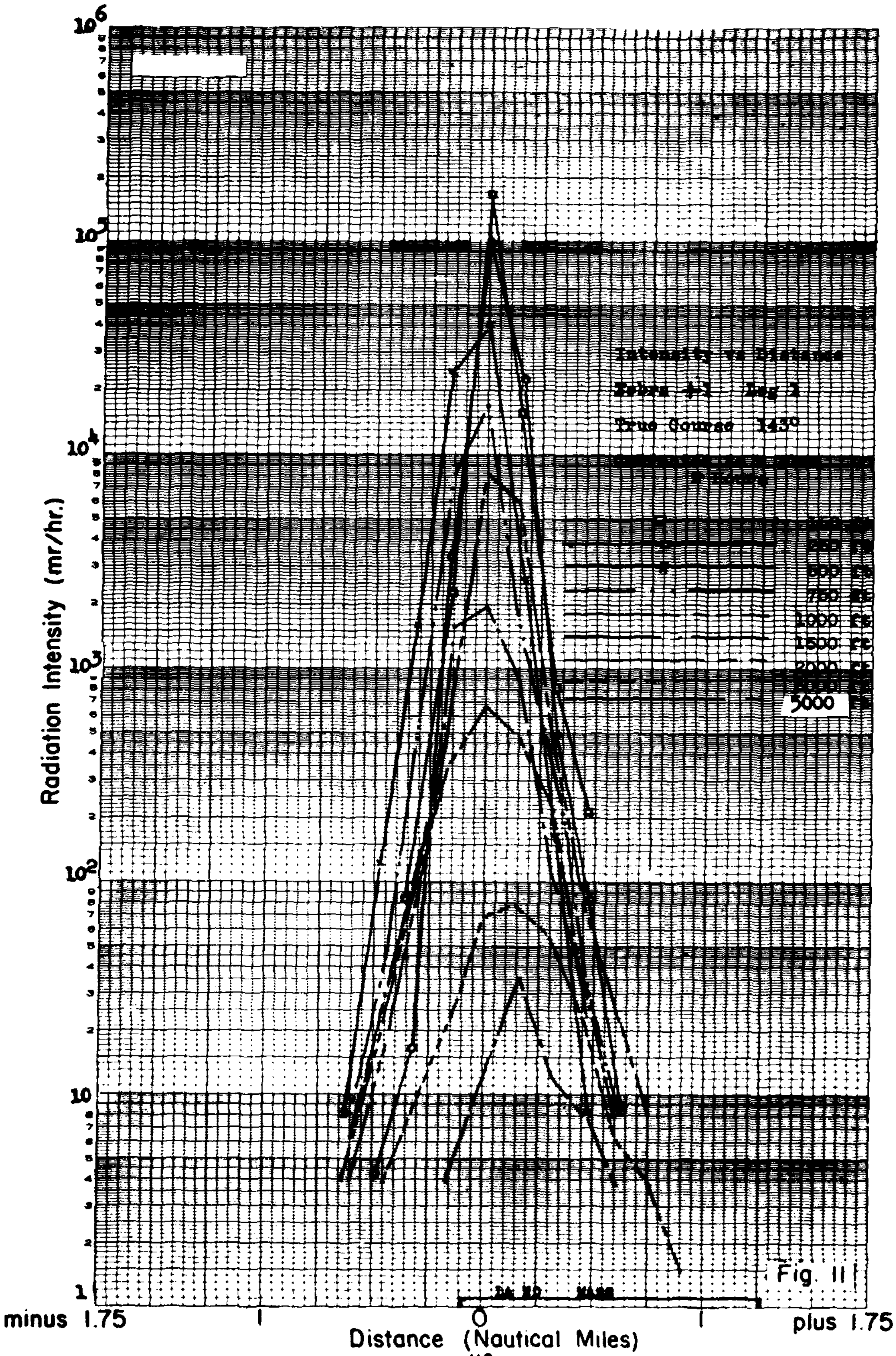


Fig. 10
Intensity vs Distance
Zebra Day Leg-3
True Course 023°
Corrected to H plus 2 Hours
400 ft.
500 ft.
750 ft.
1000 ft.
1500 ft.
2000 ft.
3000 ft.
4000 ft.
5000 ft.
RADIATION INTENSITY (mr/hr)
LAND MASS
minus 1.75
plus 1.75
DISTANCE (NAUTICAL MILES).



Radiation Intensity (mr/hr.)
10^6
10^5
10^4
10^3
10^2
10
1
1000
1500
5000
minus 1.75
1
0
1
plus 1.75
Distance (Nautical Miles)

Fig. 11

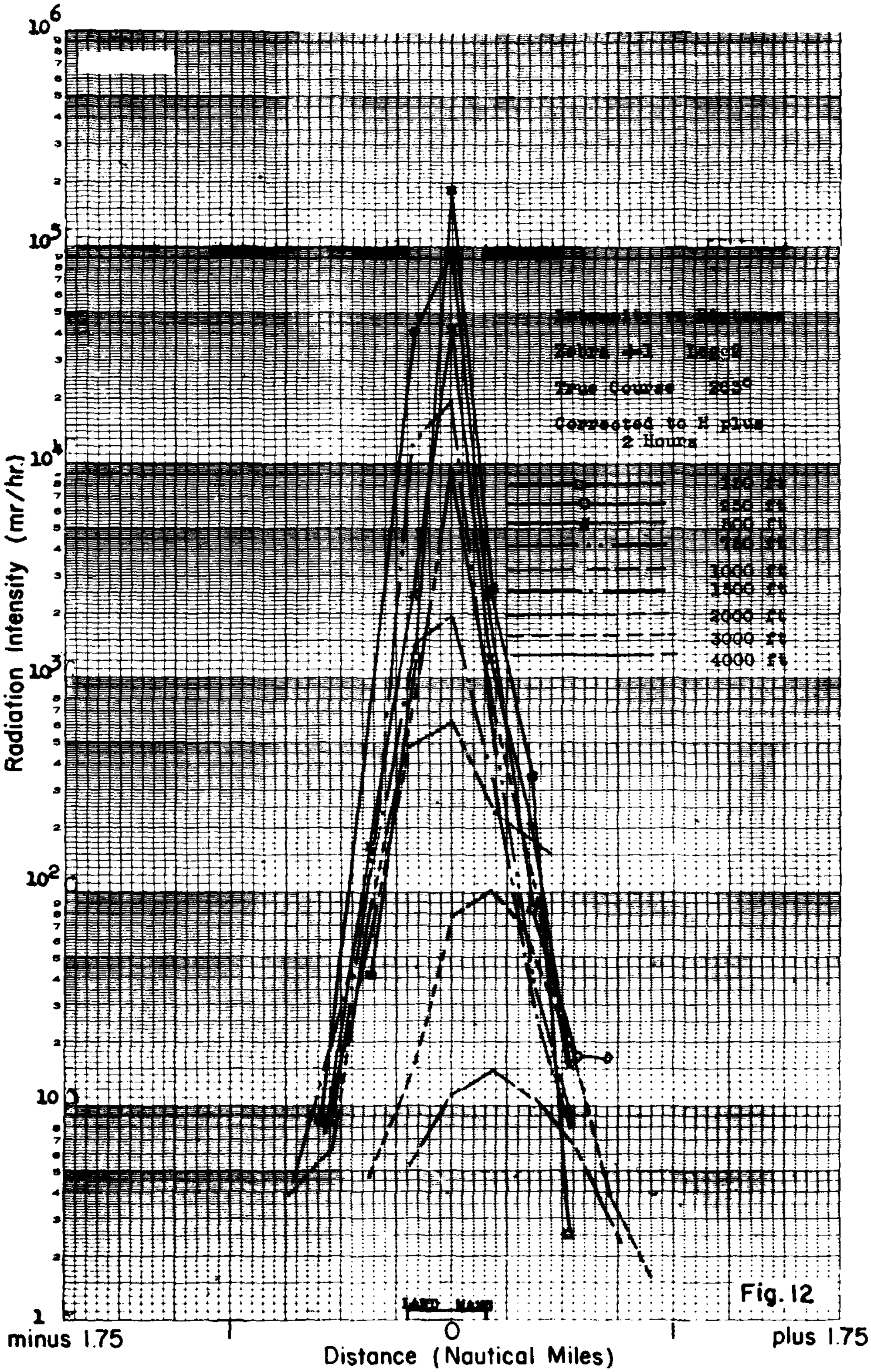

Radiation Intensity (mr/hr.)
10^6
10^5
10^4
10^3
10^2
10
1
Corrected to H plus
2 Hours
1000 ft
1500 ft
2000 ft
3000 ft
4000 ft
minus 1.75
0
plus 1.75
Distance (Nautical Miles)

Fig. 12

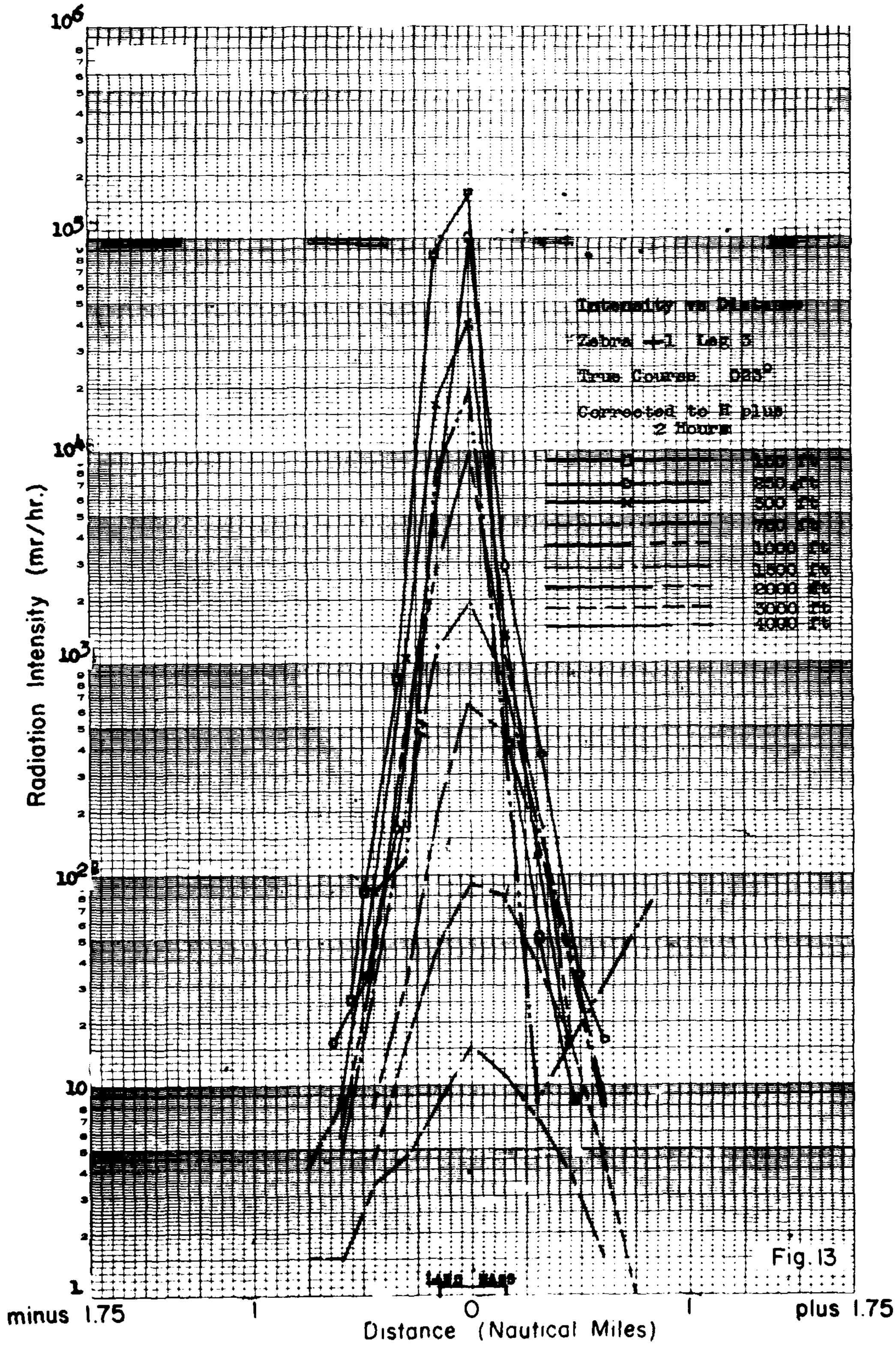

Radiation Intensity (mr/hr.)
Zebra +1 Leg 3
True Course 023°
Corrected to H plus
2 Hours
250 ft
300 ft
1000 ft
1500 ft
2000 ft
3000 ft
4000 ft
minus 1.75
1
0
1
plus 1.75
Distance (Nautical Miles)

Fig. 13

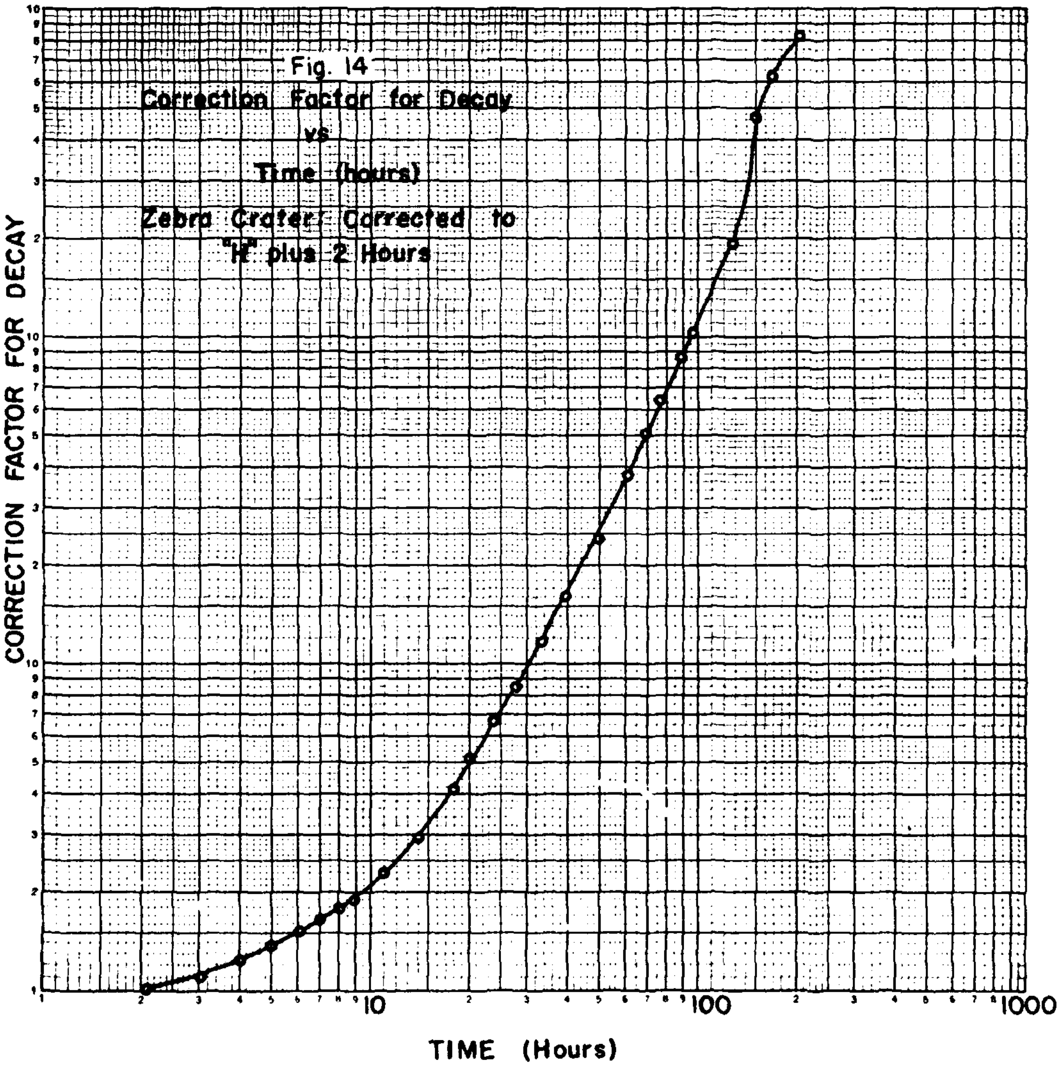


Fig. 14
Correction Factor for Decay
vs
Time (hours)
Zebra Crater Corrected to
"H" plus 2 Hours
CORRECTION FACTOR FOR DECAY
10
100
1000
TIME (Hours)

FIGURE 15

ZEBRA CRATER.

Intensity x Altitude^2 vs Altitude Values

Altitude	Average Maximum Intensity Corrected to H + 2 hrs	Altitude^2	IA^2
Zebra Day			
6000	1.06	3.6×10^7	3.82×10^7
5000	3.18	2.5×10^7	7.95×10^7
4000	11.2	1.6×10^7	1.8×10^8
3000	62.7	9×10^6	5.64×10^8
2000	367	4×10^6	1.46×10^9
1500	1300	2.25×10^6	2.93×10^9
1000	4250	$\times 10^6$	4.25×10^9
750	7010	5.6×10^5	3.92×10^9
500	15,850	2.5×10^5	3.96×10^9
400	22,700	1.6×10^5	3.64×10^9
Zebra plus 1			
5000	3.8	2.5×10^7	9.5×10^7
4000	14.6	1.6×10^7	2.34×10^8
3000	91.0	9×10^6	8.2×10^8
2000	644.0	4×10^6	2.57×10^9
1500	1,925.0	2.25×10^6	4.36×10^9
1000	9,100.0	10^6	9.1×10^9
750	18,430.0	5.6×10^5	1.03×10^{10}
500	4.05×10^4	2.5×10^5	1.05×10^{10}
250	9.9×10^4	6.25×10^4	6.19×10^9
150	1.7×10^5	2.25×10^4	3.38×10^9

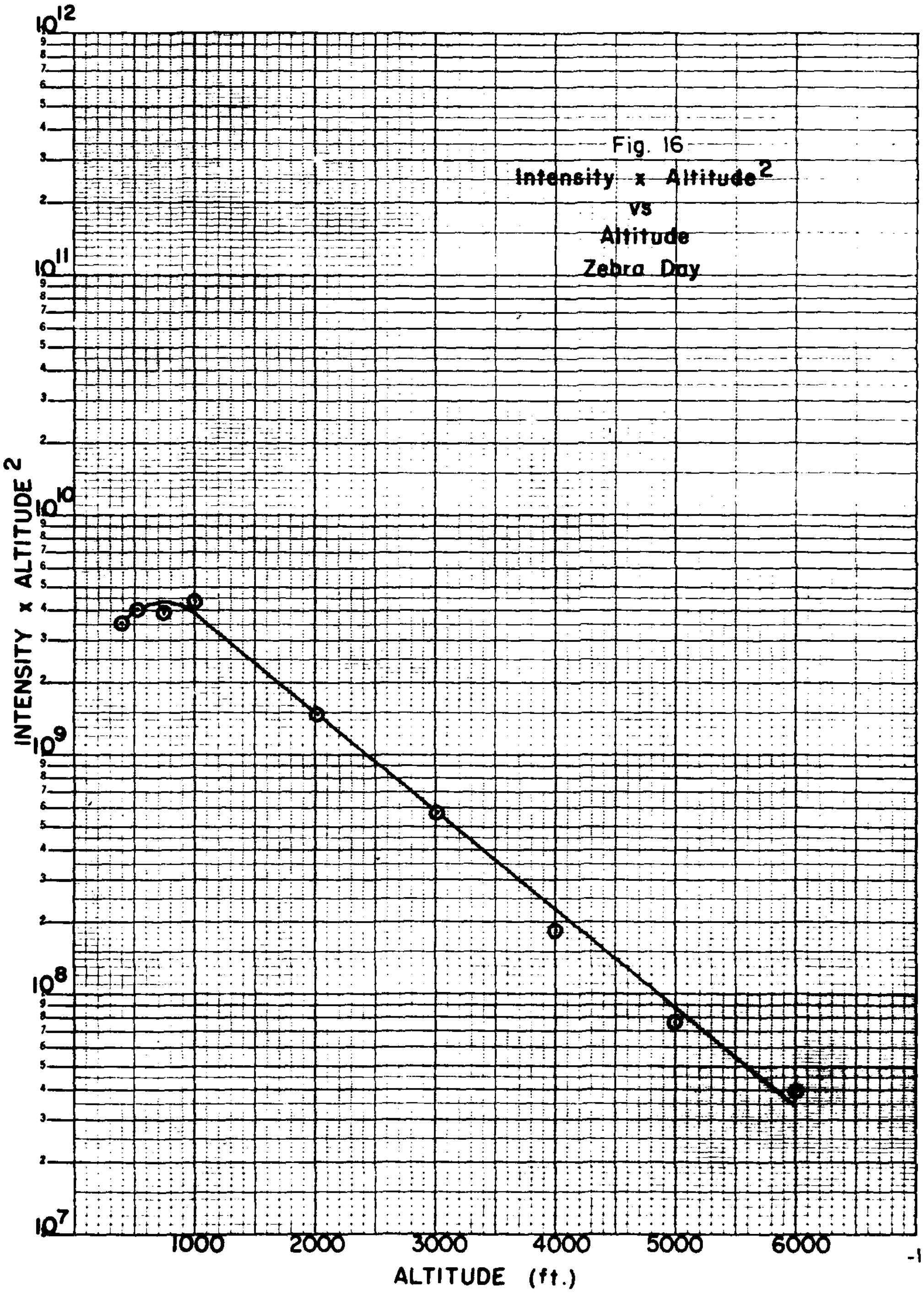


Fig. 16
Intensity x Altitude^2
vs
Altitude
Zebra Day
INTENSITY x ALTITUDE ^{2}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
1000
2000
3000
4000
5000
6000
ALTITUDE (ft.)

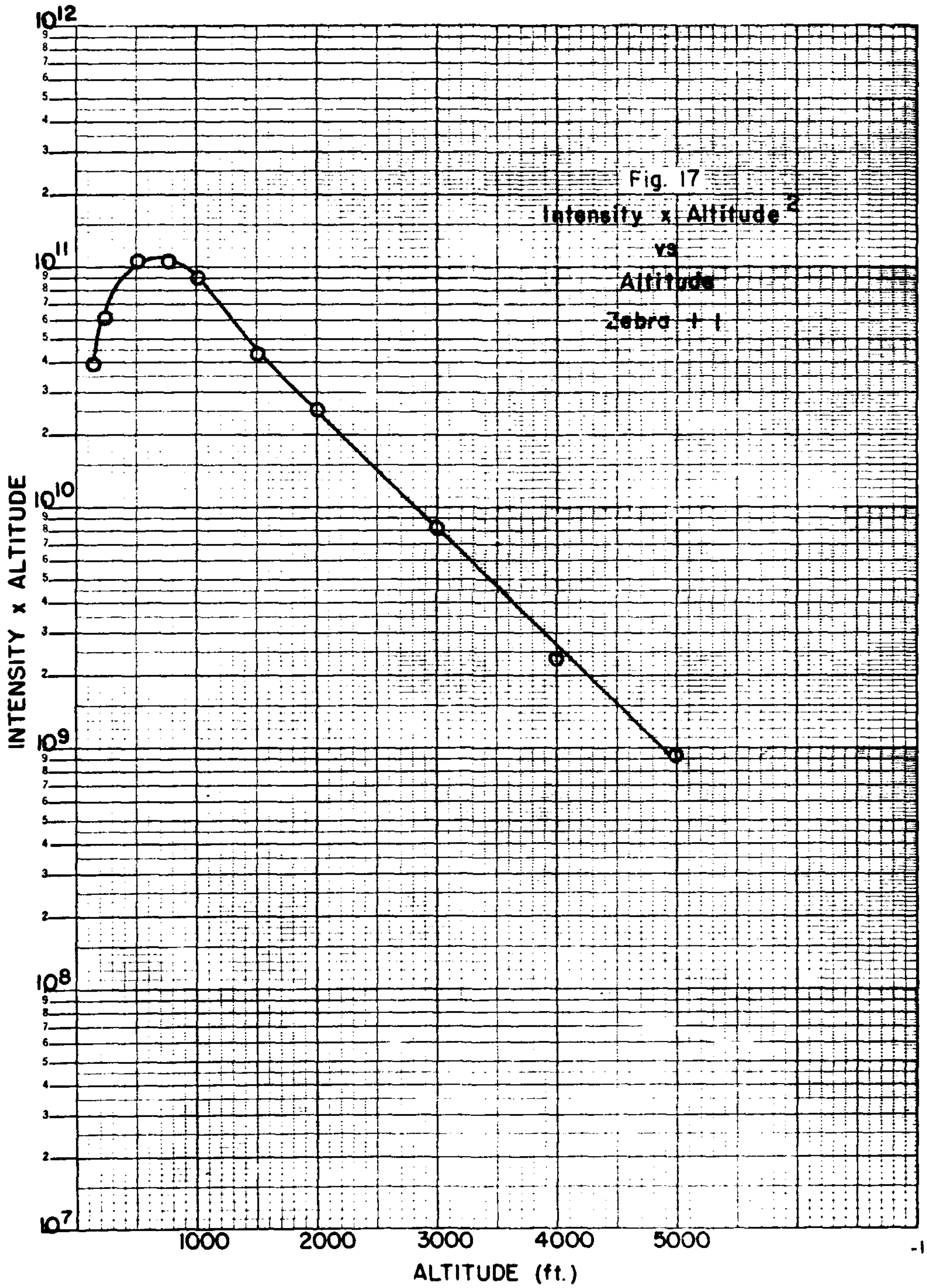


Fig. 17
Intensity x Altitude²
vs
Altitude
Zebra + 1
INTENSITY x ALTITUDE
ALTITUDE (ft.)
1000
2000
3000
4000
5000

FIGURE 18

NAVIGATOR'S DATA - ZEBRA DAY

Altitude (feet)	True Heading	Drift Correction	True Course	Ground Speed (knots)
5000	144°	+1°	143°	114
	260	-3	263	121
	025	+2	023	124
4000	142°	-1°	143°	113
	261	-2	263	126
	026	+3	023	122
3000	140°	-3°	143°	114
	262	-1	263	128
	027	+4	023	118
2000	140°	-3°	143°	110
	262	-1	263	131
	028	+5	023	116
1500	140°	-3°	143°	110
	262	-1	263	131
	028	+5	023	116
1000	139°	-4°	143°	112
	262	-1	263	132
	028	+5	023	115
750	139°	-4°	143°	112
	262	-1	263	132
	028	+5	023	115
500	139°	-4°	143°	112
	262	-1	263	134
	028	+5	023	116
400	140°	-3°	143°	111
	263	-1	263	132
	028	+5	023	115

FIGURE 18

NAVIGATOR'S DATA - ZEBRA DAY
(Continued)

Altitude (feet)	True Heading	Drift Correction	True Course	Ground Speed (knots)	
6000	268°	-2°	270°	121	5th leg
7000	093	+3	090	120	4th leg
8000	265	-5	270	117	3rd leg
9000	094	+4	090	126	2nd leg
10,000	266	-4	270	113	1st leg, Phase 2

FIGURE 19

NAVIGATOR'S DATA - ZEBRA PLUS 1 DAY

Altitude (feet)	True Heading	Drift Correction	True Course	Ground Speed (knots)
4000	138°	-5°	143°	113
	262	-1	263	140
	029	+6	023	105
3000	139°	-4°	143°	111
	262	-1	263	135
	028	+5	023	112
2000	138°	-5°	143°	113
	262	-1	263	136
	029	+6	023	108
1500	138°	-5°	143°	114
	262	-1	263	133
	028	+6	023	109
1000	138°	-5°	143°	111
	262	-1	263	134
	029	+6	023	110
750	138°	-5°	143°	112
	262	-1	263	132
	029	+6	023	109
500	139°	-4°	143°	115
	263	0	263	130
	028	+5	023	114
250	139°	-4°	143°	116
	263	0	263	132
	027	+4	023	115
150	139°	-4°	143°	115
	263	0	263	131
	027	+4	023	115

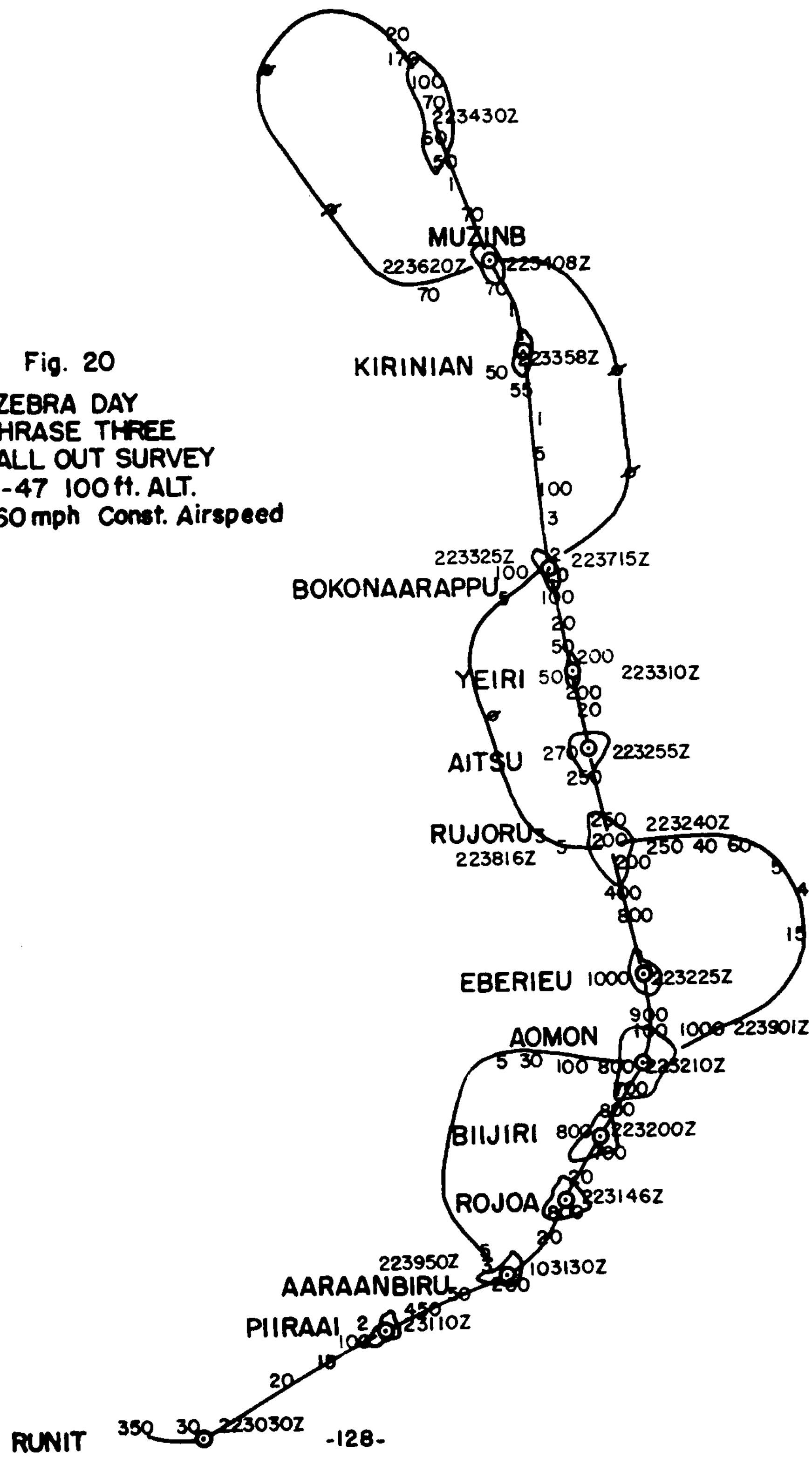


Fig. 20

ZEBRA DAY
PHRASE THREE
FALL OUT SURVEY
C-47 100 ft. ALT.
160 mph Const. Airspeed

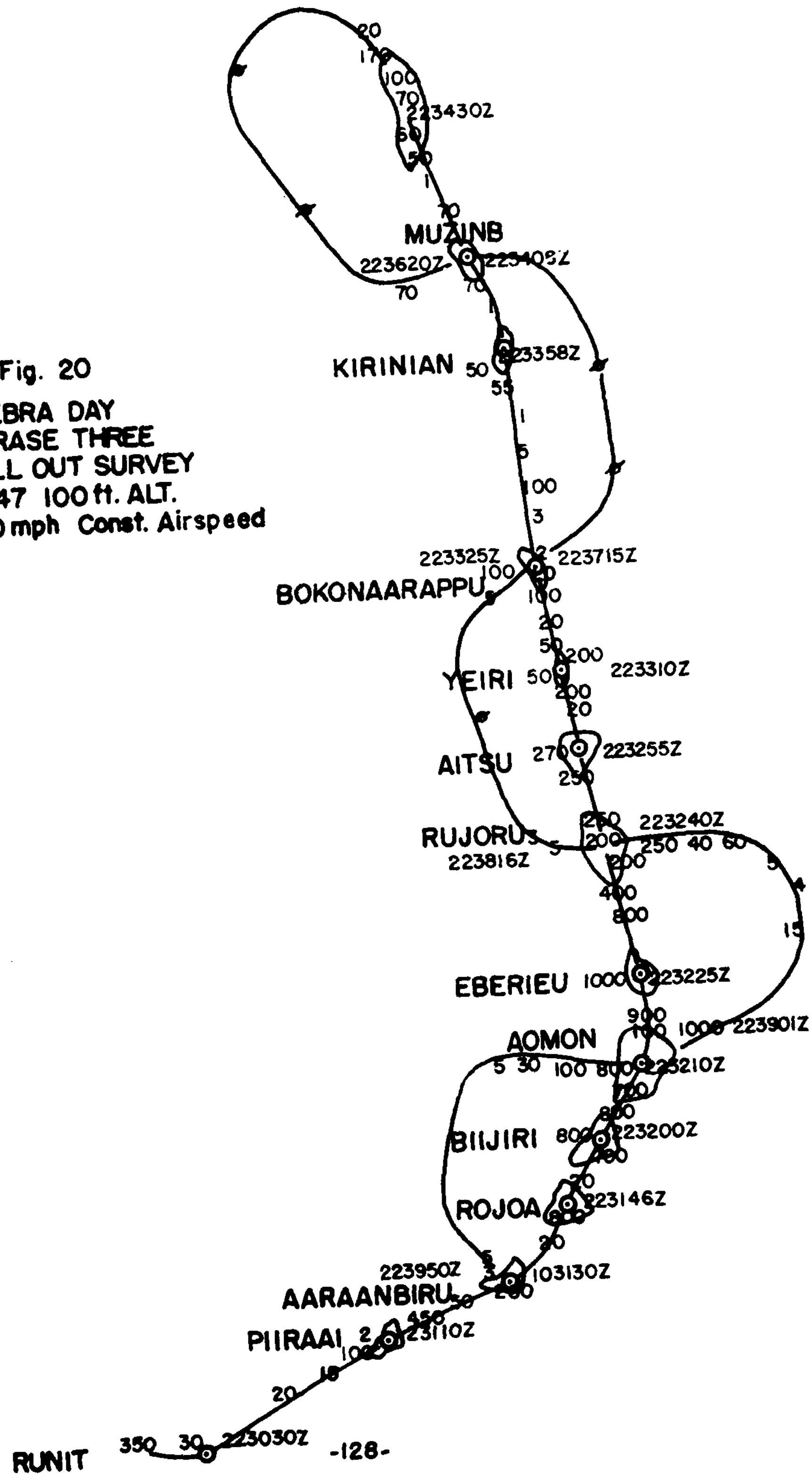


Fig. 20

ZEBRA DAY
PHRASE THREE
FALL OUT SURVEY
C-47 100 ft. ALT.
160 mph Const. Airspeed

APPENDIX 4

AERIAL RADIOLOGICAL SURVEY IN HELICOPTER, TYPE HO3S

ZEBRA PLUS FOUR DAYS

In the original operation plan it was stated that, if necessary, routine aerial surveys would be carried out employing helicopters. Upon arrival at the target area, it was soon apparent that the helicopters available were to be used for so many functions that it was doubtful if they could be scheduled for radiological surveys. Rather than perform flights on the spur of the moment, it was decided to continue the scheduled C-47 surveys and, if possible, work in as many helicopter surveys as possible.

Not until after the Zebra test was a helicopter scheduled on the same day that ground monitors were conducting their crater surveys. On Zebra day plus four, a survey was made of Runit in a helicopter according to the following plan.

The aircraft employed started at 1000 yards from point zero and at 200 feet altitude gradually descended in a straight line. The pilot notified the monitor present at 25-foot intervals of the altitude. At these intervals, the monitor recorded a reading. This descent continued until the craft was 25 feet above the surface. The craft then ascended and the procedure was repeated at 750 yards, 350 yards, 200 yards, 50 yards, and directly over the tower remnants. At the latter spot, the craft descended to only 100 feet instead of 25 feet. The mission took only forty-five minutes to complete, and over fifty readings were recorded.

Instruments used were the same as those regularly used on the C-47 radiological survey.

No attempt will be made to evaluate the data given, but one or two interesting points will be mentioned. As can be seen from a map of Runit, the only leg where readings can be taken over the ground for any appreciable distance is on a 143° heading. The aerial readings taken on Zebra plus four gradually decreased as one neared the ground at all distances up to within 200 yards of the tower where the readings began to increase as one neared the ground. As can be seen from the ground readings, 200 yards from the tower is the spot where ground readings start to increase rapidly and continue to become higher as one approaches the tower. This agrees with the observation that the boundary of the contaminated area was between 200 and 350 yards.

Because of various factors involved in the type of flights necessary it is not felt that helicopters could be substituted for a level flying airplane in the type of survey that was planned. After enough data are available whereby one may readily convert air intensities to approximate ground intensities, then the helicopter may well be very valuable in aerial radiological reconnaissance.

Factors which speak against use of the helicopter in this mission are mainly its inability to fly at altitudes above 1000 feet without using its fuel supply rapidly, inability to hover steadily, and to ascend in a straight line. Riding in a helicopter is not a smooth level operation, nor is hovering, ascending, or descending. With instruments fluctuating badly on the ground, the rapid changing of levels does not assist matters. These and other factors speak against the use of this type craft for taking careful precise data. The pilots of the helicopters themselves, as well as the Rotary Wing Section of the Bureau of Aeronautics, were pessimistic as to successful use of the craft in this type of work.

ZEBRA DAY PLUS FOUR AERIAL READINGS

Readings given are not corrected for decay and are all in mr/hr.

Altitude	200	175	150	125	100	75	50	25
1000 yards	0.6	0.5	0.6	0.5	0.65	0.7	0.7	0.7
750 yards	5	5	5	5	5	5	5	5
500 yards	15	15	15	15	15	14	13	12
350 yards	450	450	420	400	380	350	320	320
200 yards	700	900	1000	1000	1200	1300	1500	1700
50 yards (over tank)	1100	1400	1600	1700	1800	2100	2500	2900
0 yards (over tower)	1700	2000	2500	2800	3200			

ZEBRA DAY PLUS FOUR GROUND READINGS (143° HEADING)

Readings are not corrected for decay and are all in mr/hr.

Distance in yards	mr/hr
0	20,000
10	12,000
20	11,000
30	10,000
40	9000
50	8000
60	7500
70	7000
80	6500
90	6000
100	5200
110	5000
120	4900
130	4500
140	4500
150	4000
160	3000
170	2500
180	2200
190	2000
200	1800
285	600
550	100

APPENDIX 5

A CORRELATION BETWEEN AERIAL SURVEY DATA AND GROUND SURVEY DATA BY T. N. WHITE, M. D.

There follows an examination of the possibility of correlating aerial and ground survey data on the assumption that the gamma-ray source material is confined to, and uniformly distributed over, a flat circular disk herein called the crater.

It will be convenient to neglect absorption and to calculate an "effective distance", X_1, from a point of intensity measurement on the ground to a fictitious point source. This fictitious point source has the same gamma-ray activity as the whole crater; it is located not at the zero point (center of the crater) but at some other point such that the intensity at the measuring point is given by the inverse square law of distance from the fictitious point source. If <u>a</u> is the crater radius, and <u>r</u> is the distance of the measuring point from the zero point, then it can be shown by integral calculus that

$$X_1^2 = \frac{a^2}{\log\left(\dfrac{r_1^2}{r_1^2 - a^2}\right)}$$

Similarly in the case of the aerial survey, if $\underline{r_2}$ is the altitude, it can be shown that the "effective altitude", X_2, is given by

$$X_2^2 = \frac{a^2}{\log\left(\dfrac{r_2^2 + a^2}{r_2^2}\right)}$$

In both formulas, logarithms are to the base e.

Thus, if absorption is negligible, the source intensity should be observed on the ground at a distance r_1 as in the air at an altitude r_2, if r_1 and r_2 are so chosen that $X_1 = X_2$. Both the ground survey intensities and the aerial survey intensities were affected by air absorption, so that this factor will cancel out for equal effective distances, provided that the air absorption occurs in the same way in both cases. Actually the geometrical conditions of the two cases are quite different, so that the air absorption factors will not be identical. However, it can be shown that the difference is not of much importance in comparison with the difference in absorption in the soil. On account of irregularities in terrain, leaching, and sub-surface induced activities, we would expect that the average ray would have to traverse much more soil to reach an instrument on the ground than to reach an instrument in an airplane over the crater. Let us suppose that on this account the intensity, I_2, observed in an aerial survey, will be <u>k</u> times the intensity, I_1, observed at an equal effective distance on the ground. We would not expect <u>k</u> to be entirely independent of distance. However, in the ground surveys, the instrument reading does not change much within a range of one to six feet above the ground. This indicates that the variation of <u>k</u> with distance is probably not very important.

From the above it follows approximately that $I_2 = kI_1$ if $X_2 = X_1$. The latter equation can be simplified to: $r_1^2 = r_2^2 + a^2$ by using the expressions for X_1 and X_2 given above. In order to test whether the aerial and ground survey data can be correlated on the basis of the preceding assumption, the following simple procedure is followed. First, we plot I_1 vs r_1 and I_2 vs r_2. Then by trial and error method we select a value for <u>k</u>, and either multiply all I_1, or divide all I_2 values by this factor, and obtain an adjusted curve. For various intensities, we then obtain pairs of values (r_1, r_2), and see whether $r_1^2 - r_2^2$ is essentially the same for all pairs. If not, we try another value of <u>k</u> and repeat. If the correlation is to be regarded as successful, each day's survey should give approximately the same crater radius; but the value of <u>k</u> would not be expected to remain constant from day to day, because the depth distribution of active material in the soil of the crater will change appreciably with time.

The following data show the extent to which correlation can be obtained for certain surveys. The basic data were used to find reasonable values for **k** and **a**, which values were then used to calculate I_1 from I_2.

TABLE I

X-ray Plus One Day Surveys

Basic Data				Calculated I_1
I_1 (mr/hr)	Avg r_1 (yds)	I_2* (mr/hr)	r_2 (Alt ft)	(For comparison with first column)
500	460	14,200	500	590
100	650	5400	750	105
50	730	2660	1000	51
25	830	272	2000	25.5
12.5	930	32.1	3000	12
4	1100	4.05	4000	4.2
		0.5	5000	

* Adjusted to H plus 27 hr.

As between k = 5,6,7, k = 6 gives the most constant value of a^2; from the average a^2, a = 345 yds.

TABLE II

X-ray Plus Six Day Surveys

	Basic Data			Calculated I_1
I_1 (mr/hr)	Avg r_1 (yds)	I_2 (mr/hr)	r_2 (Alt ft)	(For comparison with first column)
500	340	800	100	330
100	380	340	250	95
50	410	130	500	48
25	440	60	750	23
12.5	500	10.2	1000	9.5
4	560	3.25	1500	4.5
		1.32	2000	

K = 1 gives reasonably constant values of a^2; from the average a^2, a = 328 yds.

TABLE III

Yoke Plus One Day Surveys

Basic Data				Calculated I_1
I_1 (mr/hr)	Avg r_1 (yds)	I_2 (mr/hr)	r_2 (Alt ft)	(For comparison with first column)
500	520	25,000	250	500
100	700	7830	500	95
50	780	4770	750	49
25	890	2500	1000	24
12.5	1000	700	1500	12
4	1280	205	2000	
		83.3	2500	
		30.7	3000	

Disregarding the 4 mr/hr at 1250 yd point, which is way out of line with the remainder of the ground curve, a fairly constant value of $\underline{a}^2$ is obtained with $k = 3.7$; from the average a^2, $a = 370$ yds.

Considering all of the factors that are concerned, it is seen that the correlation between the aerial survey data and the ground survey data is very satisfactory.

Perhaps the most notable feature of the results is the variation of the factor $\underline{k}$ between X-ray plus one and X-ray plus six, the reason for the variation is not clear. It may be noted that a method has been worked out for predicting intensities on the ground from the aerial survey data above. This method involves a procedure for estimating the radius of the crater from the aerial survey data. However, there is no known way of finding the appropriate value of the factor $\underline{k}$ from the aerial surveys as performed in these tests. Therefore, although the predicted intensities run parallel with the observed intensities, they exceed them by the unknown factor k. Hence, the method is not very useful in its present state of development, and it will not be described here.

The values derived for crater radius are large enough to include some considerable areas of water. For the most part these areas are on the opposite side of the crater from the side on which the ground surveys were made; therefore, the presence or absence of radioactive material in these areas would have relatively little effect on the ground intensities. As for the intensities observed in the aerial survey, there is no way of knowing exactly over what ground point the maximum intensities occurred, so that the "center of activity" of the crater might have been displaced away from the zero point without much effect on the results.

SCIENTIFIC DIRECTOR'S REPORT

OF ATOMIC WEAPON TESTS

AT ENIWETOK, 1948

Annex 9

CONTAMINATION STUDIES

Part III

RADIOACTIVITY PRODUCED IN THE CLOUD

BY ATOMIC BOMB EXPLOSION

Task Group 7.6

Project Report

Cloud Radioactivity

RADIOACTIVITY IN THE CLOUD PRODUCED

by

AN ATOMIC BOMB EXPLOSION

* * *

OPERATION SANDSTONE

by

Herbert Scoville, Jr.

Lt. Col. J. J. Cody, Jr., USAF

LCDR E. R. King (MC) USN

30 June 1948

Project 7.1-17/RS-7

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TABLE OF CONTENTS

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CLOUD RADIOACTIVITY

I ABSTRACT

The external radiation exposure was measured by means of film badges in the drone planes which passed through the radioactive clouds following the explosions in Tests X-ray, Yoke, and Zebra. In Test X-ray and Test Yoke the exposures inside of the plane were in general found to be less than 400 roentgens, while in Test Zebra where several of the planes passed through the head of the cloud, exposures of greater than 400 roentgens were obtained inside the aircraft. Comparison of the readings obtained inside and on the surface of the plane indicate that a B-17 aircraft provides considerable protection to its personnel from the external radiation of a radioactive cloud. Calculations have been made which indicate that the exposure resulting from the material actually deposited on the aircraft is a small fraction of the total exposure experienced by the plane in passing through the cloud. Rough calculations indicate that the average intensity in a plane passing through the mushroom head of a cloud seven minutes after detonation is about 1000 r/min. It is concluded that the external radiation hazard to a plane operating in wartime in the vicinity of an atomic bomb detonation would not be too serious and could easily be avoided without the need for excessive special equipment.

II OBJECTIVE

The object of this project is to determine the gamma radiation exposure in a plane passing through the cloud shortly after an atomic bomb burst, and if possible, in addition, estimate from this the mean radiation intensity of the cloud.

III HISTORICAL

At Bikini, drone planes were flown through the radioactive cloud, but in Test Able, no direct measurements were made of the radiation exposure to which the planes were subjected. In Test Baker, this was attempted, but the planes passed through the remnants of the cloud too late to receive important exposures. Since a knowledge of the exposure in the cloud is important in estimating the hazard of aircraft operations in atomic warfare, the Armed Forces Special Weapons Project proposed a project to carry out this measurement. This project received the approval of the SANDSTONE Scientific Director.

IV EXPERIMENTAL

A. MATERIALS AND OPERATIONS

Total range film badges were used to measure the gamma radiation exposure. The range of the films, which were incorporated into three packets in a single badge, is 0.05 to 22,000 r. A more detailed description of the films and the methods of development, reading, and calibration, is included in the report of project 7.1-17/RS-1 - Gamma Radiation vs Distance. Records for each drone aircraft were kept of the altitude flown through the cloud and the approximate time of entry into and exit from the cloud by the Radio-

[redacted]

logical Safety Officer assigned to the mother aircraft of each drone. Unfortunately for the purposes of this project all drone aircraft penetrated the cloud more than once so that estimation of the cloud intensity cannot be very precise. The Radiological Safety Officer removing the film badges from the planes at Eniwetok recorded the radiation intensity of the location of each badge so that the contribution of residual contamination on the plane to the total exposure could be calculated.

B. LOCATION OF FILM BADGES ON AIRPLANES

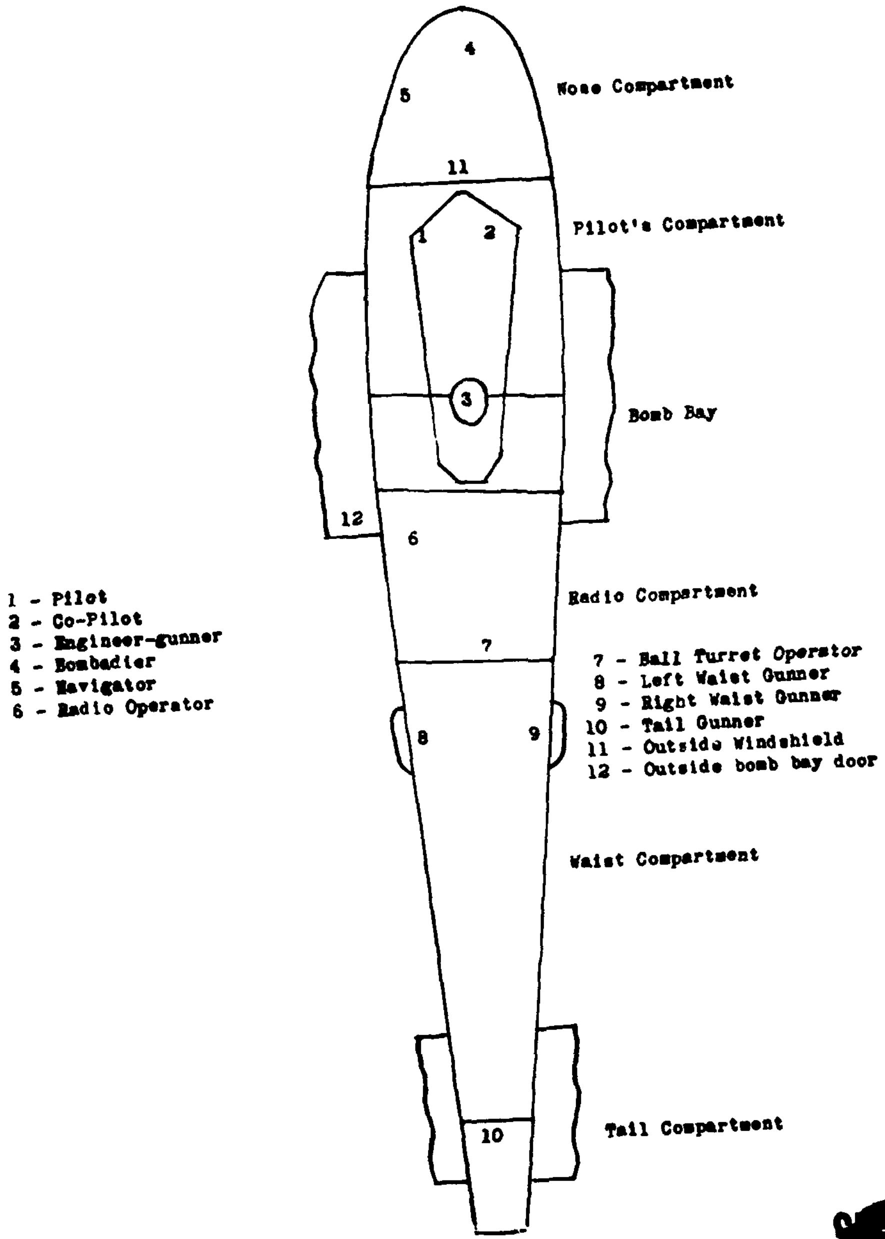
The location of the film badges in the planes are shown in Figures 1 and 2 and are listed below:

1. Back of pilot seat facing forward.
2. Back of co-pilot seat facing forward.
3. Back of top turret gunners chair.
4. Back of bombardier's seat, facing forward.
5. Back of navigator's seat, facing left from direction of flight.
6. Back of radio operator's seat facing forward.
7. On ball turret, taped to inner surface.
8. Left waist gunner's position.
9. Right waist gunner's position.
10. Tail gunner's position, facing astern, taped to headrest.
11. Outside pilot's windshield.
12. Outside of aft end of port bomb bay door.

The badges were placed on the drone planes the evening prior to

[redacted]

SECRET

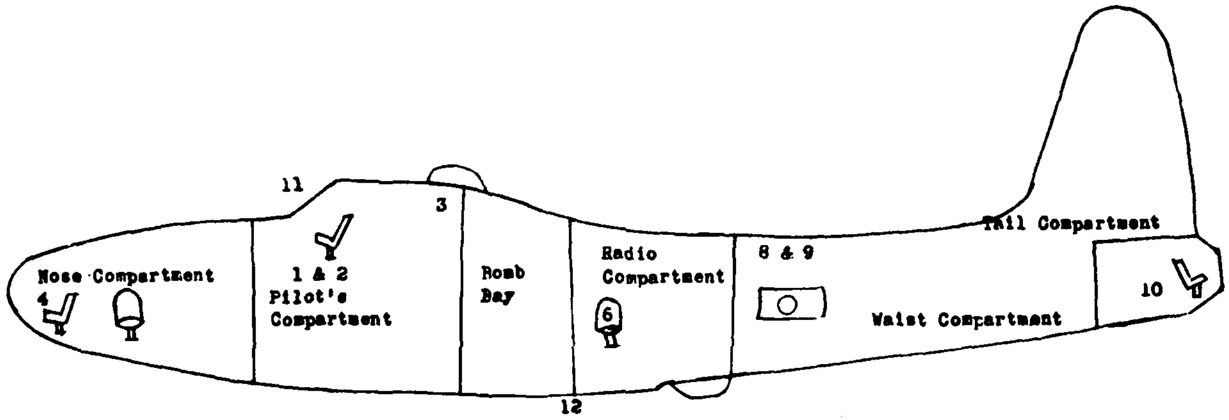


SECRET

TOP VIEW B-17 AIRPLANE CREW POSITIONS

Figure 1

SECRET



1 - Pilot
2 - Co-pilot
3 - Engineer-gunner
4 - Bombadier
5 - Navigator
6 - Radio Operator
7 - Ball Turret Operator
8 - Left Waist Gunner
9 - Right Waist Gunner
10 - Tail Gunner
11 - Outside windshield
12 - Outside bombay door

LATERAL VIEW B-17 CREW POSITIONS

SECRET

Figure 2

each shot. When the drones landed after having completed their penetration of the cloud, they were monitored to determine the extent of the radioactive contamination. As soon as the filters had been removed from the drones and when the intensity was sufficiently how to permit entry into the planes without exposing personnel to excessive radiation, the film badges were removed from the plane. At the time of removal the intensity at the location of the badge was measured by the monitor with a portable ionization chamber meter in order to permit calculation of the exposure due to residual contamination. The badges were returned to the U. S. S. BAIROKO, where the contaminated aluminum foil covers were removed. The films were shipped to the United States, where they were developed and read at the National Bureau of Standards.

V RESULTS

Twelve badges were placed in each of the drone planes for Tests X-ray and Yoke. Six badges in each plane were all that were available for Test Zebra. The recovery of these badges was about 95 per cent. The total exposure as recorded for each badge in Test X-ray, Yoke, and Zebra is listed in Tables I, II, and III respectively. The time at which the drone planes entered and left the cloud on each of their passes was recorded by the monitor in the drone mother and this information is summarized in Tables IV, V, and VI.

VI DISCUSSION

A. TOTAL EXPOSURE INSIDE THE DRONE AIRCRAFT

It will be noted in Table I that with one or two exceptions none

TABLE I

TOTAL EXPOSURE - DRONE FILM BADGES

X-RAY TEST

ALTITUDE (feet)	28,000	26,000	24,000	22,000	20,000	18,000	16,000	14,000
AIRCRAFT SERIAL NUMBER	483622	483635	483589	483606	483645	483591	483605	483664
DRONE NUMBER	8	1	2	3	4	5	6	11
POSITION								
1	59r	43r	45r	46r	436r	131r	500r	AIRCRAFT CRASHED. ALL BADGES LOST IN SEA.
2	89	52	50	50	78	92	86	
3	71	58	56	54	766	102	72	
4	4	63	57	55	110	164	—	
5	55	32	40	34	74	169	43	
6	58	37	50	52	65	—	40	
7	48	32	163	76	68	115	42	
8	58	47	63	54	127	91	47	
9	70	43	42	49	75	98	43	
10	62	70	60	74	—	140	50	
11	—	228	—	102	892	1760	—	
12	48	—	125	122	53	413	—	

TABLE II

TOTAL EXPOSURE - DRONE FILM BADGES

YOKE TEST

ALTITUDE (Feet)	30,000	28,000	26,000	24,000	22,000	18,000	16,000	14,000
AIRCRAFT SERIAL NUMBER	483622	483635	483589	483624	483645	483591	483605	483613
DRONE NUMBER	8*	1	2	7	4	5	6	9
POSITION								
1	7r	148r	118r	186r	664r	82r	90r	85r
2	7	152	184	—	83	132	90	282
3	—	—	112	—	113	145	125	120
4	7	182	—	80	71	115	145	90
5	8	141	186	80	70	98	140	279
6	8	168	122	90	146	142	540	90
7	—	—	100	77	71	80	91	120
8	8	173	102	—	73	186	—	80
9	10	231	125	79	82	—	100	71
10	12	242	140	—	120	132	139	200
11	175	1500	—	—	140	433	—	2000
12	—	670	275	138	116	82	460	91

* Number 8 Drone did not pass through the cloud.

TABLE III

TOTAL EXPOSURE - DRONE FILM BADGES

ZEBRA TEST

ALTITUDE (feet)	28,000	26,000	24,000	22,000	20,000	18,000	16,000	14,000
AIRCRAFT SERIAL NUMBER	483624	483589	483606	483645	483622	483591	483605	483613
DRONE NUMBER	7	2	3	4	8	5	6	9
POSITION								
1	55r	40r	350r	436r	BADGES WERE NOT INSTALLED IN THIS AIRCRAFT	240r	245r	105r
2	—	—	—	—		—	—	—
3	—	—	—	—		—	—	—
4	70	68	444	600		385	413	175
5	—	—	—	—		—	—	—
6	47	47	448	700		276	203	102
7	—	—	—	—		—	—	—
8	48	61	150	710		385	365	117
9	—	—	—	—		—	—	—
10	—	—	—	—		—	—	—
11	540	—	720	2000		460	—	1000
12	178	115	1400	616		820	232	100

TABLE IV

DRONE AIRPLANE CLOUD CONTACTS

X-RAY DAY

ALTITUDE (feet)	DRONE NUMBER	1st PASS		2nd PASS		3rd PASS	
		ENTER	EXIT	ENTER	EXIT	ENTER	EXIT
28,000'	8	062600	062615	063710	063745	065115	065230
26,000'	1	062445	062515	063900	063945	065410	065515
24,000'	2	062350	062410	063400	063430	065000	065100
22,000'	3	062451	062505	063840	063855	065400	065450
20,000'	4	062335	062405	063840	063900	NONE	
18,000'	5	062315	062325	063708	063714	NONE	
16,000'	6	062350	062440	063530	063630	064830	064930
14,000'	11	AIRCRAFT CRASHED					

HOW HOUR: 061700

[redacted]

TABLE V

DRONE AIRPLANE CLOUD CONTACTS

YOKE DAY

ALTITUDE (feet)	DRONE NUMBER	1st PASS ENTER	1st PASS EXIT	2nd PASS ENTER	2nd PASS EXIT	3rd PASS ENTER	3rd PASS EXIT
30,000	8		AIRCRAFT	DID NOT	ENTER	CLOUD	
28,000	1	061527	061540	062546	062611	064037	064137
26,000	2	061550	061610	062905	062940	064415	064445
24,000	7	061545	061555	062854	062909	064430	064530
22,000	4	061745	061807	062908	062935	064315	064345
18,000	5	061425	061431	062850	062903	064120	064210
16,000	6	061620	061640	062545	062645	063840	063915
14,000	9	061426	061446	062740	062810	064412	064442

HOW HOUR: 060900

[redacted]

[redacted]

TABLE VI

DRONE AIRPLANE CLOUD CONTACTS

ZEBRA DAY

ALTITUDE (feet)	DRONE NUMBER	1st PASS		2nd PASS		3rd PASS	
		ENTER	EXIT	ENTER	EXIT	ENTER	EXIT
28,000	7	OVER*	061125*	061715	061730	063210	063220
26,000	2	OVER*	061100*	062340	062400	063815	063835
24,000	3	061100	061110	061800	061812	062820	062843
22,000	4	060925	061040	062338	062441	063705	063802
20,000	8	060710	060740	061440	061500	062340	062420
18,000	5	061000	061010	062253	062335	063835	063855
16,000	6	060945	061020	062030	062100	063300	063400
14,000	9	060945	061015	062345	062415	063940	064018

* Penetration of cloud on 1st pass is doubtful

HOW HOUR: 060400

[redacted]

of the film badges inside any of the drone planes recorded a total exposure which would have been lethal had the planes been manned. The exposure in all seven drones which returned to their bases was quite uniform in the neighborhood of 50 roentgens. Only the drones at 20,000 and 18,000 feet had readings consistently higher than this average. This is surprising in view of the different quantities of material that were collected on the filters on each plane. For comparison purposes the relative amount of radioactive material on the filters is given in Table VII. Visual observation, as indicated in Table IV, showed that all seven planes went through the cloud

TABLE VII

RELATIVE AMOUNT OF RADIOACTIVE MATERIAL ON DRONE PLANE FILTERS

	RELATIVE STRENGTH		
ALTITUDE (Feet)	X-RAY	YOKE	ZEBRA
14,000	—	469	475
16,000	237	906	1107
18,000	157	81	1270
20,000	155	—	1870
22,000	477	1276	2444
24,000	467	833	1613
26,000	410	739	192
28,000	685	1285	405

on their initial pass so that it is impossible to draw any conclusions as to

[redacted]

the importance of this pass as compared with the succeeding ones. However, it is interesting to note that the two planes which made only two passes through the cloud were those at 18,000 and 20,000 feet. These two planes were those having the highest exposure which would tend to indicate that the largest part of the exposure is obtained on the initial passes.

Examination of the film badges from the planes in Test Yoke indicates that the exposures were in general about twice as great as those experienced in Test X-ray. The one exception to this is the drone at 30,000 feet which did not pass through the cloud. Nevertheless, an exposure of 175 roentgens was measured on the badges placed on the outside of the windshield. Despite the higher exposures obtained in Test Yoke, few badges inside the planes recorded values above the median lethal exposure (400 r). In Test Yoke all planes which entered the cloud made three passes so it is impossible to draw any conclusions as to the relative importance of each pass. Although the results are somewhat less consistent than for the planes in Test X-ray, there does not appear to be a wide variation in the exposures sustained at the various altitudes.

In Test Zebra the exposures were considerably higher than those measured from the planes in the first two tests. Several of the drones, namely those at 22,000 and 24,000 feet, have exposures above 400 roentgens in manned locations. Unfortunately, due to a misunderstanding, no badges were placed in the drone at 20,000 feet which, on the basis of the monitor readings made when the planes had landed, was more heavily contaminated than

[redacted]

any of the others. The higher exposures on the drones from Test Zebra can probably be explained by the fact that the planes penetrated th mus'room head of the cloud in this test while in the earlier tests only the tail of the cloud was entered. It is worthy of note that the exposures on the drones at 26,000 and 28,000 feet which did not penetrate the cloud on the first pass were very much lower than on the other planes. This would indicate that the largest fraction of the exposure was obtained during the initial penetration of the cloud. This would imply that there should be some correlation between the exposure experienced on a plane and the time of initial penetration. However, examination of the results from all three tests failed to indicate any such correlation within the experimental error. Other effects such as the exact part of the cloud traversed by the plane probably mask the minor differences which would be due to a variation of one or two minutes in the time of initial entry.

B. PROTECTION PROVIDED BY THE AIRPLANE

Of the twelve locations selected for the film badges two of these (11 and 12) are on the outer surface of the airplane while the remaining ten were in locations inside the plane. While the results are not too consistent it is apparent that the B-17 aircraft does provide considerable protection to the rew when operating in or near the radioactive cloud. In general the exposures inside the plane were 1/10 to 1/3 those on the outer surfaces. This difference was in many cases the difference between a lethal exposure outside the planes and a sub-lethal exposure inside. This might seem surprising in view of the light materials used in the construction of an aircraft, but it probably can be explained if the geometry of the problem is considered. A plane penetrating the radioactive cloud is operating in the middle of a large radioactive source so that the radiation is arriving from all directions. Therefore, a person placed in the forward part of the plane is being shielded from nearly half of the radiation by the entire material of the plane. Similar considerations apply to other locations. The data in Tables I, II, III have been examined to see if some locations in the plane are better protected than others, but no very obvious differences are apparent. Possibly, the exposures in position #6 in the radio compartment and position #10 in the tail are somewhat higher than the average.

C. EXPOSURE DUE TO CONTAMINATION OF AIRPLANE

The fraction of the total exposure which resulted from the deposition of radioactive material on the aircraft can be calculated with a knowledge of the intensity (I_2) at the time (t_2) the badge was removed from the plane, a knowledge of the time (t_1) at which the plane was contaminated, and the decay rate of the radioactive deposit. I_2 was measured by the monitor at the time he collected the badge. t_1 could not be measured directly, but for the purpose of general calculation, it was assumed to be H plus 15 minutes. However, a check calculation was made on some badges for t_1 = H plus 5 minutes, the earliest time of penetration into the cloud. Another calculation was made for t_1 = 1 hr., the time at which a plane might have landed after penetration of a cloud, in order to determine the increase in exposure resulting from having allowed the badge to remain in the plane after it landed.

The exposure may be calculated as follows:

$$E_c = \int_{t_1}^{t_2} I \, dt \qquad (1)$$

Laboratory measurements gave the following for the decay rate.

$$I = I_2 \left(\frac{t_2}{t}\right)^{1.2} \qquad (2)$$

Substituting $E_c = I_2 \, t_2^{\;1.2} \int_{t_1}^{t_2} t^{-1.2} \, dt$

Solving $E_2 = \frac{I_2 \, t_2}{0.2} \left[\left(\frac{t_2}{t_1}\right)^{0.2} - 1 \right]$ (3)

where E_c = exposure in roentgens due to contamination

I_2 = intensity (r/hr.) at the time badge was collected

t_2 = time (H plus hour) badge collected

t_1 = time (H plus hour) contamination occurred.

By means of equation (3), E has been calculated for a number of badges removed from the plane in Tests Yoke and Zebra. These results are summarized in Table VIII. From these it is seen that the contamination was responsible for only about 10% of the total exposure.

TABLE VIII

EXPOSURE FROM CONTAMINATION OF AIRPLANE

Badge Number	Drone Number	Position	Total Exposure (roentgens)	I_2 (r/hr.)	t_2 (H-hr.)	E_2* (roentgens)	% Total
TEST YOKE							
2680	7	6	122	280	11	22	18
2673	1	11	1500	900	8	36	2
2668	1	6	168	500	8	20	12
2615	4	11	140	1000	4	15	11
TEST ZEBRA							
2649	4-2	11	2000	1000	28	220**	11
3228	6-2	6	276	55	28	12	4
3227	5-2	4	385	400	48	180	47

* Calculated for $t_1 = 15$ minutes.

** When this exposure was calculated for other values of t_1, the following values were obtained

310 r for $t_1 = 5$ minutes

133 r for $t_1 = 1$ hour

If a decay rate proportional to $T^{-1.3}$ was assumed, then contamination exposure for $t_1 = 15$ minutes was 280 r.

TABLE IX

RADIATION INTENSITY IN CLOUD

TEST ZEBRA

1st PASS

Drone Number	Altitude (feet)	Badge Number	E(r)	t_1(min.)	t_2(min.)	I_2(r/min.)*
3	24,000	2687	300	7	7 1/6	1800
4	22,000	2414	380	5 5/12	6 2/3	260

2nd PASS

Drone Number	Altitude (feet)	Badge Number	E(r)	t_1(min.)	t_2(min.)	I_2(r/min.)*
7	28,000	3236	50	13 1/4	13 1/2	140
2	26,000	2405	36	19 2/3	20	470

* The badges for these calculations were selected from inside the plane in order to improve reproducibility. Therefore, the intensity should be multiplied by about five in order to obtain the unshielded intensity within the cloud.

D. RADIATION INTENSITY IN CLOUD

As was mentioned earlier, it is impossible to make any direct calculation of the intensity within the clouds because of the fact that all drones made more than a single penetration. However, a rough estimate to provide an order of magnitude can be made on the basis of the Test Zebra results, since for this test two of the planes failed to contact the cloud on the initial pass. If it is assumed that the exposures obtained by these planes is representative of that obtained on the second and third passes for some of the other planes, then it is possible by subtraction of this value to make an estimate of the exposure encountered by the other planes on their initial pass. From this value one can calculate the intensity in the clouds by means of Equation (3) using the times of entry and exit from the cloud at t_1 and t_2 respectively. This has been done for the drones at 22,000 and 24,000 feet and the results listed in Table II.

The agreement between these calculations is not good, but when it is considered that the planes were passing through different parts of the cloud they are probably the best that might be expected. One of the greatest errors may be in the recorded times of entry into and exit from the cloud since a small error in time makes a large error in I_2. On the basis of these results it may be said that the average intensity inside a plane passing through the cloud is about 1000 roentgens per minute at H plus 7 minutes and about 1/3 that value at H plus 15 minutes.

Further analysis is not warranted without information on the part of the cloud entered by the planes.

A similar calculation can be made for the second pass for the planes at 26,000 and 28,000 feet if it is assumed that on the third pass only about 10 per cent of the total exposure was received. That this assumption is not too unreasonable is indicated by the fact that in Test X-ray the planes with the highest exposure were those which did not make a third pass. The results of these calculations are also included in Table IX.

E. IMPORTANCE OF BETA RADIATION

All results which have been mentioned previously have been for measurements made underneath a lead cross placed on the film badges and must therefore be considered as due to gamma radiation alone. No detailed analysis has been made of the exposures as measured outside the lead cross which would provide a measure of the extent of the beta and soft gamma radiation. However, in general it may be said that for the badges inside the planes, the readings outside the lead cross were approximately 10 to 25 per cent greater than those underneath. As would be expected, this difference between the outside and underneath readings was greater for the badges placed on the outer surface of the plane where there was a greater opportunity for thebadge to come in direct contact with the radioactive material. However, since the planes were not airtight, considerable amounts of radioactive material did penetrate into the aircraft themselves.

VII CONCLUSIONS AND RECOMMENDATIONS

The external gamma radiation exposure of personnel in a plane penetrating the tail of the radioactive cloud following an atomic bomb explosion would not in most cases prove lethal. Nevertheless, it would be sufficiently high as to provide considerable hazard, and therefore such contact should be avoided. If the mushroom head of the cloud is penetrated, the external radiation exposure would frequently be greater than 400 roentgens and therefore be lethal to the personnel within the plane. Because of the uncertainty in the symptoms which would result from an exposure of this magnitude, no definite conclusions can be drawn as to the ability of the crew to land their plane before becoming incapacitated. However, such a return does not appear to be ruled out, for the effects of radiation exposure are frequently sufficiently delayed as to permit such an operation even though the crew were eventually doomed.

The protection from external radiation provided the crew of a B-17 operating in or near a radioactive cloud is appreciable and might well mean the difference between a lethal and sub-lethal exposure. No particular positions in the plane are better protected than others.

A plane operating in a radioactive cloud will become contaminated but this contamination would not in general be sufficiently great to prove lethal to the plane's crew prior to their return to base. In all cases where the contamination was sufficient to provide a lethal external radiation hazard the radiation from the cloud itself would already have proved deadly. It should be emphasized, however, that the presence of radioactive material inside the plane would provide an internal hazard if the crew and maintenance personnel did not take adequate preventive measures. Such measures might include wearing of masks or the insertion of filters in the ventilating systems.

The average radiation field in the head of the radioactive loud from an atomic bomb explosion seven minutes after the detonation wave was approximately 1000 r/min.

In conclusion it should be noted that the danger to aircraft operating in or near the radioactive cloud from an atomic bomb explosion is not as great as previously anticipated. Lethal exposures w re obtained only in planes which penetrated the head of the cloud within five to ten minutes after the detonation. At this time the cloud would have been clearly visible and distinguishable, probably even at night so that evasive action could have easily been taken. Therefore, it would seem that the need for elaborate detection instruments on aircraft carrying out wartime operations in the vicinity of atomic bomb explosions is not as great as has previously been thought. It is recommended, therefore, that development of instruments for this type of operation be given lower priority than the development of instruments for aerial survey of ground contamination and for operations on the ground itself. The major emphasis should be placed on insuring the protection of personnel in planes from incurring an internal radiation hazard. This protection could take the form of filtered air supply or the use of 100 per cent oxygen when near or in contact with atomic bomb clouds.

SCIENTIFIC DIRECTOR'S REPORT

OF ATOMIC WEAPON TESTS

AT ENIWETOK, 1948

Annex 9

CONTAMINATION STUDIES

Part IV

PARTICLE SIZE OF MATERIAL IN CLOUD

Task Group 7.6

Project Report

PARTICLE SIZE OF MATERIAL IN CLOUD

* * *

OPERATION SANDSTONE

by

Bernard Siegel

CDR H. L. Andrews, USPHS

Raymond E. Murphy

30 June 1948

Project 7.1-17/RS(CC)-9

TABLE OF CONTENTS

ABSTRACT

Objective

The object of the work on this project was to determine the particle size distribution of the radioactive material in the cloud caused by an atomic bomb explosion.

Results

Three of the four structures in which the Cascade Impactors were installed during test X-ray were rolled over by the explosion. However, all of the units apparently operated satisfactorily, except the one in the structure closest to the detonation, which was crushed by the door blown inside the building. Fifteen of the sixteen Cascade Impactor slides were recovered. The quantity of dust collected on the slides during the first test was too large for a reliable measurement of particle size distribution by this method.

The results obtained during tests Yoke and Zebra signify that the radioactive material in the cloud is composed of very small particles. Since a comparatively minute amount of radioactive material was retained on the first slides of the Cascade Impactors, indications are that the majority of the particles are less than 0.5-micron diameter. By far the greatest amount of material was collected on the canister filters, which were on the effluent end of the Cascade Impactors on the drone planes, and were essentially a fifth stage.

All of the glass slides from the Cascade Impactors were returned to the Army Chemical Center, Maryland for a measurement of the particles

on them with an electron microscope. These results will be included in a supplementary report to be submitted upon completion of the work.

By measuring the amount of radioactive material retained on various depths of the filter paper in canisters M11 on the drone planes, penetrations through the filter paper of 0.021% and 0.018% were determined. These particulate penetration results are in line with those obtained in the standard laboratory test on this paper using an aerosol of 0.3-micron diameter.

Conclusions

It is concluded that:

1. The Cascade Impactor equipment used for these tests is an excellent field apparatus. It is easy to operate, portable and withstands rough usage.

2. The radioactive material in the cloud apparently consists of very small particles. Present indications are that a major portion is below 0.5 micron in diameter.

3. The protection afforded by canister M11 against the radioactive particulates in the cloud is comparable to that obtained in laboratory tests using a non-toxic aerosol of 0.3-micron diameter.

Recommendations

None, pending results of additional electron microscope measurements which will be included in a supplementary report.

PARTICLE SIZE OF MATERIAL IN CLOUD

I. OBJECTIVE

The object of the work on this project was to determine the particle size distribution of the radioactive material in the cloud caused by an atomic bomb explosion.

Theories have been advanced that, because of the tremendous energies released by the explosion, the radioactive materials may be present primarily in the form of extremely small particles. Information on the size of the radioactive particles is extremely important for the development of adequate means of filtration and for determining biological effects.

II. HISTORICAL

Appendix C contains the report, "Evaluation of Dusts with the Cascade Impactor", giving the details of the preliminary work on this project including the construction and calibration of the Cascade Impactors and auxiliary equipment. The equipment was calibrated with the dusts from Aomon, Engebi and Runit Islands. Also included in the report is a discussion of the previous work on Cascade Impactors.

III. EXPERIMENTAL PROCEDURE

A. Test X-Ray

One Cascade Impactor with auxiliary equipment was assembled and installed in each of four Corps of Engineer structures on Engebi Island. One was at 1000 feet, two at 1500 feet and the fourth

Cascade Impactor was at 2500 feet from Zero. The apparatus was attached to a one-inch pipe which led to the outside. A photograph of the equipment installed in a structure is shown in Figure 2, Appendix A. The rupture disc adapter, with the appropriate disc in place, was attached to the inlet end of the one-inch pipe on the outside of the building (Figure 3, Appendix A).

After the batteries were fully charged, the electric lead from the blower and timing mechanism was connected to the battery case. The dial of the clock was turned to "on" in order to check the operation of the blower.

The microscope slides were cleaned and numbered. On X-ray minus two days the slides were placed in their respective Cascade Impactors. On X-ray minus one day the dial of the clock was set so that the "on" switch would start the blower fifteen minutes before the detonation, and the "off" switch was set to allow the blower to operate for one hour after the explosion.

As soon after the explosion as radiological safety conditions permitted, the Cascade Impactors and canisters were removed from the structures. The amount of radioactivity of the material on each slide inside the impactors was measured in the laboratory on the U.S.S. Bairoko (CVE-115) by a Scaler Unit, model 161-G, with an Eck and Krebs tube having a window thickness of 30 mg/cm^2. Samples of the filter material (8.7 cm^2 disc) and charcoal in the canisters were also measured for radioactivity. At a later date the radioactivity of the material on the glass slides was measured again to determine its rate of decay.

The Cascade Impactor slides were packed and returned to the Army Chemical Center, Maryland for a count of particles with the light and electron microscopes.

B. Test Yoke

One Cascade Impactor unit was set up on an LCM boat which was anchored in the lagoon downwind from the detonation at 2500 yards from Zero. A second unit was assembled on Rujuro Island, the second island west of Aomon, at 2000 yards from Zero. The third Cascade Impactor apparatus was installed on Drone Plane No. 6 which flew through the cloud at an elevation of 16,000 feet and a speed of about 180 knots per hour.

The legs were removed from the apparatus installed in Drone Plane No. 6, and the unit was placed inside the photo well in the radio compartment of the plane. Approximately 3 feet of one-inch pipe led from an opening in the belly of the plane at about 12 inches from the after edge of the bomb bay doors to a 90° ell connected to the intake of the expansion chamber on the Cascade Impactor equipment. Figures 4 and 5, Appendix A, show the equipment installed in the photo well. An aluminum shield was placed around the motor operating the blower to prevent interference with the radio circuits of the plane. A scoop, in the form of a semi-ellipse about 2 inches long and with a one-half-inch radius, was riveted to the fuselage over the opening in the belly of the plane. A close-up of the scoop intake to the Cascade Impactor apparatus and its relative position on the plane are shown in Figures 6 and 7, Appendix A, respectively. A piece of tape was placed over the open end of the scoop to keep dust from blowing into the unit before the test. The tape was removed by the crew chief of the drone after it was taxied on the runway prior to being picked up by the mother plane.

As soon after the explosion as radiological safety conditions permitted, the Cascade Impactors and canisters were removed from their respective positions. The amount of radioactivity of the material on the Cascade Impactor slides and canister filters was measured in the laboratory on the U.S.S. Bairoko (CVE-115) as described under test X-ray. At a later date the radioactivity was measured again to determine the rate of decay of the material. The alpha radiation on the slides from the impactor in the drone plane is being measured with nuclear track plates. The Cascade Impactor slides were returned to the Army Chemical Center, Maryland for a count of particles with the light and electron microscopes.

Two days after the explosion "fall-out" was detected on the U.S.S. Bairoko (CVE-115). A Cascade Impactor unit was set up on the forward end of the flight deck and operated for 3 hours. The slides were removed from the impactor, and the radioactivity on them was measured in the laboratory. The following day the Cascade Impactor unit operated for 6 hours, after which the slides were removed and evaluated. The slides used for these "fall-out" tests were also returned to the Army Chemical Center, Maryland.

C. <u>Test Zebra</u>

One Cascade Impactor unit was set up on an LCM boat which was anchored in the lagoon downwind from the detonation at 4000 yards from Zero. One Cascade Impactor apparatus was installed in each Drone

Plane No. 6 and Drone Plane No. 2, which flew through the cloud at 16,000 feet and 26,000 feet, respectively. The installation of the equipment in the drone planes is described under test Yoke.

As soon after the explosion as radiological safety conditions permitted, the Cascade Impactors and canisters were removed from their respective positions and returned to the laboratory aboard the U.S.S. Bairoko (CVE-115) for evaluation as described under test Yoke. These Cascade Impactor slides also were returned to the Army Chemical Center, Maryland.

IV. TEST RESULTS

A. Test X-Ray

The OCE Type A structure at 1000 feet from Zero was thrown over 100 feet from its original position, turned upside down and the door blown inside the structure as a result of the explosion. The equipment inside the structure was smashed, and the Cascade Impactor was broken in half. However, three of the four slides inside the impactor were recovered.

The OCE Type A structure at 1500 feet from Zero was turned upside down, but the Cascade Impactor equipment was intact and apparently operated during the test. The electric leads were still connected to the battery case, and the unit remained attached to the one-inch inlet pipe to the structure. Figure 8, Appendix A, shows the condition of the Cascade Impactor equipment in the structure after the explosion.

The OCE Type B structure at 1500 feet from Zero was thrown over

100 feet from its original position and turned upside down by the explosion. The one-inch air inlet pipe was sheared off at the connection to the expansion chamber on the Cascade Impactor apparatus, and the electric leads were torn loose from the battery case. However, there was sufficient dust on the glass slides in the Cascade Impactor to indicate that the unit operated for at least a short time after the explosion. Figure 9, Appendix A, shows the condition of the Cascade Impactor equipment in this structure after the explosion.

The OCE Type B structure at 2500 feet from Zero was moved along the ground only about 3 feet, and the Cascade Impactor equipment functioned satisfactorily during the test.

The amount of radioactivity of the material on the glass slides in each of the Cascade Impactors and on the canister filters is given in Table 1, Appendix B. Photographs of the glass slides after the test are shown in Figures 10 to 12, Appendix A.

B. <u>Test Yoke</u>

As a result of the explosion the Cascade Impactor apparatus on the LCM boat was turned over on its side with the inlet pipe facing upward. However, the electric leads remained connected to the battery case, and the unit functioned satisfactorily throughout the test.

The Cascade Impactor equipment on Rujuro Island, the second island west of the Zero island, was rolled over on the ground with the air inlet pipe facing upward. No damage was done to the apparatus, and this unit operated satisfactorily throughout the test.

Drone Plane No. 6 on which the third Cascade Impactor was installed made three passes through the cloud. The plane flew through the cloud at an elevation of 16,000 feet, and the times at which it entered and left the cloud are given in Table 4, Appendix B.

The glass slides and canisters were recovered from all three Cascade Impactor units. The amount of radioactivity of the material on each of the glass slides and on the canister filters is given in Table 2, Appendix B.

On the second day following the explosion "fall-out" was detected on the U.S.S. Bairoko (CVE-115). A Cascade Impactor unit set up on the flight deck of the ship operated for 3 hours on that day and for 6 hours on the following day. The radioactivity of the material collected on each of the slides is shown in Table 2, Appendix B.

C. Test Zebra

The Cascade Impactor equipment assembled on the LCM boat, which was anchored at a distance of 4000 yards from Zero, was not affected by the explosion and functioned throughout the test. However, no "fall-out" occurred in the vicinity of the boat, and no radioactivity was detected on the glass slides.

Drone Plane No. 6 at an elevation of 16,000 feet made three passes through the cloud, while Drone Plane No. 2 at 26,000 feet went over the cloud on its first pass and made only two passes through the cloud. The times at which each plane entered and left the cloud are given in Table 4, Appendix B.

The material on the glass slides and canisters from the three Cascade Impactor units were measured for intensity of radiation, and the results are given in Table 3, Appendix B.

Since the concentration of radioactive material on the canister filters from the drone planes was high, measurements were made to determine its efficiency in removing radioactive particulates. A sample of the Type 6 paper from the canister M11 was weighed, and the radioactivity of the material on it was measured. A layer from the influent surface of the paper was peeled off, and the amount of radioactivity on the remainder of the filter was measured. Since the influent and effluent concentrations of particulates through a given depth of filter is known, the filtration constant, s, can be determined from the theoretical filtration equation:

$$N/N_o = e^{-s\chi}$$

Where N = concentration of particulates penetrating a filter

N_o = initial concentration of particulates

s = filtration constant

χ = depth or quantity of filter

The results obtained on the filters from the canisters on Drone Plane No. 2 and Drone Plane No. 6 were as follows:

	No. 2	No. 6
Weight of Original Sample (full thickness), mg	231	176
Radioactivity of Material on Sample, N_o, dpm	4,010	39,600
Weight of Paper Removed, χ, mg	63	115
Amount of Radioactivity on Remainder of Filter, N, dpm	144	158
Filter Constant, s	3.33	5.53

(Note: The filter constant, s, was calculated from the theoretical filter equation by assigning a value of unity to the respective weights, χ, of the filters, i.e., 63 mg of the filter from Drone Plane No. 2 would be one unit, while a weight of 115 mg would be one unit for the filter from Drone Plane No. 6.)

The theoretical filtration equation plotted on semi-log paper results in a straight line with a slope of "s". Knowing "s" and one value of N/N_o, the curves for the filters from the canisters in Drone Plane No. 2 and Drone Plane No. 6 were plotted on semi-log paper and are shown in Figure 1, Appendix A. From these curves the penetration, N/N_o, through the full thickness (or weight) of the filter paper from canister M11 on Drone Plane No. 2 was 2.1×10^{-4} or 0.021% and one Drone Plane No. 6 was 1.8×10^{-4} or 0.018%.

A charcoal sample was taken from the influent layer of the charcoal bed in the canister on Drone Plane No. 6. The sample weighed 428 mg, and its radioactivity was 788 disintegrations per minute when measured at H plus 52 hours. However, after all of the charcoal in the canister was thoroughly mixed, a sample weighing 708 mg had a radioactivity of only 115 disintegrations per minute. A charcoal sample (estimated about 600 mg) from the influent layer in the canister on Drone Plane No. 2 had a radioactivity of 114 disintegrations per minute, when measured at H plus 32 hours. The total weight of charcoal in a canister M11 is about 150 grams.

The results of the particle size measurements of the material on the glass slides returned to the Army Chemical Center, Maryland will be submitted at a later date as a supplement to this report upon completion of this work. The alpha radiation measurements also will be included in this supplemental report.

V. DISCUSSION

In the original plan of test, Cascade Impactor equipment was to be placed in each of four Corps of Engineer structures on Engebi Island for the measurement of particle size of the material in the cloud during test X-ray only. However, the apparatus functioned so satisfactorily and was in such good condition after test X-ray that three of the units were used in the subsequent tests. The only apparatus that was not usable after the first test was the unit in the structure at 1000 feet from Zero, since it was crushed by the door which was blown inside the building as a result of the explosion. The Cascade Impactor was broken in half, but three of the four glass slides inside the impactor were recovered. All of the glass slides in the other three Cascade Impactors were recovered. Although three of the four structures were rolled over by the explosion, the functioning of the Cascade Impactor equipment was not adversely affected by this rough usage. Its performance as a field apparatus for the measurement of particle size was entirely satisfactory.

The results obtained during test X-ray, shown in Table 1, Appendix B, probably are not conclusive of the particle size distribution of the radioactive dust in the cloud. The quantity of dust collected on the glass slides was too large for an accurate measurement by this method.

The dust was accumulated on some of the slides to a depth of about 1/16 inch. Apparently there was much "slippage" from one stage to another. There was no wide variation in radioactivity among the stages in each Cascade Impactor, but less radioactive material was collected in the Impactor at 2500 feet from Zero than at the closer stations, as would be expected. When the dust on some of the slides was leveled to a thin layer, the measured radioactivity of the material increased about 40%, indicating much self-absorption. No radioactivity was detected on the filters of the canisters M11, which were at the effluent end of the Cascade Impactors, due to decay of the radioactive material since the measurements were made about seven days after the explosion and only a small portion (about 1/69) of the total effective filter was used.

The results in Tables 2 and 3, Appendix B, obtained during tests Yoke and Zebra clearly indicate that the radioactive material in the cloud is composed of extremely fine particles. The glass slides from the the first stages of the Cascade Impactors on the drone planes which flew through the cloud at elevations of 16,000 and 26,000 feet, had a comparatively small amount of radioactive material on them. The other three stages of the impactors had a considerably greater amount of radioactive material on them, while by far the greatest amount of material was collected on the filters of canisters M11, which were on the effluent end of the Cascade Impactors and are essentially a fifth stage. If the calibration of the impactors given in the interim report in Appendix C is applicable, most of the particles were less than 0.4 micron in diameter with the majority less than 0.1 micron. However, the calibration may not apply since the pressure and flow rate at that elevation may alter the distribution curves. Therefore no final interpretation can be made until the particles are measured with an electron microscope. These measurements will be made at the Army Chemical Center, Maryland, and the results will be submitted in a supplementary report upon completion.

The glass slides from the second stages of the Cascade Impactors on the LCM boat at 2500 yards and on Rujuro Island at 2000 yards from Zero during test Yoke retained the largest amount of radioactive material. The third stages contained considerably less material, while the first and fourth stages retained a comparatively small amount of radioactive material. This indicates that the radioactive material at those distances from the detonation follows the particle size distribution curves given in Figures 2 to 5 of the interim report in Appendix C with a maximum retention of 0.2 to 0.3 micron.

A Cascade Impactor unit operated for 3 hours on the flight deck of the U.S.S. Bairoko during the second day following the explosion of test Yoke when "fall-out" was detected. The glass slide from the second stage of the impactor retained most of the radioactive particles indicating a particle size distribution with a maximum retention of 0.3 micron. The unit operated for 6 hours during the third day following the explosion and a similar particle size distribution was indicated although the quantity of radioactive material collected was considerably less. The actual size of the particles collected on the glass slides from all of the tests will be determined with an electron microscope at the Army Chemical Center, Maryland, and the results will be included in the supplementary report.

In all cases the decay of the radioactive material on the various Cascade Impactor slides followed the same rate of decay as either the crater sample or the drone sample. This would indicate that there was no segregation of the various radioactive products in the cloud, and that the radioactive material is probably carried on dust particles.

The efficiency of canister M11 in removing radioactive particulates was determined by measuring the amount of radioactive material retained on various depths of the Type 6 filter paper in the canisters. By this method the penetrations through the filter paper in the canisters from Drone Plane No. 2 and Drone Plane No. 6 were calculated to be 0.021% and 0.018%, respectively. The flow rate through the canisters, which were on the effluent end of the Cascade Impactors, was approximately 16 liters per minute, and these results of particulate penetrations are comparable to those obtained in the laboratory on this same type of filter material using an aerosol of 0.3-micron diameter.

A moderate amount of radioactive material was detected on the charcoal in the canister M11 on Drone Plane No. 6, which flew through the cloud at 16,000 feet during test Zebra. The majority of the radioactive material was collected on the influent layer of the charcoal bed in the canister. These results intimate that either some radioactive material in the cloud is present in vapor form or some of the radioactive material is vaporizing off the dust particles after being collected by the filter.

VI. CONCLUSIONS

It is concluded that:

1. The Cascade Impactor equipment used for these tests is an excellent field apparatus. It is easy to operate, portable and withstands rough usage.

2. The radioactive material in the cloud apparently consists of very small particles. Present indications are that a major portion is below 0.5 micron in diameter.

3. The protection afforded by canister M11 against the radioactive particulates in the cloud is comparable to that obtained in laboratory tests using a non-toxic aerosol of 0.3-micron diameter.

VII. RECOMMENDATIONS

None, pending results of additional electron microscope measurements which will be included in a supplementary report.

APPENDIX A

Figures 1 through 12

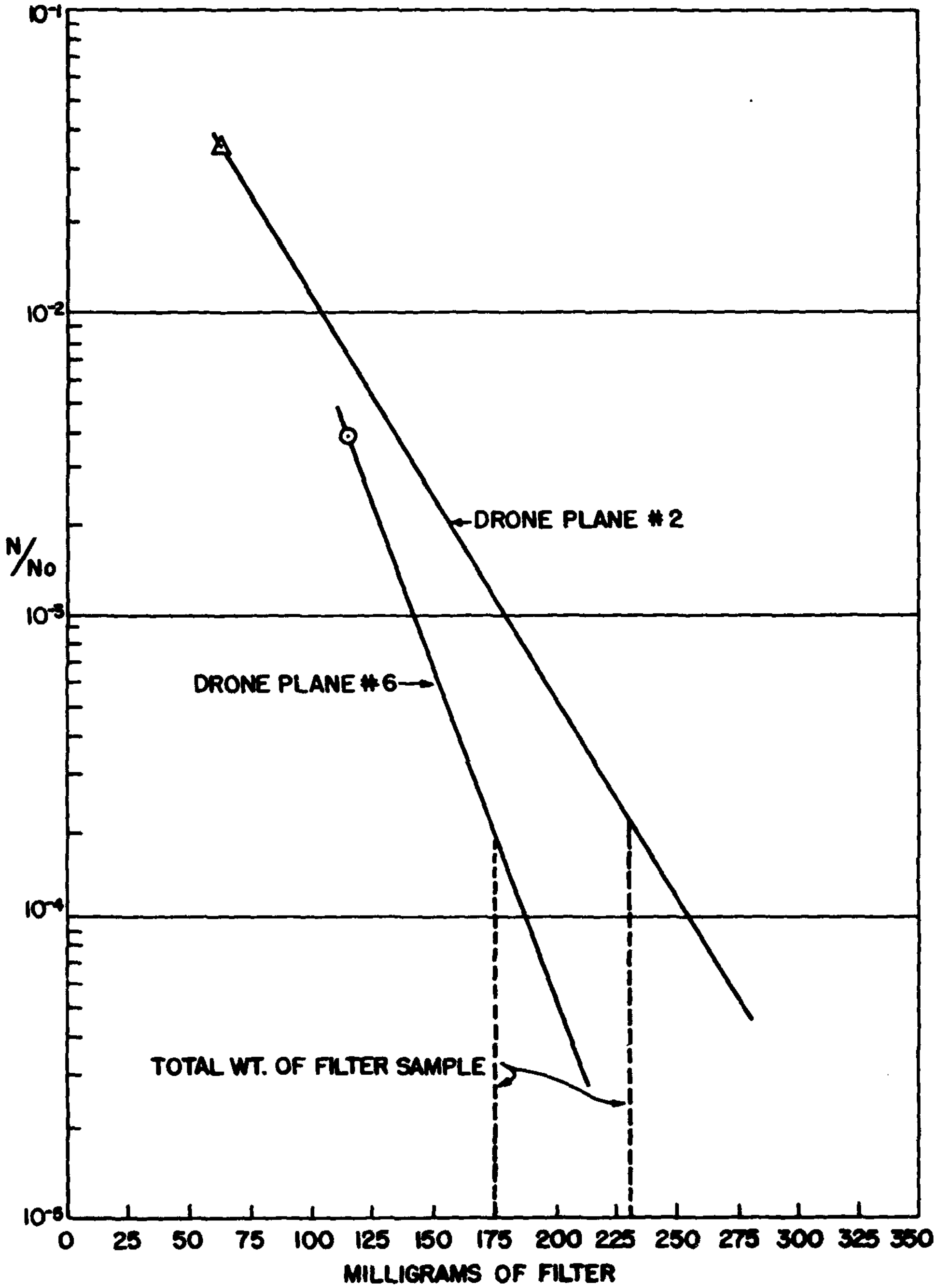


Fig. 1 Filtration Efficiency of Type 6 Paper in Canisters M11 on Drone Plane No. 2 and Drone Plane No. 6

Fig. 2 Cascade Impactor Installed Inside OCE Structure

Fig. 3 Inlet Tube for Cascade Impactor Showing Rupture Disc (Outside View)

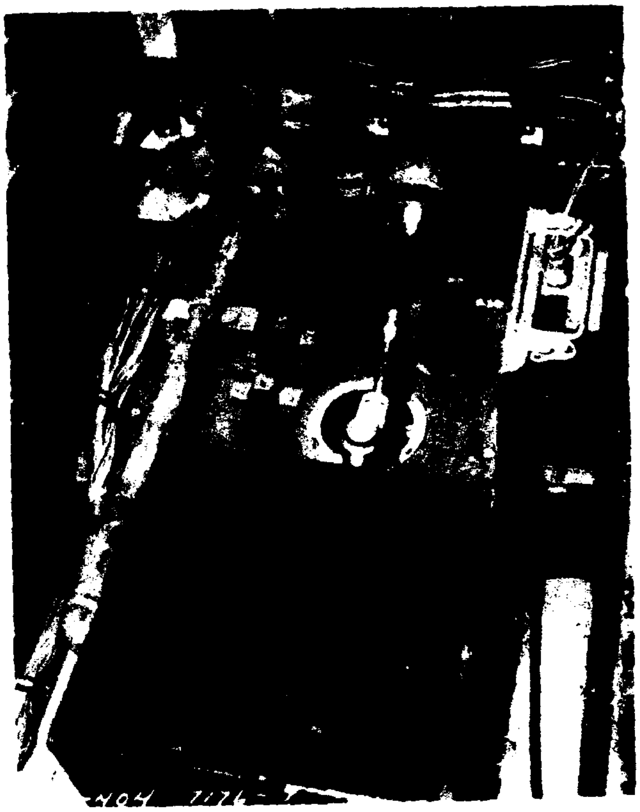


Fig. 4 Cascade Impactor Installed in Photo Well of B-17 Drone Plane

Fig. 5 Cascade Impactor Installed in Photo Well of B-17 Drone Plane

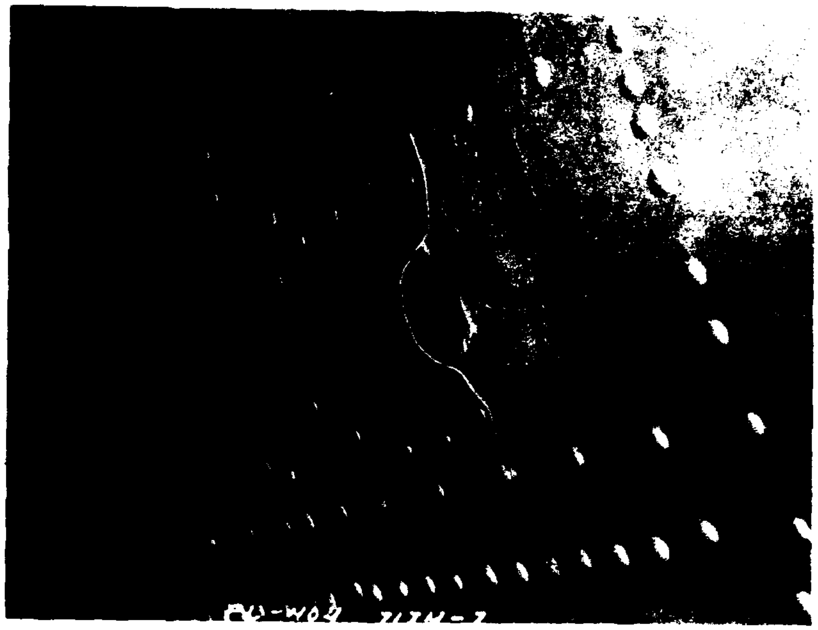
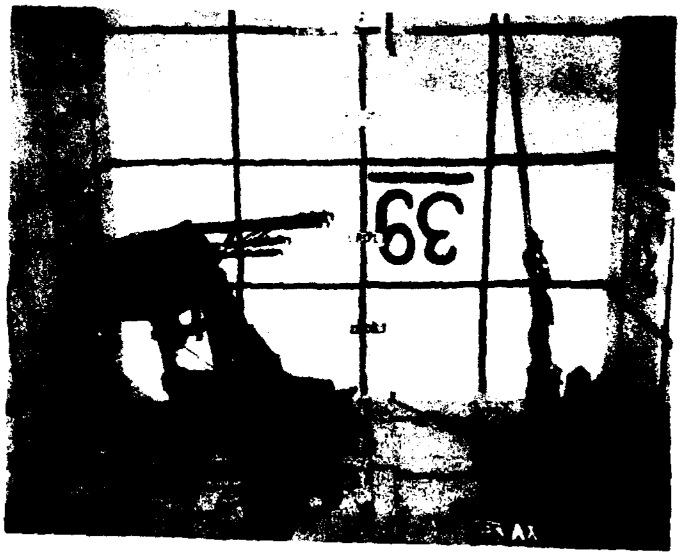


Fig. 6 Inlet Scoop for Cascade Impactor (Close-up View)

Fig. 7 Inlet Scoop for Cascade Impactor (Distant View Showing Location on Plane)

PA-198-8-3200-8 OCE Structure
"A"- 1500' interior 17 Apr 48

Fig. 8 OCE Structure "A" - 1500-feet Interior



PA-198-11-3203-11 OCE Structure
"B" 1500' interior 17 Apr 48

Fig. 9 OCE Structure "B" - 1500-feet Interior

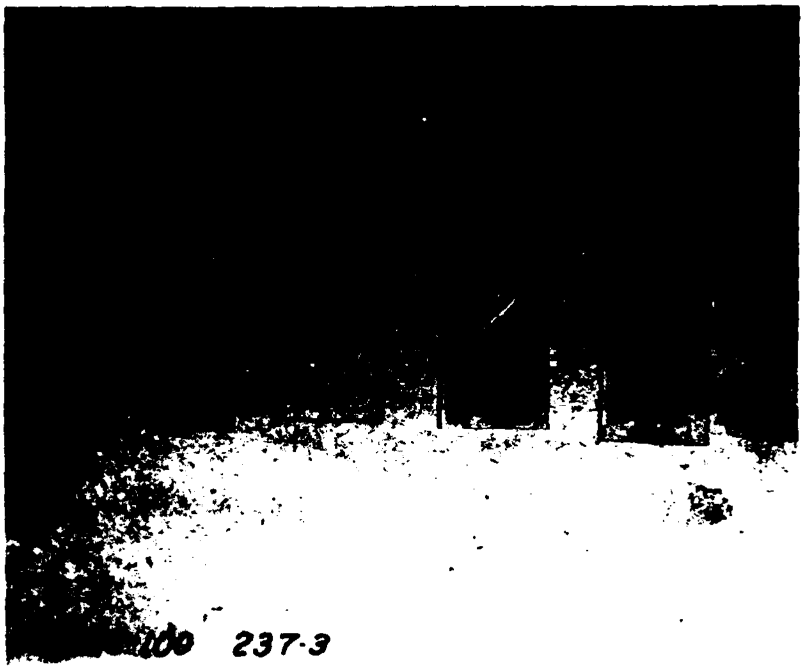


Fig. 10 Slides Recovered from Cascade Impactor in OCE Type A Structure at 1000 Feet

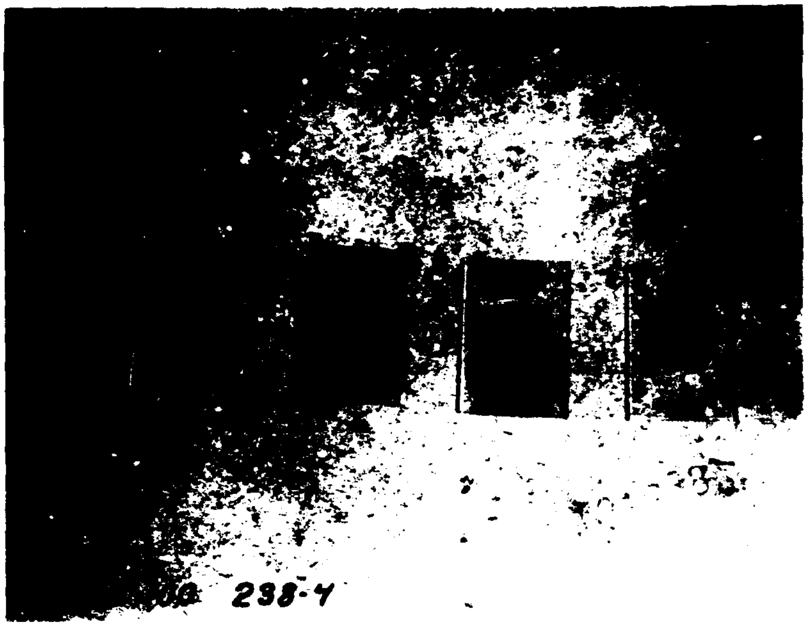


Fig. 11 Slides from Cascade Impactors in 1500-feet Type A Structure

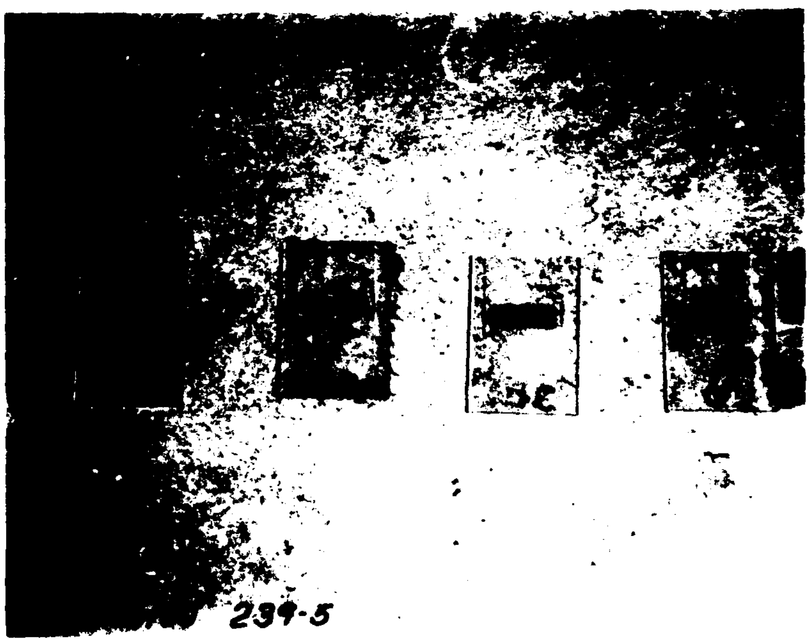


Fig. 12 Slides from Cascade Impactors in 1500-feet Type B Structure

APPENDIX B

Tables 1 through 4

Table 1

Radioactivity of Material on Cascade Impactor Slides and Canisters

Test X-Ray

Sampling Position	Slide No.	Time Measured plus H hours	Radioactivity disintegrations per minute	Remarks
OCE Type A at 1000 feet	1A	154	644	Cascade impactor broken in half.
"	1B	-	-	Not recovered.
"	1C	154	505	Corner of slide broken off.
"	1D	154	761	
"	Canister M11	172	0	
"	1A	172	300	) Decay follows same curve
"	1C	172	238	) as for crater sample.
"	1D	172	414	)
OCE Type A at 1500 feet	2A	83	925	
"	2B	83	1,737	) Dust piled up to about
"	2C	83	1,450	) 1/16 inch on slides
"	2D	83	1,320	) 2B, 2C, and 2D.
"	Canister M11	172	0	
"	2A	172	195 (?)	Result questionable.
"	2B	172	169	
"	2C	172	102	
"	2D	172	64	
"	2A	176	93	) Dust on slides leveled
"	2B	174	238	) to a thin layer.
"	2C	176	145	)
"	2D	176	76	)
OCE Type B at 1500 feet	3A	54	15,700	
"	3B	54	14,700	
"	3C	54	16,100	
"	3D	54	16,400	

Table 1 (continued)

Sampling Position	Slide No.	Time Measured	Radioactivity	Remarks
		plus H hours	disintegrations per minute	
OCE Type B at 1500 feet	Canister M11	173	0	
"	3A	173	112	) Decay follows same curve
"	3B	173	100	) as for crater sample.
"	3C	173	105	)
"	3D	173	81	)
OCE Type B at 2500 feet	4A	84	210	
"	4B	84	293	
"	4C	84	244	
"	4D	84	229	
"	Canister M11	174	0	
"	4A	174	7	) Decay follows same curve
"	4B	174	14	) as for crater sample.
"	4C	174	10	)
"	4D	174	10	)

Note: Letters A, B, C and D after the slide numbers represent the first, second, third and fourth stages, respectively, of the Cascade Impactor.

Table 2

Radioactivity of Material on Cascade Impactor Slides and Canisters

Test Yoke

Sampling Position	Slide No.	Time Measured plus H hours	Radioactivity disintegrations per minute	Remarks
Drone #6 at 16,000 feet	6A	14	29,250	) Material on slides) barely visible with) naked eye.
"	6B	14	403,000	)
"	6C	14	272,000	)
"	6D	14	276,100	)
"	Canister M11	82	*25,000	Reading on sample disc of filter.
"	"	82	1,725,000	Calculated to total of area of filter.
"	"	14	12,420,000	Extrapolated back to H plus 14 hours on fission products decay curve.
"	6A	41	9,790	) Decay follows same curve) as for drone sample) (fission products).
"	6B	41	119,000	)
"	6C	41	82,200	)
"	6D	41	77,500	)
"	Canister M11	122	17,000	) Reading on sample disc of filter.
LCM Boat at 2,500 yards	7A	10	48	
"	7B	10	10,350	
"	7C	10	2,750	
"	7D	10	16	
"	Canister M11	10	0	
"	7A	34	0	) Decay follows same curve) as for crater sample.
"	7B	34	1,294	)
"	7C	34	384	)
"	7D	34	14	)

Table 2 (continued)

Sampling Position	Slide No.	Time Measured	Radioactivity	Remarks
		plus H hours	disintegrations per minute	
Rujuro Island				
at 2,000 yards	8A	42	30	
"	8B	42	1,460	
"	8C	42	930	
"	8D	42	316	
Flight Deck of U.S.S. Bairoko	9A	62	66	Operated for 3 hours from 1345 to 1645 on 3 May 1948
"	9B	62	480	
"	9C	62	21	
"	9D	62	82	
Flight Deck of U.S.S. Bairoko	10A	86	0	Operated for 6 hours from 0910 to 1510 on 4 May 1948
"	10B	86	185	
"	10C	86	7	
"	10D	86	24	

* Average reading of four samples of filter 8.7 sq. cm. in area.

Total effective area of filter in canister M11 is 600 sq. cm.

Note: Letters A, B, C and D after the slide numbers represent the first, second, third and fourth stages, respectively, of the Cascade Impactor.

Table 3

Radioactivity of Material on Cascade Impactor Slides and Canisters

Test Zebra

Sampling Position	Slide No.	Time Measured plus H hours	Radioactivity disintegrations per minute	Remarks
Drone #6 at 16,000 feet	16A	11	1.15×10^4	) Material on slides
"	16B	11	3.50×10^5	) barely visible with
"	16C	11	2.27×10^5	) naked eye.
"	16D	11	4.90×10^5	)
"	Canister M11	33	*7.61×10^4	Reading on sample disc of filter.
"	"	33	5.25×10^6	Calculated to total eff. area of filter.
"	"	11	1.52×10^7	Extrapolated back to H plus 11 hours on fission products decay curve.
"	16A	51	2.96×10^3	) Decay follows same curve
"	16B	51	1.01×10^5	) as for drone sample
"	16C	51	6.91×10^4	) (fission products).
"	16D	51	1.27×10^5	)
Drone #2 at 26,000 feet	12A	11	2.79×10^3	) Material on slides
"	12B	11	1.48×10^5	) plainly visible.
"	12C	11	4.78×10^5	)
"	12D	11	3.29×10^5	)
"	Canister M11	33	*1.14×10^4	Reading on sample disc of filter.
"	"	33	7.87×10^5	Calculated to total eff. area of filter.
"	"	11	2.42×10^6	Extrapolated back to H plus 11 hours on fission products decay curve.
"	12A	51	5.95×10^2	) Decay follows same curve
"	12B	53	2.87×10^4	) as for drone sample
"	12C	53	6.84×10^4	) (fission products).
"	12D	53	6.41×10^4	)

Table 3 (continued)

Sampling Position	Slide No.	Time Measured	Radioactivity	Remarks
		plus H hours	disintegrations per minute	
LCM Boat at 4,000 yards	11A	10	0	No "fall-out" in vicinity of boat.
"	11B	10	0	
"	11C	10	0	
"	11D	10	0	

* Average reading of two samples of filter 8.7 sq. cm. in area.

Total effective area of filter in canister M11 is 600 sq. cm.

Note: Letters A, B, C and D after the slide numbers represent the first, second, third and fourth stages, respectively, of the Cascade Impactor.

Table 4

Pass Times of Drone Planes Through the Cloud

Test	Drone Number	First Pass Enter	First Pass Exit	Second Pass Enter	Second Pass Exit	Third Pass Enter	Third Pass Exit
Yoke (060900)*	6	061620	061640	062545	062645	063840	063915
Zebra (060400)*	6	060945	061020	062030	062100	063300	063400
Zebra (060400)*	2	Over		062340	062400	063815	063835

* The time of the explosion is given in parenthesis.

APPENDIX C

Interim Report

EVALUATION OF DUSTS WITH THE CASCADE IMPACTOR

by

Howard Lanier

APPENDIX C

TABLE OF CONTENTS

Interim Report

EVALUATION OF DUST WITH THE CASCADE IMPACTOR

ABSTRACT

Object

The object of this work has been to construct and calibrate Cascade Impactors and auxiliary equipment for the sampling of a particulate cloud produced by a highly explosive weapon.

Results

1. The three types of dusts are all of comparable density.

Dust	Density
A	2.41
E	2.66
R	2.49

2. The four impactors used gave comparable Frequency-Diameter Curves.

Discussion

The increased impaction efficiency of the cloud has appreciably shifted the peaks of the frequency curves. For example, the peak frequency for jet 4 on all impactors is 0.1 micron, for jet 3 it is 0.2 micron, for jet 2 it is 0.3, and where adequate counts permitted, it is 0.4 micron on jet 1. Thus, the separation of the cloud has actually occurred; however, all in the range below 0.5 micron.

Conclusions

The Cascade Impactors uniformly separate the cloud as follows:

Jet	Frequency Peak
1	0.4 micron
2	0.3 micron
3	0.2 micron
4	0.1 micron

Apparently there is no serious loss of particles in the chamber. Based upon a rather limited count, no peak shift occurred and there is little evidence that there is a serious loss of larger particles prior

to reaching the impactor.

Recommendations

It is recommended that provisions be made for return of the samples to this laboratory for a count of the particles with the electron microscope. This would enable presentation of the data on a mass basis. Thus, not only would presentation of a Frequency-Diameter curve be possible; however, it would be possible to express an mmd per stage as well as for the entire cloud.

Interim Report

EVALUATION OF DUSTS WITH THE CASCADE IMPACTOR

I. INTRODUCTION

A. Object

The object of this work has been to construct and calibrate Cascade Impactors and auxiliary equipment for the sampling of a particulate cloud produced by a highly explosive weapon.

B. Authority

Letter dated 7 November 1947, from Armed Forces Special Weapons Project, to the Chief, Chemical Corps. Subject: Request for Cascade Impactors.

II. HISTORICAL

K. R. May, H. L. Green and J. W. Stevenson described the Cascade Impactor in Porton 1600 (U3968) April 1, 1944. May later reported the impactor in the Journal of Scientific Instruments in 1945. The impactor as designed by May was used extensively during the war at all experimental chemical warfare installations, and was found to be the most practical field sampling device for the evaluation of aerosols.

Recently a number of modifications of the original design have been made. L. S. Sonkin described a "Modified Cascade Impactor" in the Journal of Industrial Hygiene and Toxicology, November 1946. Also, H. C. Hodges redesigned the impactor and it is his design that has been duplicated for this test.

III. THEORETICAL

The Cascade Impactor is a four stage impinger which is used for sorting particulates into four size ranges. The separation of the cloud into portions is accomplished by increasing the velocity of the air stream through each of the four jets, thus, a progressively smaller range of particles is "impacted out" as the sample passes from jet to jet. This sorting presents a number of convenient methods of expressing the nature of the cloud being sampled.

The cloud under consideration in this test will be composed of irregularly shaped dusts with an average specific gravity considerably greater than the dispersed material reported by May; therefore, the size ranges per stage will be considerably lower.

The calibration of the impactors will be conducted with a cloud of the same density materials as anticipated during the actual test. To establish this, the density of the dusts "A", "E" and "R" are to be determined. The three dusts will then be dispersed separately and sampled with one impactor. A comparison of the counts from one stage should then indicate the approximate distribution for each dust. If the frequency curves are comparable the dusts will be mixed for a final calibration.

The presentation of the data will be a plot of frequency versus size. Thus, if the impactors are uniform in the size range they remove per stage, it will be possible to state that a given stage may be represented by a frequency curve with a maximum retention of a stated size.

IV. EXPERIMENTAL

A. Materials and Equipment

1. Cascade Impactor

The Cascade Impactors employed for this work were constructed from drawings by Dr. H. C. Hodges. Details of construction are given in drawings A through G, Enclosure D.

2. Expansion Chamber

To reduce the shock on the impactor from the bomb burst a sheet metal chamber has been placed in front of it. This chamber is approximately one foot square with entrance and exit pipes of one-inch diameter. See drawing H, Enclosure D and Fig. 1, Enclosure C.

3. Rupture Discs

To absorb the initial blast of the bomb burst a rupture plate has been placed at the port of the pipe leading to the expansion chamber and impactor. These aluminum discs are to be used at the three inner positions. The 0.0015 inch thickness has been selected for the middle positions, and the 0.003 inch thickness has been selected for the inner position. No disc will be used at the outer sampling station. The disc will be mounted in an adapter at the intake pipe. The adapter is shown in drawing J, Enclosure D. Tables 1 and 2, Enclosure B, give the rupture pressures for the discs used.

4. Canister

A M11 canister has been placed as a filter at the effluent of each Cascade Impactor to serve as a fifth impaction stage. The location of the canister in the completed assembly is shown by drawing H, Enclosure D and Fig. 1, Enclosure C.

5. Blower

Vacuum for the system is supplied by a 24-volt blower taken from a Protector, Facepiece, E22. The blower is shown in drawing H, Enclosure D and Fig. 1, Enclosure C.

6. Batteries

The batteries employed are 6-volt plastic storage batteries type BB-207/U. The batteries are housed two to a case with cannon plug connectors from the housing to the Blower-Timer circuit.

7. Timer

A timer has been installed to close the Battery-Blower circuit. This timer is spring wound with "on" and "off" tabs to make and break the circuit. The minimum time that may be set between "on" and "off" is approximately forty-five minutes. A special catch was placed on the clock to stop it's operation after the circuit has been cut off. This will eliminate the clock running another twenty-four hour period and taking a sample the following day. Location of the timer is shown in Fig. 1, Enclosure C.

8. Assembly Stand

The expansion chamber, impactor, canister, blower and timer are mounted on a rugged frame to permit ease of assembly at the proper height. Appropriate double end wrenches are chained to the stand to insure the availability of the proper sized tools. See Fig. 1, Enclosure C. Directions for field setup and operation are given in Enclosure A.

B. Calibration Procedure

1. Adjustment of Flow

The blowers were operated at 12 volts rather than the rating of 24. The units were assembled (including three feet of one-inch pipe on the intake of the expansion chamber) and the flow was determined through each system operating at 12 volts.

2. Preparation of Dust

Dusts "A", "E" and "R" were pulverized and a density determination was made on each type. A cloud of dust "R" was then dispersed and inspected under the light microscope. Inasmuch as the particles found were in a range at the limit of resolving power of the microscope, it was decided to use the electron microscope for further calibration work. Each of the dusts were then dispersed and sampled on electron microscope screens in impactor No. 1.

3. Sampling Technique

The final calibration of the four impactors to be used was made with a mixture of the three dusts. The four impactors were mounted in a hood in which the dust mixture was being dispersed and a sample taken for 60 seconds.

To determine if a serious loss occurred in the expansion chamber, another test was conducted with impactor No. 1 with an expansion chamber and No. ? impactor without sampling a cloud of mixed dust.

4. Measurement of Particles

The increased impaction efficiency of the dusts necessitated the examination of the slides with greater resolving power than the light microscope could afford. In order to employ the RCA Universal Type Electron Microscope, a technique was devised that permitted collection of the samples of 200 mesh electron microscope screens coated with Formvar. This technique consisted of spreading Formvar on water and "dipping out" with the half of the microscope slide to be used. The Formvar firmly held the screen on the slide even in the air stream from the jet. A specimen screen was then placed at each side of the slide with collodion to space the Formvar coated sample screen the correct distance from the jet. The samples were then photographed at a magnification of approximately 6900 diameters and enlarged photographically to 27,500 diameters. This made 0.1 of a micron approximately 0.10 of an inch which made particles less than a 0.10 micron countable.

The preliminary counts of the three dusts were made at a magnification of 2,380 and enlarged to 9,500 diameters. At this magnification, greater error in the 0.1 and 0.2 micron sizes was experienced; therefore, it was decided to increase the magnification to the 27,500 diameter stated above.

Calibration photographs of each magnification used are presented in Enclosure E. This calibration is the standard method of photographing a diffraction grating replica. The grating used for this calibration had 15,000 lines per inch.

C. Results

1. The determination of the dust densities indicated that the three dusts were of comparable density.

Dust	Density
A	2.41
E	2.66
R	2.49

2. The limitations of density determination on dust required an actual test with each material dispersed and sampled by impactor No. 1. Results of these three tests are given in Table 3, Enclosure B, also Fig. 6, Enclosure C.

3. Data from the final calibration of the four impactors are given in Tables 4 through 7, Enclosure B. All four impactors gave comparable frequency curves as indicated by the Frequency-Diameter curves in Figs. 2 through 5, Enclosure C.

4. Results of the test to determine chamber loss are given in Table 8, Enclosure B.

V. DISCUSSION

A. General

The increased impaction efficiency of the cloud has appreciably shifted the peaks of the frequency curves. For example, the peak frequency for jet 4 on all impactors is 0.1 micron, for jet 3 it is 0.2 micron, for jet 2 it is 0.3, and where adequate counts permitted, it is 0.4 micron on jet 1. Thus, the separation of the cloud has actually occurred; however, all in the range below 0.5 micron.

VI. CONCLUSIONS

A. The Cascade Impactors uniformly separate the cloud as follows:

Jet	Frequency Peak
1	0.4 micron
2	0.3 micron
3	0.2 micron
4	0.1 micron

Apparently there is no serious loss of particles in the chamber. Based upon a rather limited count, no peak shift occurred and there is little evidence that there is a serious loss of larger particles prior to reaching the impactor.

VII. RECOMMENDATIONS

A. It is recommended that provisions be made for return of the samples to this laboratory for a count of the particles with the electron microscope. This would enable presentation of the data on a mass basis. Thus, not only would presentation of a Frequency-Diameter curve be possible; however, it would be possible to express an mmd per stage as well as for the entire cloud.

ENCLOSURE A

DIRECTIVE

INSTRUCTIONS FOR INSTALLING

CASCADE IMPACTOR SAMPLING APPARATUS

1. Place acid in batteries. The acid furnished has already been adjusted for specific gravity.

2. Charge batteries at a 2 ampere rate for 20 to 24 hours. If the colored balls are up, they are ready for use. Check batteries as near shoot time as possible for condition of charge. Double the number of batteries needed and four times as much acid as needed has been shipped. Extra fuses are in battery charger case.

3. Attach rupture disc adapter (appropriate disc is in place) to opening on outside of barricade. Adapter wrench and extra discs (value marked on cover) are sent in carton with spare parts. See Tables 1 and 2, Enclosure B, for rupture pressures.

4. Assemble apparatus framework making necessary adjustments with horizontal and perpendicular slides and locknuts. Attach apparatus to opening in barricade by means of the union on side of chamber. Double end wrenches are attached to side of apparatus for attaching impactor to union on other side of chamber. Attach a canister to blower housing. Attach union between impactor and canister with double end wrench. Attach electric lead to battery case. Manually, turn dial of clock to "on" in order to check operation of blower.

5. Set dial of clock using black tabs, along sides of dial, in such a way that "on" switch will activate about fifteen minutes before burst, and "off" switch so that the blower will operate for the desired number of minutes. Set hook so that it will engage knob on the dial soon after the sampling period is over and blower has stopped. This will stop the clock.

6. Wash, polish and number microscope slides. Place in impactors, being certain when installing springs, the sleeves are in position to allow slides to be exactly equal distances from each side of jet and perpendicular to air stream. Replace knurled caps snugly.

ENCLOSURE B

TABLES

TABLE 1

Sample No. Size - 0.003"	Res. Pressure P.S.I. Air	Breaking Pressure P.S.I. Air	Sample No. Size - 0.0035"	Res. Pressure P.S.I. Air	Breaking Pressure P.S.I. Air	Sample No. Size - 0.004"	Res. Pressure P.S.I. Air	Breaking Pressure P.S.I. Air
1	110	104	1	150	114	1	150	140
2	115	104	2	140	124	2	155	146[7]
3	110	102	3	135	128	3	155	146[7]
4	112	107	4	132	128	4	155	148
5	110	108	5	132	128	5	160	158[8]
6	110	108	6	130	128[5]	6	156	150
7	112	108	7	130	128	7	164	138[9]
8	110	106	8	129	128	8	162	148
9	112	106	9	132	128[6]	9	160	154
10	110	105	10	132	128	10	160	149
11	X	74	11	X	120	11	X	142
12	X	80	12	X	122	12	X	136
A	110	100	A	130	114	A	160	142

5. Held at 125 P.S.I. Ruptured at 130 P.S.I.
6. Held at 128 P.S.I. Ruptured at 132 P.S.I.
7. Held at 145 P.S.I. Ruptured at 155 P.S.I.
8. Held at 155 P.S.I. Ruptured at 160 P.S.I.
9. Held at 160 P.S.I. Ruptured at 164 P.S.I.

TABLE 2

Sample No. Size 0.001"	Res. Pressure P.S.I. Air	Breaking Pressure P.S.I. Air	Sample No. Size 0.0015"	Res. Pressure P.S.I. Air	Breaking Pressure P.S.I. Air	Sample No. Size 0.002"	Res. Pressure P.S.I. Air	Breaking Pressure P.S.I. Air	Sample No. Size 0.0025"	Res. Pressure P.S.I. Air	Breaking Pressure P.S.I. Air
1	50	24	1	50	40	1	70	70	1	90	80
2	50	20	2	50	38	2	70	60	2	100	85
3	50	19[1]	3	50	36	3	70	70	3	90	83
4	50	22	4	40	38	4	60	57	4	90	84
5	50	20	5	40	39	5	70	60[2]	5	93	84[3]
6	20	20	6	38	38	6	70	60	6	93	84
7	20	19	7	38	36	7	70	65	7	93	84
8	20	19	8	37	37	8	68	65	8	93	85
9	20	19	9	37	36	9	67	64	9	95	86[4]
10	20	18	10	37	37	10	63	63	10	94	86
11	X	17	11	X	32	11	X	48	11	X	105
12	X	17	12	X	28	12	X	59	12	X	101
A	20	18	A	40	36.5	A	70	63	A	90	82

1. Disc blew out
2. Twice at 60 P.S.I. Twice at 70 P.S.I. Ruptured at 2nd 70
3. Held 90 P.S.I. Ruptured at 93 P.S.I.
4. Held 93 P.S.I. Ruptured at 95 P.S.I.

TABLE 3

COMPARISON OF DUSTS "A", "E" AND "R"

DATA TAKEN ON IMPACTOR 1 JET 2

Size in Microns	Dust "A"		Dust "E"		Dust "R"	
	Number	% of Total	Number	% of Total	Number	% of Total
0.1	12	7.1	50	13.7	10	2.9
.2	28	16.7	68	18.6	32	9.3
.3	36	21.4	112	30.7	75	21.7
.4	14	8.3	46	12.6	62	17.9
.5	9	5.4	26	7.1	41	11.9
.6	12	7.1	20	5.5	27	7.8
.7	10	6.0	14	3.8	20	5.8
.8	8	4.8	12	3.3	21	6.1
.9	8	4.8	12	3.3	16	4.6
1.0	5	3.0	4	1.1	10	2.9
1.1	4	2.4			2	0.6
1.2	3	1.8			10	2.9
1.3	4	2.4			7	2.0
1.4	5	3.0			1	0.3
1.5	2	1.2			5	1.4
1.6	3	1.8	1	0.3	2	0.6
1.7	1	0.6				
1.8					2	0.6
1.9					1	0.3
2.0	1	0.6			2	0.6
2.1						
2.2	1	0.6				
2.3						
2.4	1	0.6				
3.0	1	0.6				

TABLE 4

FINAL CALIBRATION OF CASCADE IMPACTORS

IMPACTOR NO. 1

Size in Microns	Jet 1 Number	Jet 1 % of Total	Jet 2 Number	Jet 2 % of Total	Jet 3 Number	Jet 3 % of Total	Jet 4 Number	Jet 4 % of Total
0.1			12	1.5	39	3.6	128	7.2
.1			69	8.6	179	16.6	538	30.3
.2			167	20.8	359	33.3	472	26.5
.3			197	24.6	225	20.9	323	18.2
.4			156	19.5	127	11.8	170	9.6
.5			75	9.4	74	6.9	81	4.6
.6			54	6.7	40	3.7	37	2.1
.7			32	4.0	18	1.7	14	0.8
.8			16	2.0	10	0.9	8	0.4
.9			10	1.2	3	0.3	4	0.2
1.0			6	0.7	2	0.2	2	0.1
1.1			3	0.4				
1.2			2	0.2	1	0.1	1	0.05
1.3			2	0.2				
1.4								
1.5			1	0.1			1	0.05
			802	99.9	1077	100.0	1779	100.1

TABLE 5

FINAL CALIBRATION OF CASCADE IMPACTORS

IMPACTOR NO. 2

Size in	Jet 1		Jet 2		Jet 3		Jet 4	
Microns	Number	% of Total	Number	% of Total	Number	% of Total	Number	% of Total
0.1			8	1.3	35	1.8	101	6.6
.1	8	5.8	93	14.9	306	21.8	475	30.9
.2	21	15.1	161	25.8	290	31.3	428	27.9
.3	25	18.0	192	30.7	211	19.5	252	16.4
.4	28	20.2	56	9.0	92	12.0	136	8.9
.5	21	15.1	46	7.4	60	5.3	66	4.3
.6	14	10.1	30	4.8	31	3.7	36	2.3
.7	8	5.8	15	2.4	12	2.1	17	1.1
.8	5	3.6	10	1.6	10	0.9	12	0.8
.9	1	0.7	4	0.6	3	0.6	8	0.5
1.0	1	0.7	6	1.0	3	0.5	5	0.3
1.1			1	0.2	3	0.2	1	0.1
1.2			1	0.2	1	0.1		
1.3								
1.4	2	1.4			1	0.1		
1.5	2	1.4						
1.6	1	0.7						
1.7	1	0.7						
1.9					1			
2.0			1	0.2		0.1		
2.6			1	0.2				
4.0	1	0.7						
	139	100.0	625	100.3	1058	99.9	1537	100.1

TABLE 6

FINAL CALIBRATION OF CASCADE IMPACTORS

IMPACTOR NO. 3

Size in Microns	Jet 1		Jet 2		Jet 3		Jet 4	
	Number	% of Total	Number	% of Total	Number	% of Total	Number	% of Total
0.1	1	0.3	5	0.6	16	2.3	72	4.6
.1	25	8.5	97	11.3	141	20.4	586	37.4
.2	60	20.5	190	22.1	231	33.4	475	30.3
.3	65	22.2	227	26.4	128	18.5	250	15.9
.4	79	27.0	121	14.1	91	13.2	98	6.3
.5	17	5.8	82	9.6	39	5.6	48	3.1
.6	12	4.1	46	5.4	19	2.7	19	1.2
.7	6	2.0	31	3.6	12	1.7	12	0.8
.8	9	3.1	24	2.8	6	0.9	7	0.4
.9	5	1.7	12	1.4	4	0.6	1	0.1
1.0	5	1.7	8	0.9	1	0.1		
1.1	1	0.3	2	0.2				
1.2			2	0.2	1	0.1		
1.3	1	0.3	3	0.3	1	0.1		
1.4	1	0.3	5	0.6				
1.5					1	0.1		
1.6			1	0.1				
1.7	2	0.7	1	0.1				
1.8	1	0.3	1	0.1				
2.3	1	0.3						
2.4	1	0.3						
2.5	1	0.3						
3.0			1	0.1				
	293	99.7	859	99.9	691	99.7	1568	100.1

TABLE 7

FINAL CALIBRATION OF CASCADE IMPACTORS

IMPACTOR NO. 4

Size in	Jet 1		Jet 2		Jet 3		Jet 4	
Microns	Number	% of Total	Number	% of Total	Number	% of Total	Number	% of Total
0.1			7	0.8	35	2.9	70	6.2
.1			114	12.7	330	27.7	390	34.7
.2			208	23.2	350	29.4	317	28.2
.3			265	29.5	203	17.1	168	15.0
.4			122	13.6	113	9.5	98	8.7
.5			64	7.1	61	5.1	43	3.8
.6			35	3.9	34	2.9	17	1.5
.7			30	3.3	37	2.3	12	1.1
.8			21	2.3	14	1.2	4	0.4
.9			10	1.1	12	1.0	2	0.2
1.0			4	0.4	6	0.5		
1.1			3	0.3	1	0.1		
1.2			5	0.6	1	0.1		
1.3			3	0.3	1	0.1		
1.4			2	0.2	1	0.1	1	0.1
1.5			2	0.2	1	0.1		
1.6			2	0.2				
1.7			1	0.1				
1.8								
1.9								
2.0								
			898	99.8	1190	100.1	1122	99.9

TABLE 8

COMPARISON OF SAMPLES TAKEN WITH AND WITHOUT EXPANSION CHAMBER

Size in Microns	AI-4 Number	AI-4 % of Total	AIII-4 Number	AIII-4 % of Total
0.1	14	2.7	5	1.3
.1	159	30.3	107	28.5
.2	132	25.1	88	23.4
.3	86	16.4	64	17.1
.4	57	10.9	32	8.5
.5	31	5.9	29	7.7
.6	16	3.0	29	7.7
.7	12	2.3	10	2.7
.8	9	1.7	2	0.5
.9	5	1.0	3	0.8
1.0	1	0.2	2	0.5
1.1			1	0.3
1.2	1	0.2	1	0.3
1.3	1	0.2		
1.4	1	0.2	1	0.3
1.5				
1.6			1	0.3
2.1			1	0.3

ENCLOSURE C

FIGURES

Close-Up of Complete Assembly
Back View

Close-Up of Complete Assembly
Front View

1. Timer Mechanism
2. Blower
3. Canister, M11
4. Cascade Impactor
5. Expansion Chamber
6. Assembly Stand
7. Two Double End Wrenches

Fig. 1 Complete Assembly of Cascade Impactor and Accessories

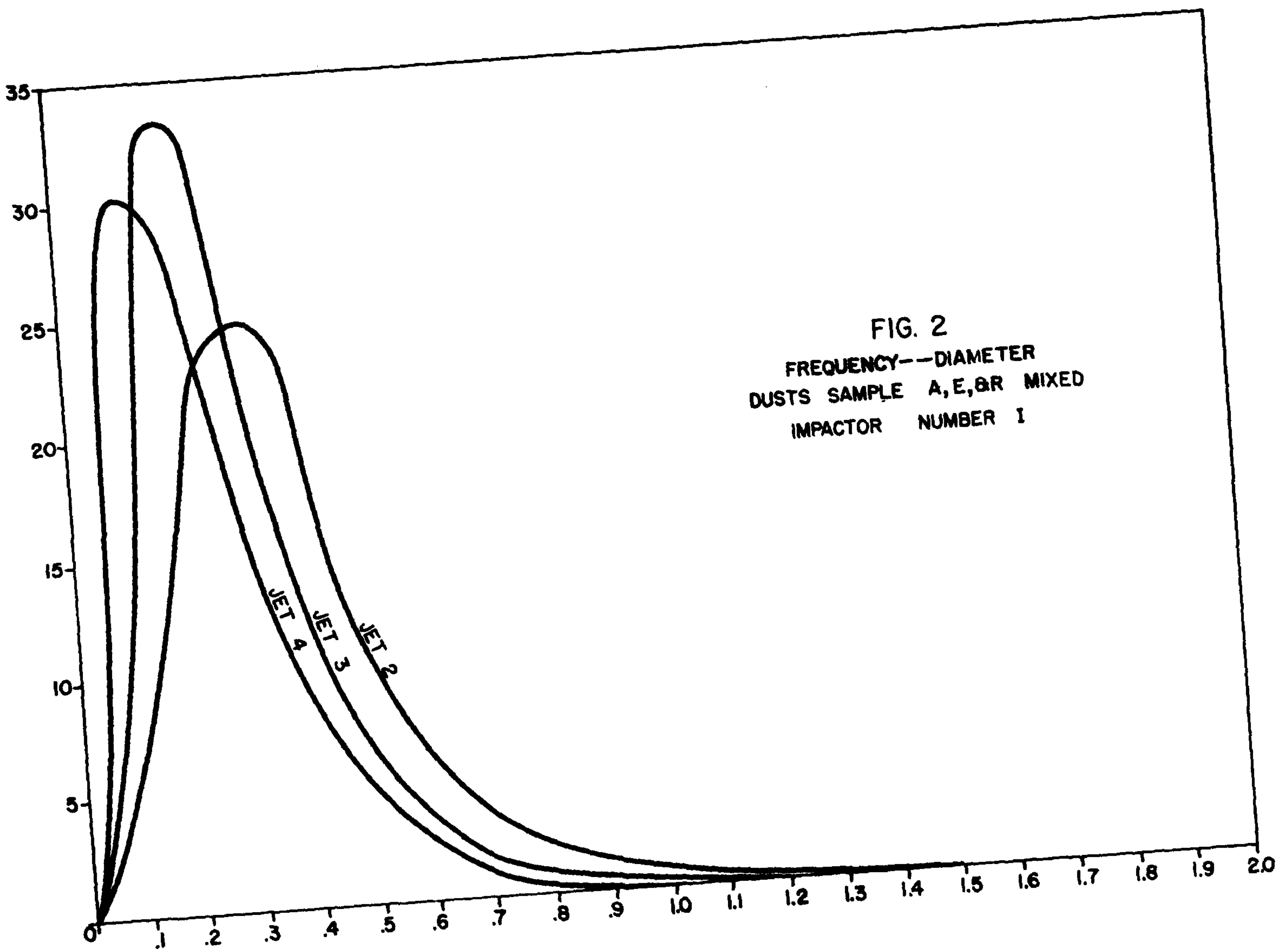


FIG. 2
FREQUENCY---DIAMETER
DUSTS SAMPLE A, E, &R MIXED
IMPACTOR NUMBER I

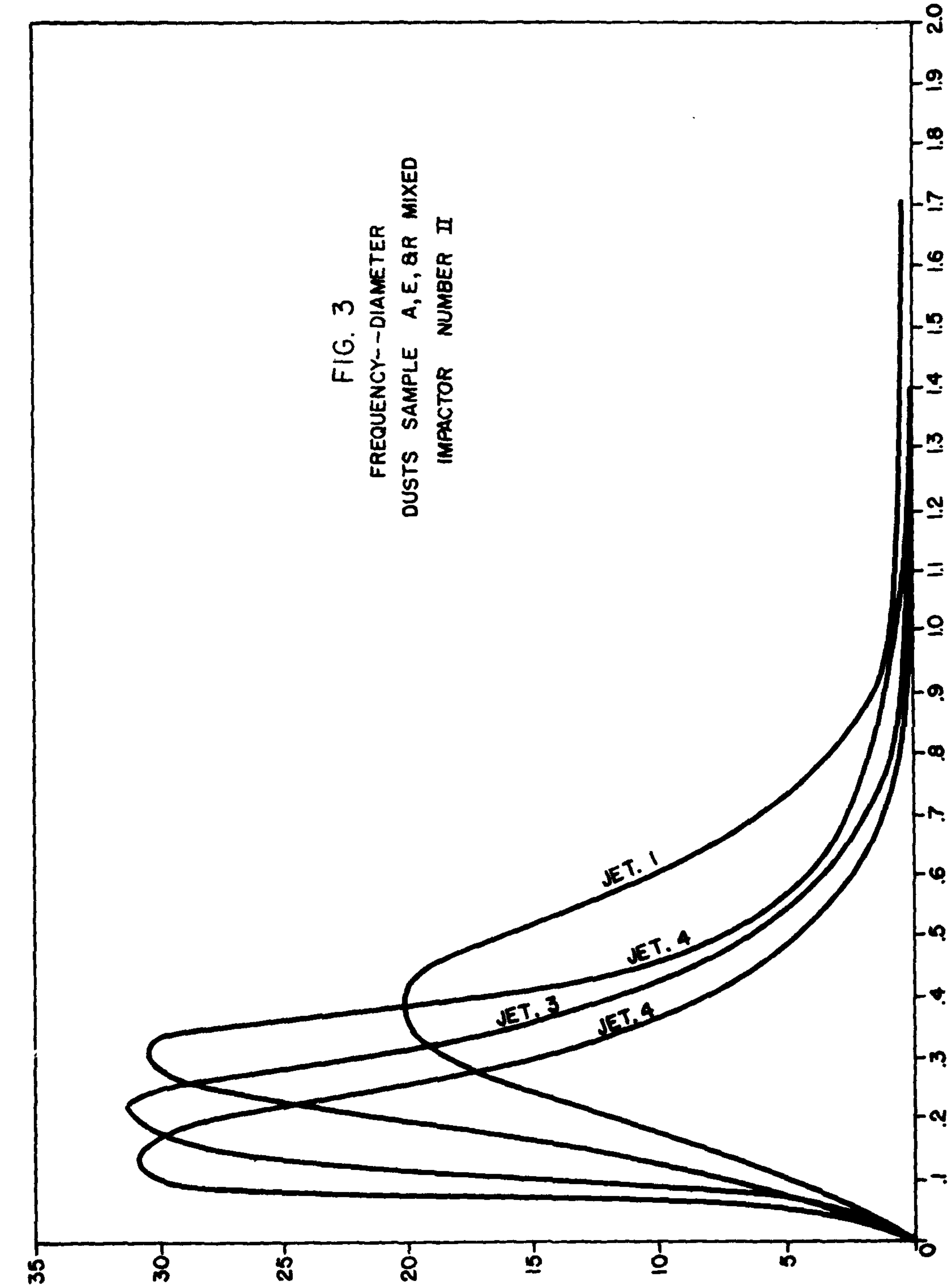


FIG. 3
FREQUENCY--DIAMETER
DUSTS SAMPLE A, E, &R MIXED
IMPACTOR NUMBER II

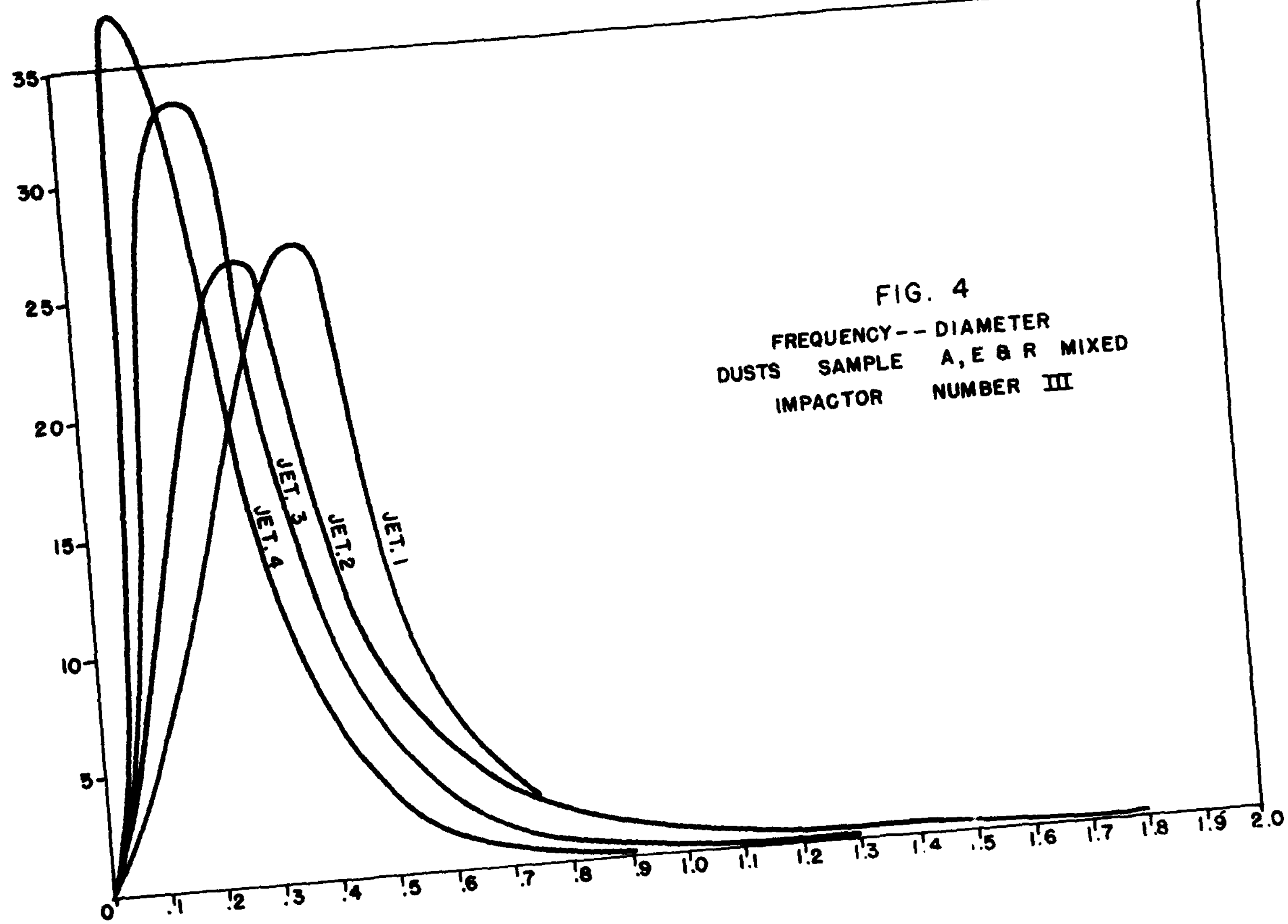


FIG. 4
FREQUENCY -- DIAMETER
DUSTS SAMPLE A, E & R MIXED
IMPACTOR NUMBER III

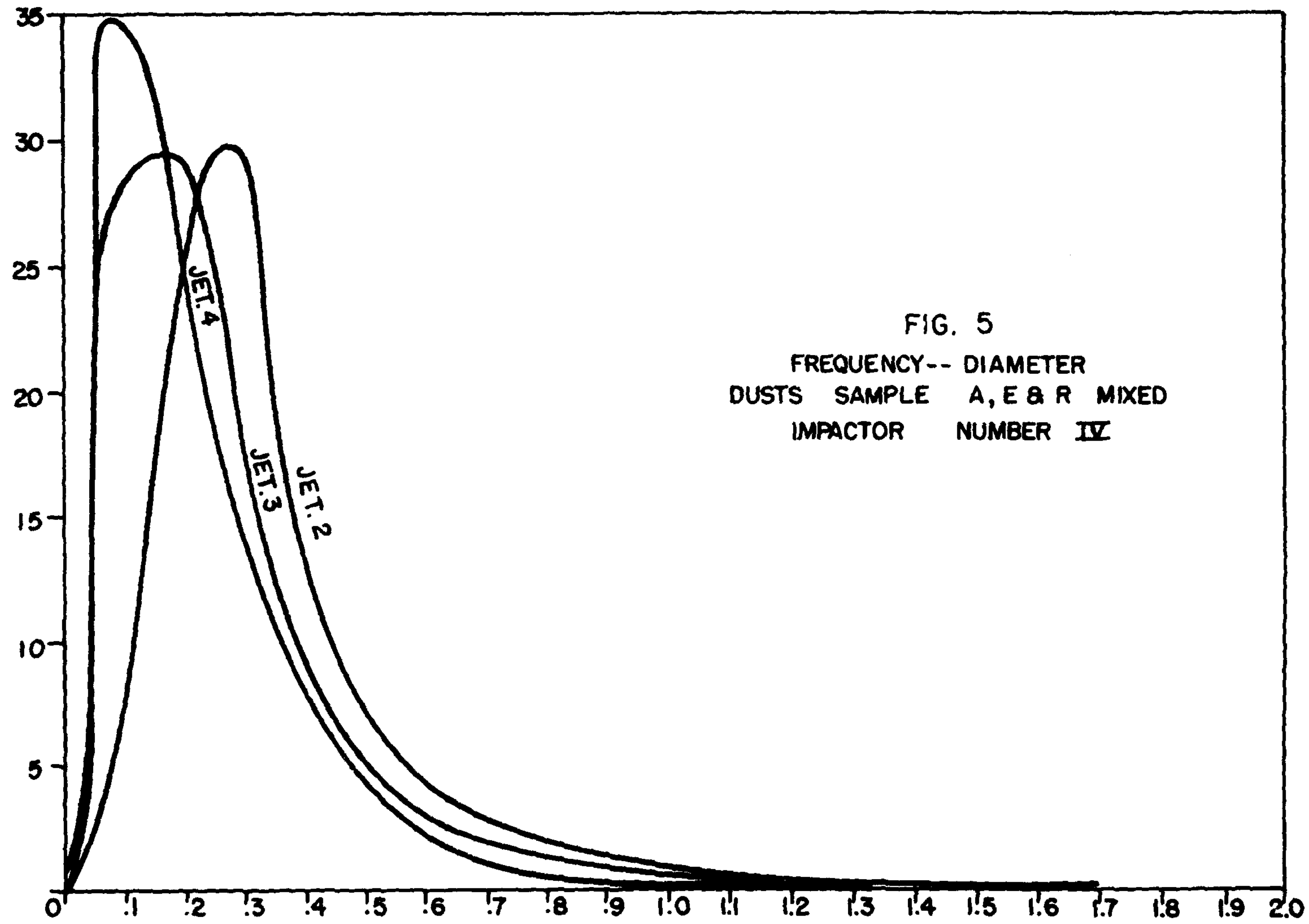


FIG. 5
FREQUENCY-- DIAMETER
DUSTS SAMPLE A, E & R MIXED
IMPACTOR NUMBER IV

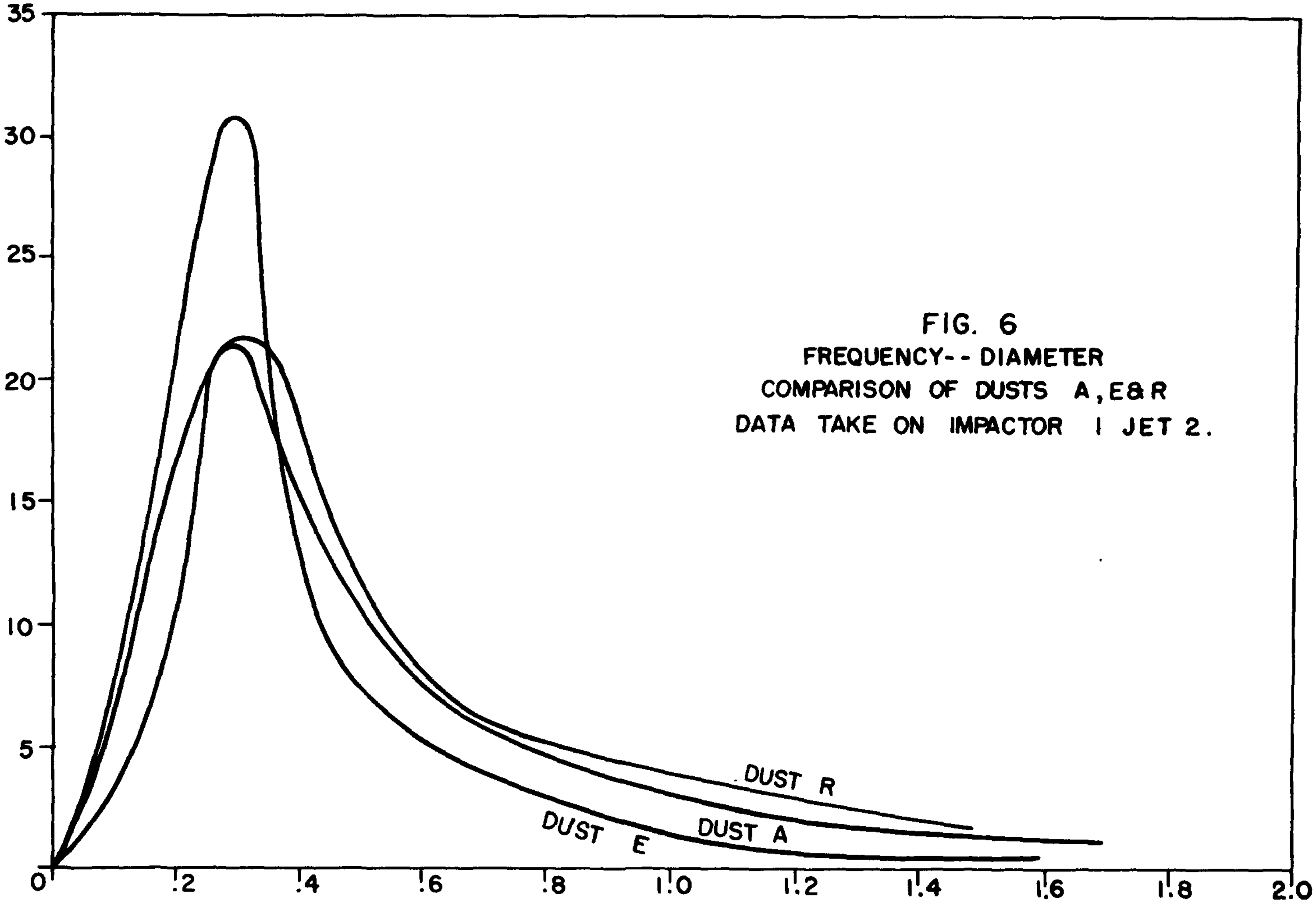


FIG. 6
FREQUENCY-- DIAMETER
COMPARISON OF DUSTS A, E& R
DATA TAKE ON IMPACTOR I JET 2.

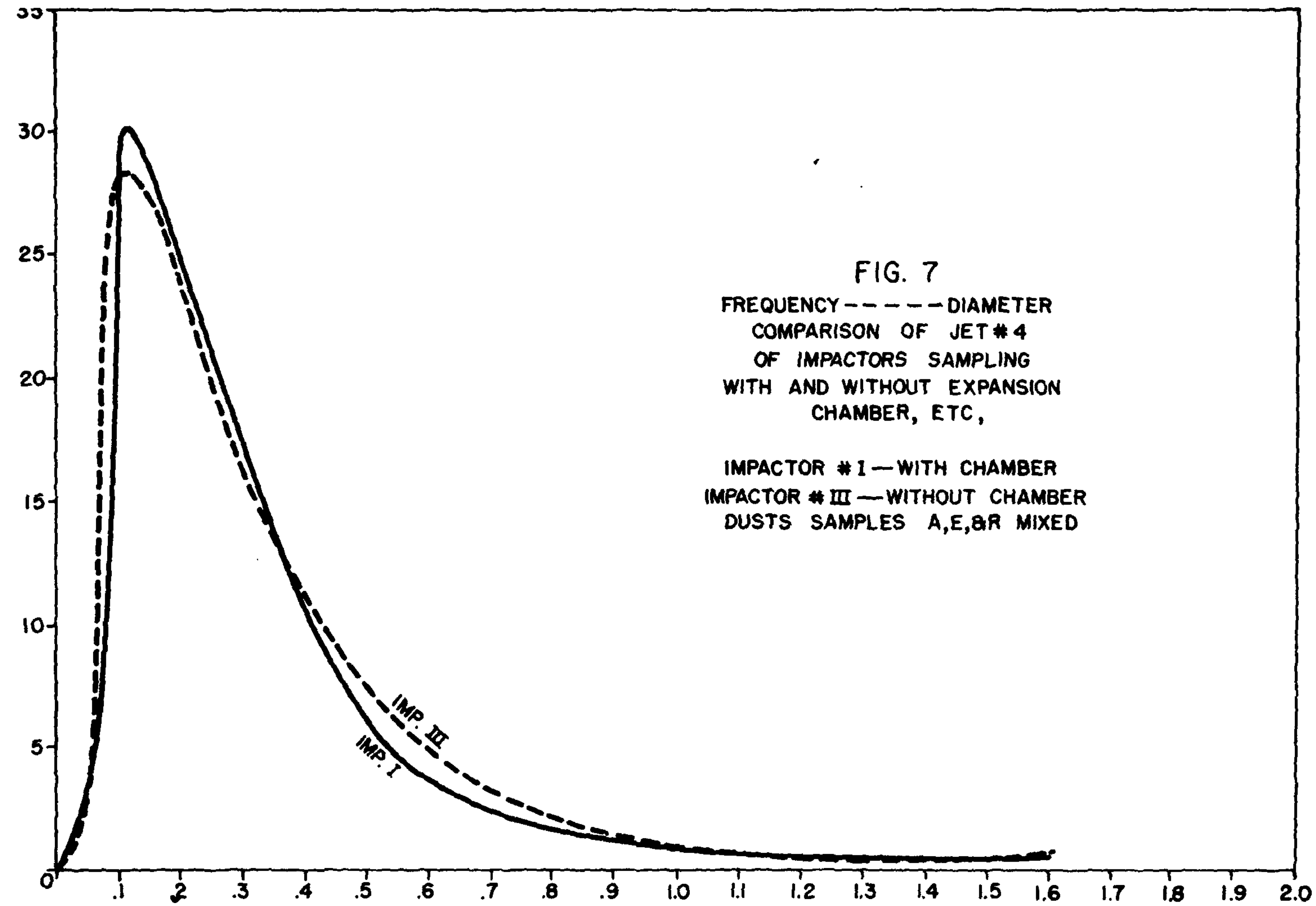


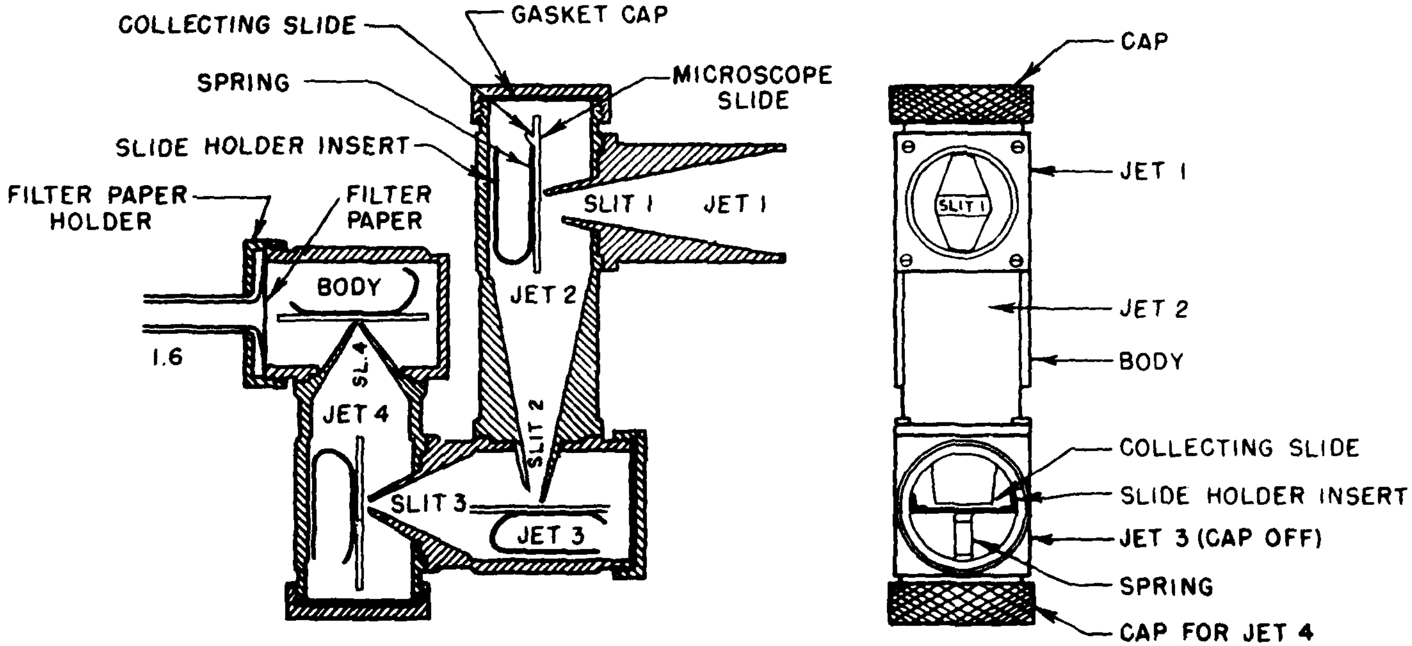
FIG. 7
FREQUENCY - - - - - DIAMETER
COMPARISON OF JET # 4
OF IMPACTORS SAMPLING
WITH AND WITHOUT EXPANSION
CHAMBER, ETC,

IMPACTOR # I — WITH CHAMBER
IMPACTOR # III — WITHOUT CHAMBER
DUSTS SAMPLES A,E,&R MIXED

ENCLOSURE D

DRAWINGS

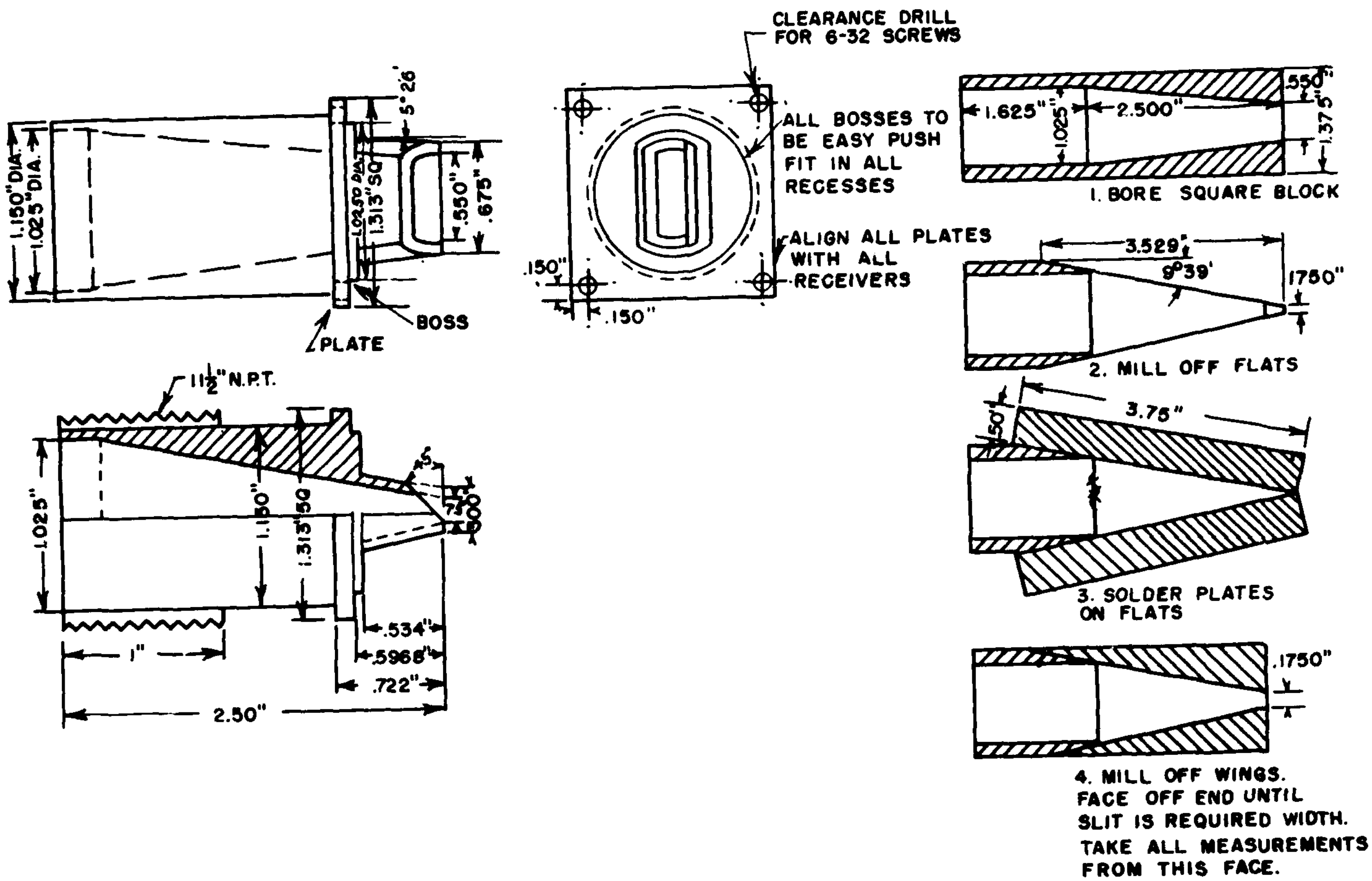
CASCADE IMPACTOR
ASSEMBLY DRAWING



LONGITUDINAL SECTION FRONTAL VIEW

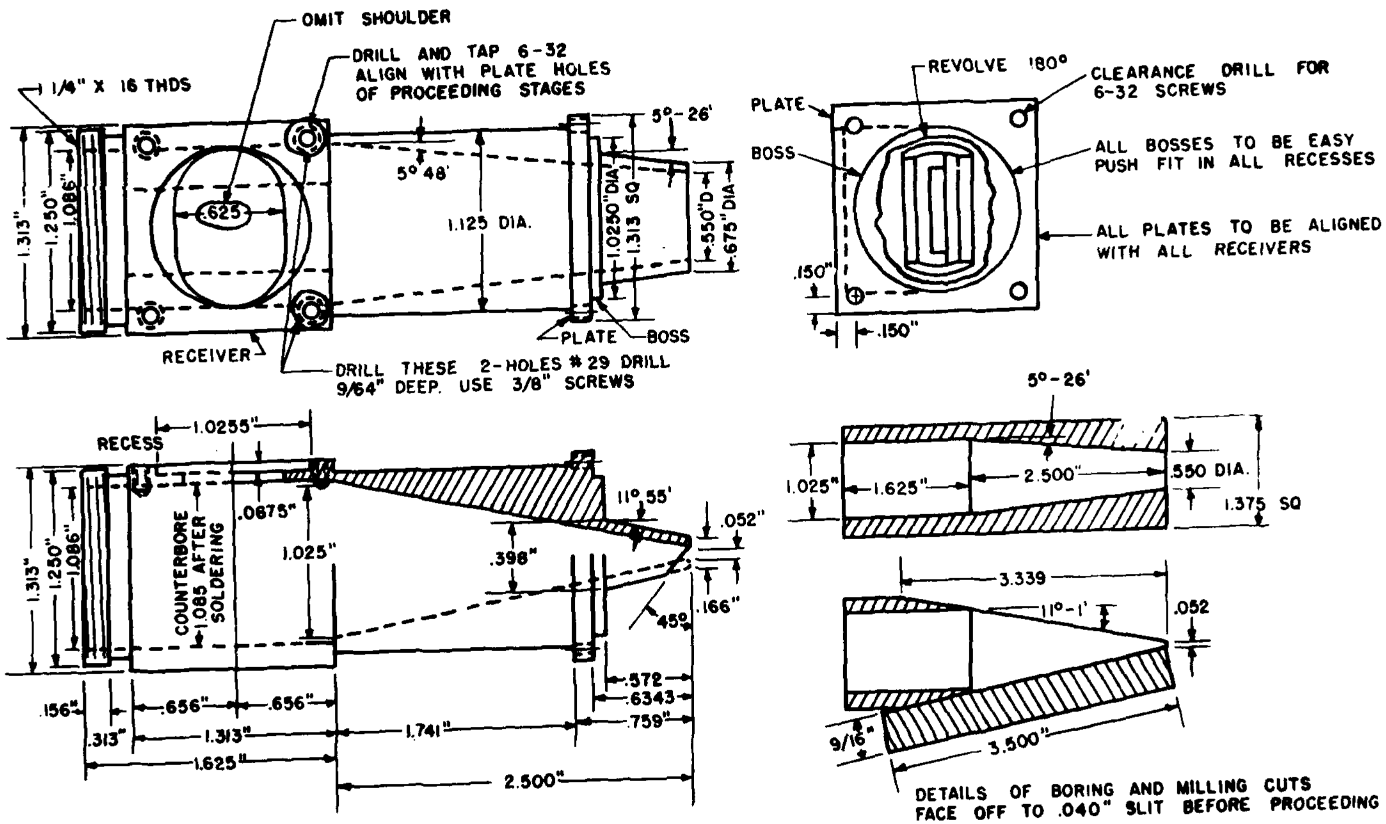
Drawing A

CASCADE IMPACTOR
JET NO. 1



Drawing B

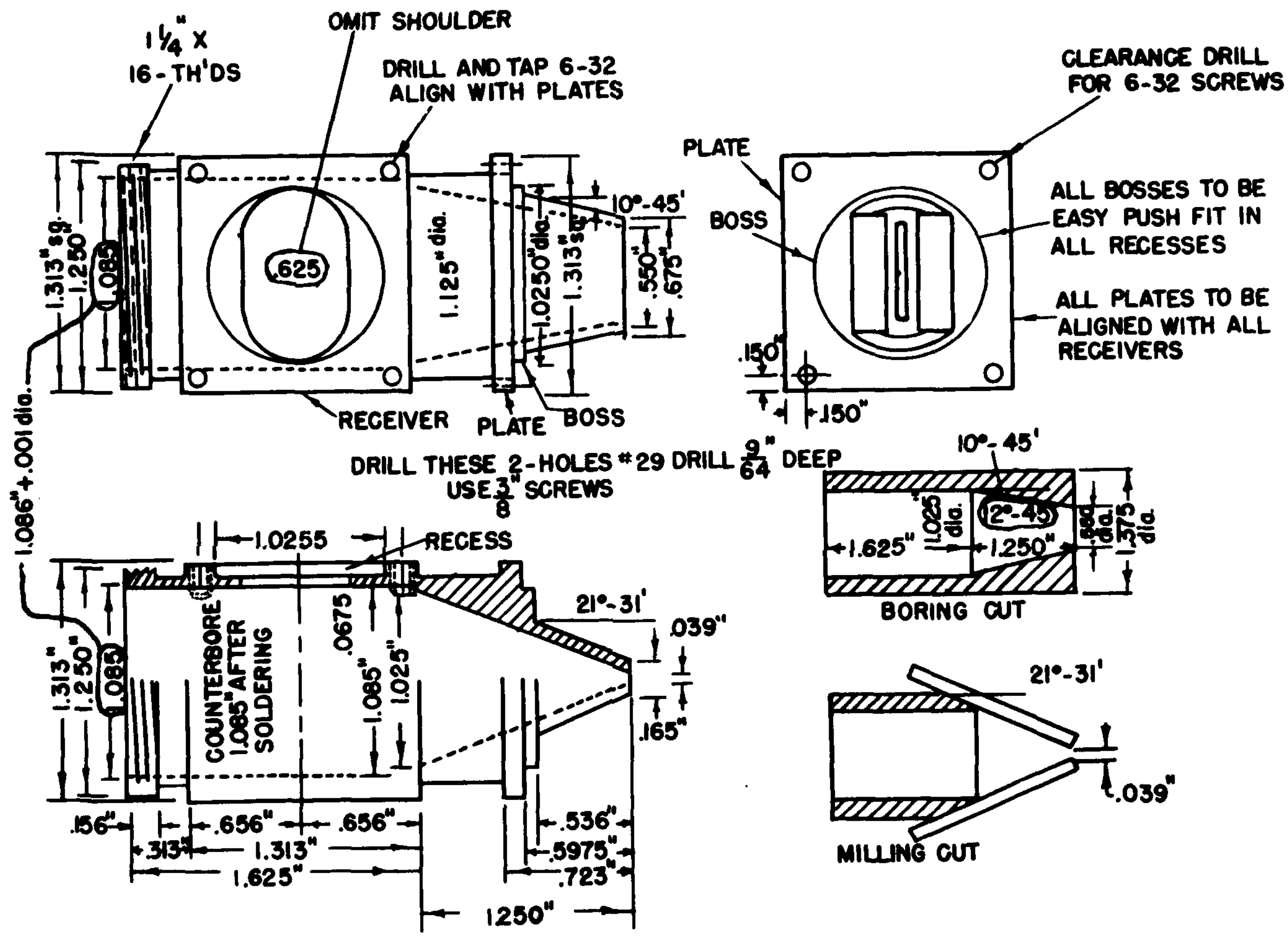
CASCADE IMPACTOR
Jet No.2



Drawing C

CASCADE IMPACTOR

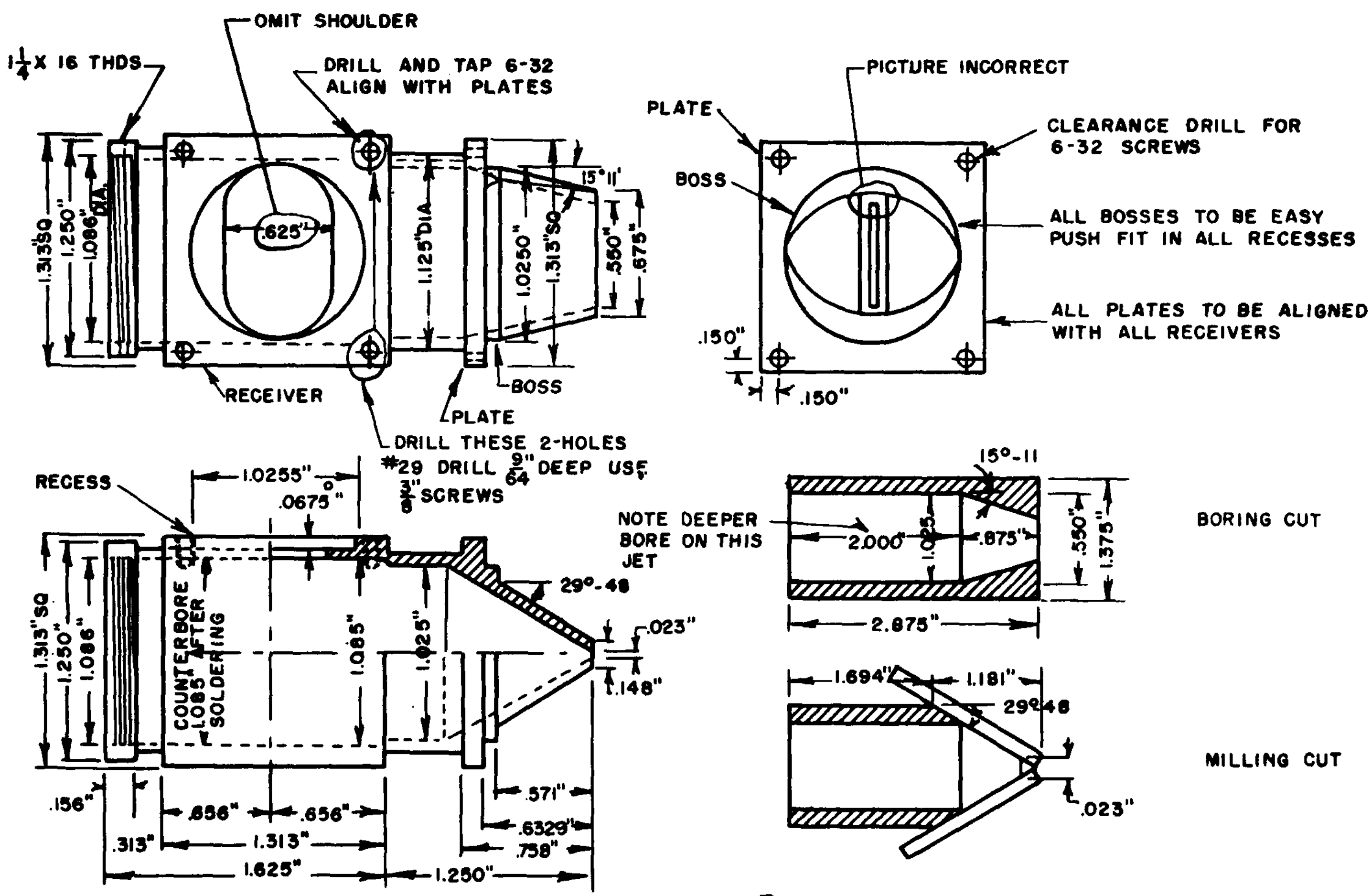
JET NO.3



Drawing D

CASCADE IMPACTOR

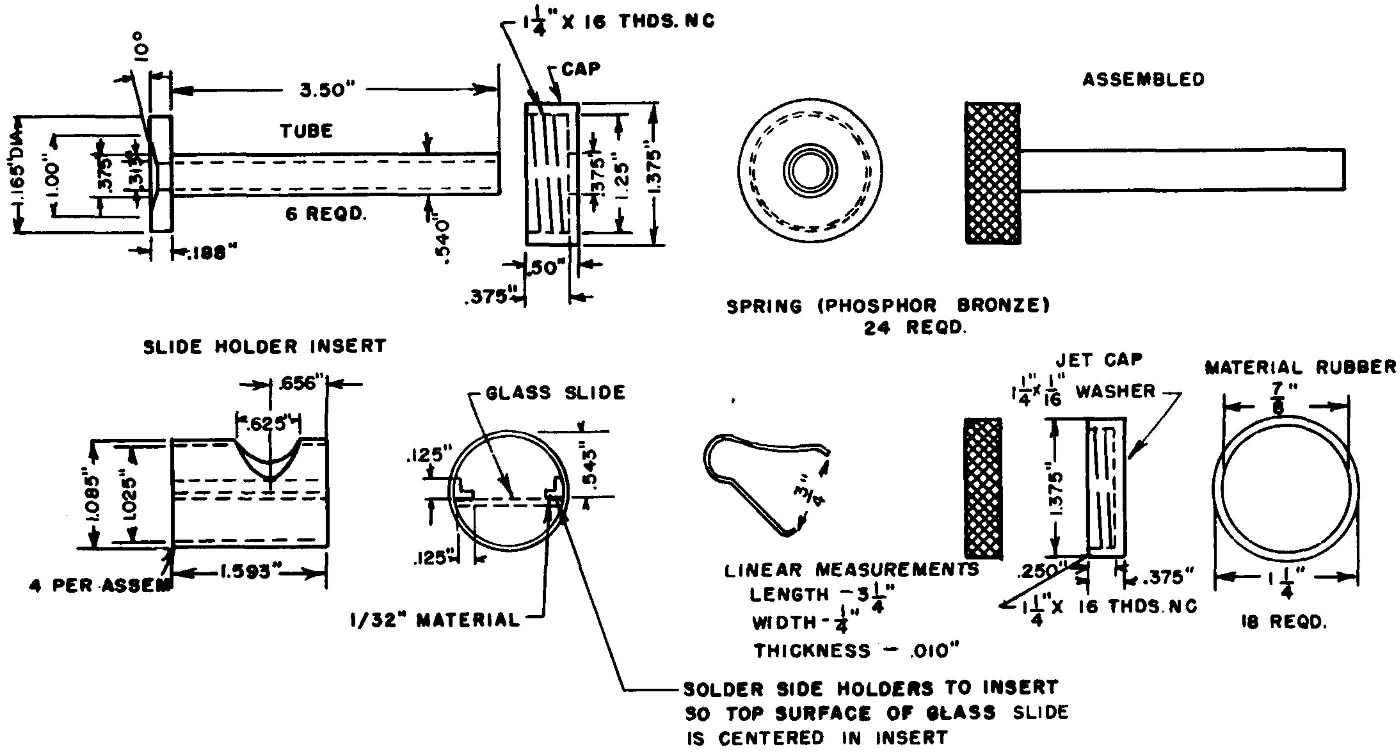
JET NO. 4



Drawing E

CASCADE IMPACTOR

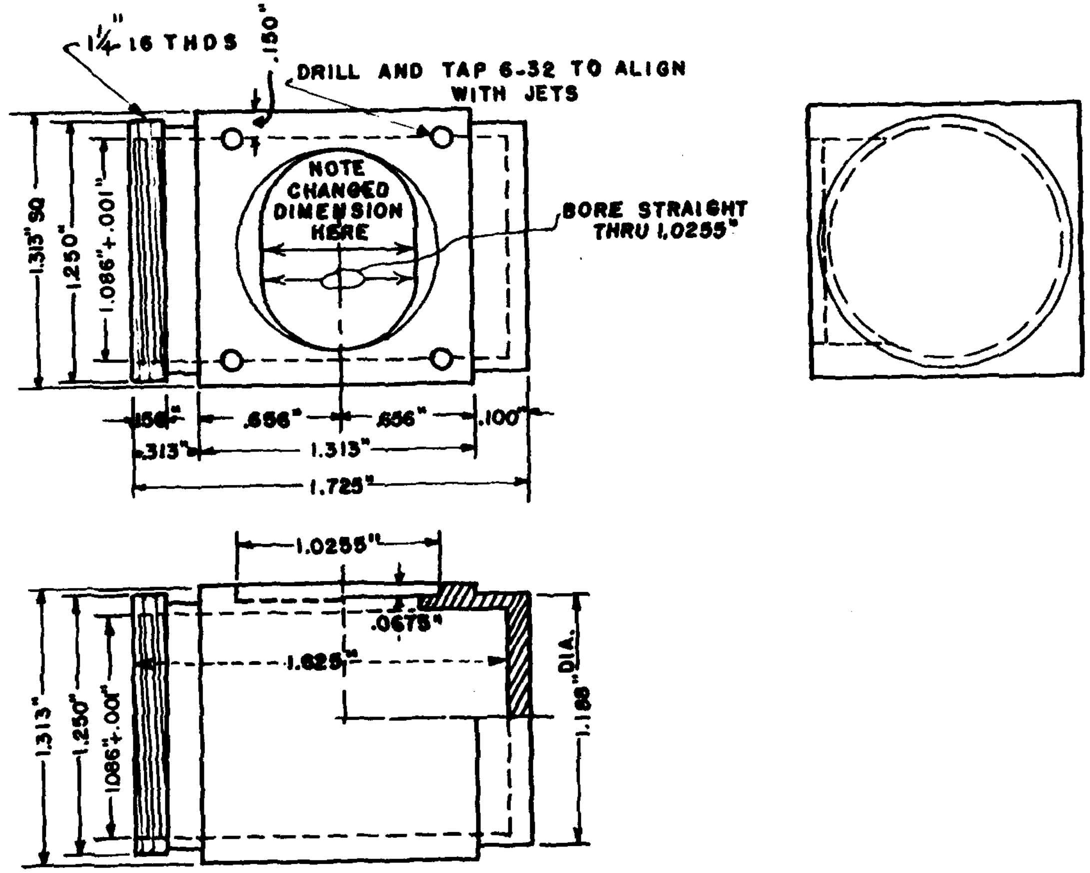
FILTER PAPER HOLDER CAP AND EXHAUST TUBE



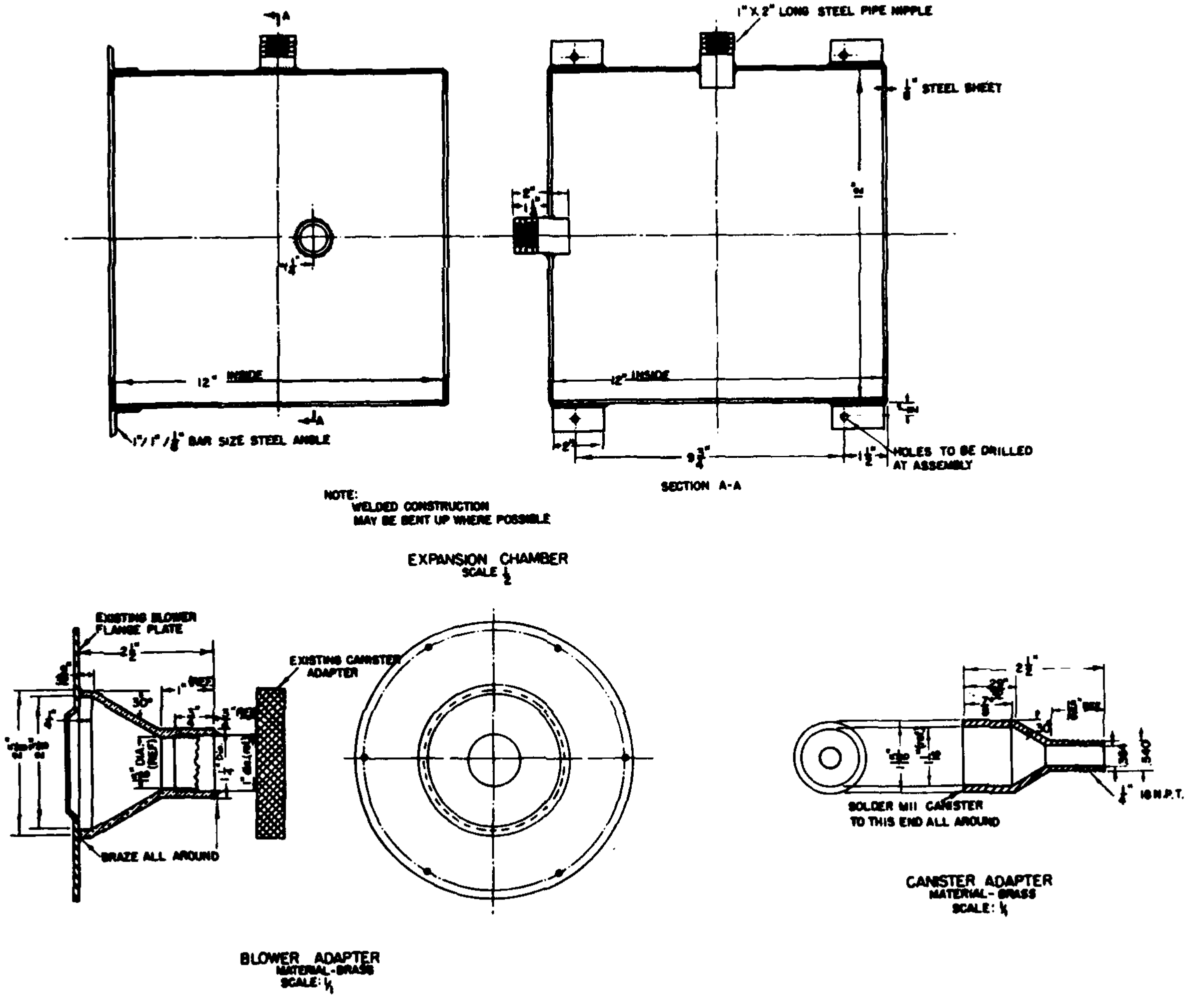
Drawing F

CASCADE IMPACTOR

BODY

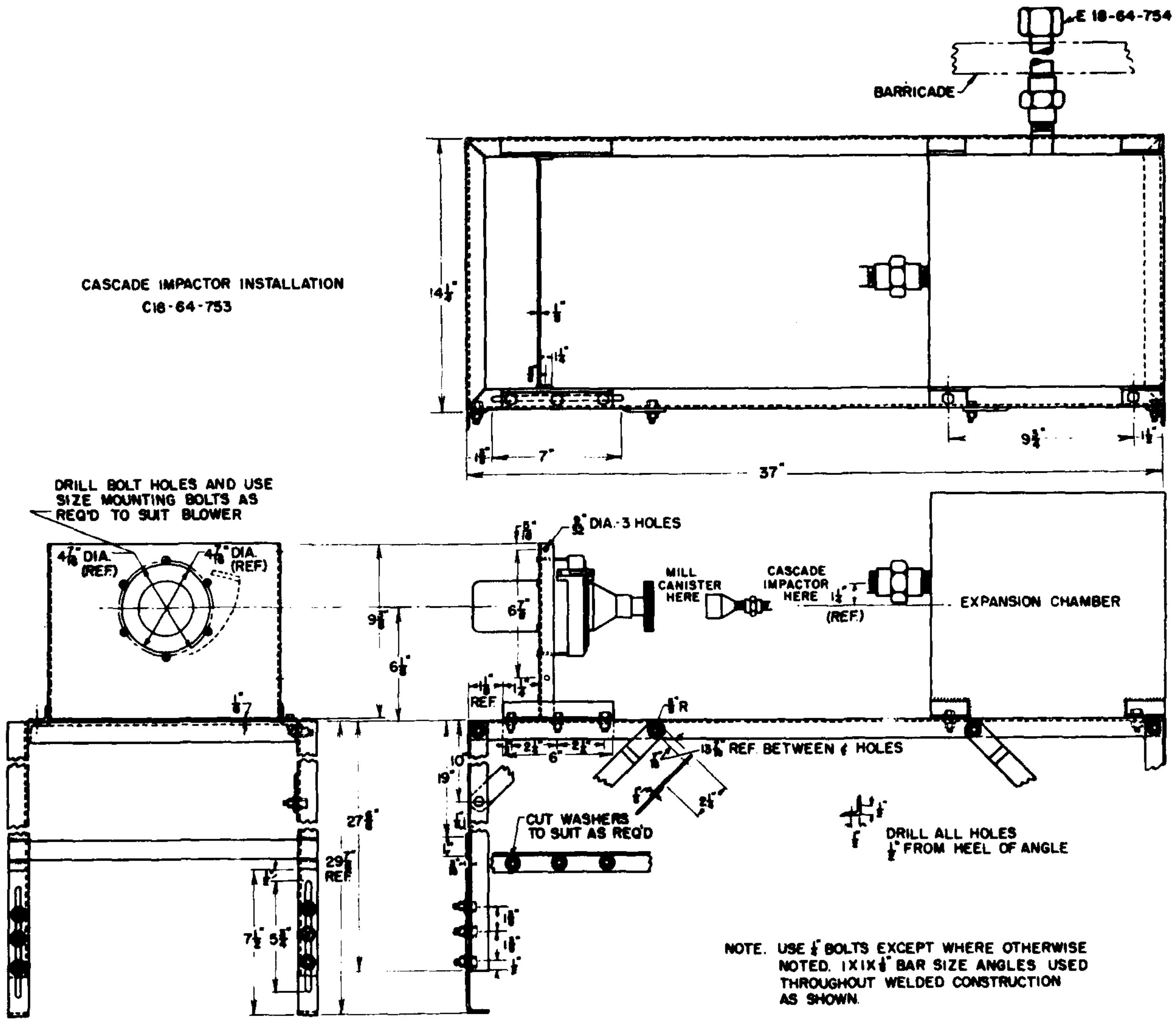


Drawing G



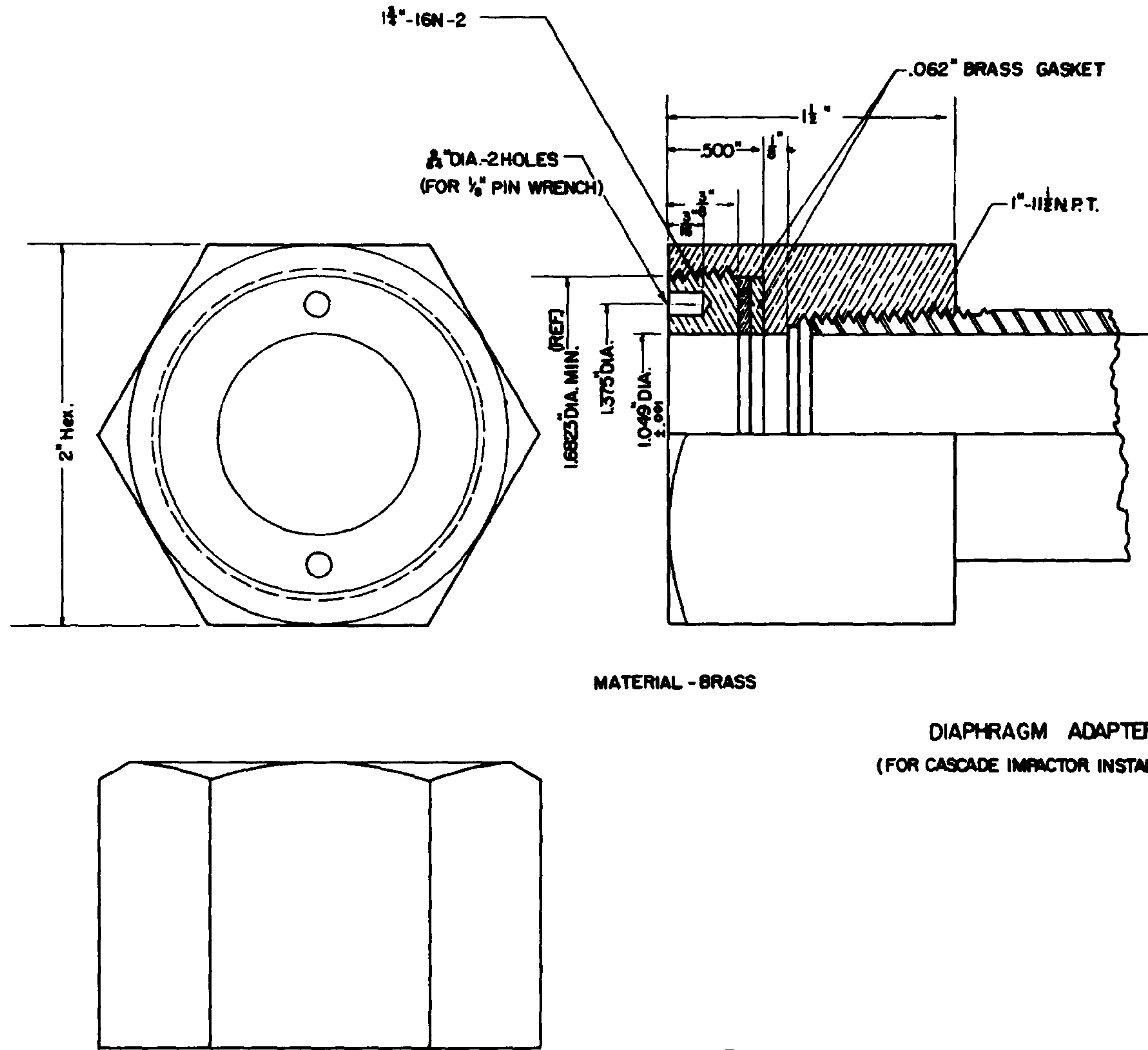
1" X 2" LONG STEEL PIPE NIPPLE
1/8" STEEL SHEET
12" INSIDE
12" INSIDE
1"/1"/1/8" BAR SIZE STEEL ANGLE
HOLES TO BE DRILLED AT ASSEMBLY
SECTION A-A
NOTE:
WELDED CONSTRUCTION
MAY BE BENT UP WHERE POSSIBLE
EXPANSION CHAMBER
SCALE 1/2
EXISTING BLOWER FLANGE PLATE
EXISTING CANISTER ADAPTER
BRAZE ALL AROUND
SOLDER M11 CANISTER
TO THIS END ALL AROUND
16 N.P.T.
BLOWER ADAPTER
MATERIAL-BRASS
SCALE: 1/1
CANISTER ADAPTER
MATERIAL-BRASS
SCALE: 1/1
DETAILS
(FOR CASCADE IMPACTOR INSTALLATION)

Drawing H



CASCADE IMPACTOR INSTALLATION
C18-64-753
E 18-64-754
BARRICADE
DRILL BOLT HOLES AND USE SIZE MOUNTING BOLTS AS REQ'D TO SUIT BLOWER
DIA.-3 HOLES
MILL CANISTER HERE
CASCADE IMPACTOR HERE
EXPANSION CHAMBER
REF. BETWEEN ¢ HOLES
CUT WASHERS TO SUIT AS REQ'D
DRILL ALL HOLES FROM HEEL OF ANGLE
NOTE. USE BOLTS EXCEPT WHERE OTHERWISE NOTED. BAR SIZE ANGLES USED THROUGHOUT WELDED CONSTRUCTION AS SHOWN.

Drawing I



DIAPHRAGM ADAPTER
(FOR CASCADE IMPACTOR INSTALLATION)

Drawing J

ENCLOSURE E

ELECTRON MICROGRAPHS

(These micrographs were never received.)

SCIENTIFIC DIRECTOR'S REPORT
OF ATOMIC WEAPON TESTS
AT ENIWETOK, 1948

Annex 9

CONTAMINATION STUDIES

Part V

EFFICIENCY OF FIELD COLLECTIVE PROTECTOR

UNCLASSIFIED

[redacted]

Task Group 7.6

Project Report

EFFICIENCY OF FIELD COLLECTIVE PROTECTOR E24R3

OPERATION SANDSTONE

by

Bernard Siegel, Project Officer
CDR H. L. Andrews, USPHS
R. E. Murphy

30 June 1948

Project 7.1-17/RS(CC)-8

[redacted]

[redacted]

Table of Contents

[redacted]

[redacted]

Project 7.1-17/RS (CC)-8: Test of Efficiency of Field Collective Protector E24R3

Abstract

Objective:

The object of this project was to determine the efficiency of Field Collective Protector E24R3 in furnishing purified air to a building by the removal of radioactive particulates and gases resulting from the explosion of an atomic bomb.

Results:

With the Field Collective Protector E24R3 installed in the OCE Type A structure at 1500 feet from Zero, the rate of flow of air through the unit was 316 cubic feet per minute, and it maintained a positive pressure of 0.8 inch of water inside the building.

As a result of the explosion the OCE structure was thrown approximately 30 feet from its original position and turned upside down. The Field Collective Protector was turned over but the only apparent damage to the unit was a crushed gasoline tank. A visual inspection of the Collective Protector showed that there were no cracks in the aluminum castings, the charcoal units were still compactly packed, and there was no visible damage to the paper in the filter units. As the Field Collective Protector did not operate after the explosion no results were obtained on its efficiency in removing radioactive particulates and gases.

In tests Yoke and Zebra the Field Collective Protector was placed on an LCM boat anchored in the lagoon downwind from Zero. However, no additional

[redacted]

information on the efficiency of the unit in removing radioactive particulates was obtained. During test Yoke the blast stopped the electric generator which was operating the Field Collective Protector and the radioactivity detecting equipment, while in test Zebra no "fall-out" occurred in the vicinity of the boat.

During pre-test trials some trouble was experienced with the blower units on the Field Collective Protectors. The impeller blades broke loose from the blower wheel to which they were spot welded. Upon riveting the impeller blades to the wheel, the blower units operated satisfactorily.

Conclusions:

It is concluded that:

(1) The Field Collective Protector E24R3 would probably operate satisfactorily during an atomic explosion if placed in a building which could withstand the blast effects of an atomic explosion.

(2) The Field Collective Protector E24R3 would withstand the rough-handling that would be expected with field usage, as indicated by the absence of mechanical failures in the unit placed in the structure which was thrown about 30 feet and turned upside down by the explosion.

(3) Satisfactory operation of the Field Collective Protector's blower unit for long periods of time could not be assured with the impeller blades spot welded to the blower wheel.

Recommendations:

It is recommended that:

(1) The impeller blades be riveted instead of spot welded to the wheel of the blower units on the Field Collective Protector. This is already

being done in the assembly of subsequent units.

(2) Further laboratory tests be conducted on the efficiency of the filter material and absorbent in the Field Collective Protector in removing radioactive particulates and gases. The particle size information obtained from Project 7.1-17/RS(CC)-9. Particle size of Material in Cloud, could be used in generating a simulated cloud.

(3) In future tests of atomic weapons, a more practical site be selected for the installation of a Collective Protector, i.e. one in which the effects of blast and radiation would not render the building uninhabitable even if furnished with purified air.

Project 7.1-17/RS(CC)-8: Test of Efficiency of Field Collective Protector E24R3

I. Objective:

The object of this project was to determine the efficiency of Field Collective Protector E24R3 in furnishing purified air to a building by the removal of radioactive particulates and gases resulting from the explosion of an atomic bomb.

In Test X-Ray one Field Collective Protector E24R3 was installed in a reinforced concrete structure, Type A, constructed on Engebi Island by the Corps of Engineers. This structure was 1500 feet from Zero. Radioactivity detecting equipment was installed inside the structure to determine the air contamination within the building. Another Field Collective Protector was placed on an LCVP boat which was anchored in the lagoon, downwind in the predicted "fall-out" area at approximately 2500 yards from Zero. Radioactivity detecting equipment was used to measure the radioactive material penetrating the Collective Protector unit.

In Tests Yoke and Zebra a Field Collective Protector E24R3 was placed on an LCM boat which was anchored in the lagoon downwind in the predicted "fall-out" area. As in the first test radioactivity detecting equipment was installed on the boat for measuring the penetration through the Collective Protector unit. The boat was anchored at a distance of approximately 2500 yards from Zero during Test Yoke and 4000 yards from Zero during Test Zebra.

II. Historical:

Collective Protectors M1 and M2 were the standard protectors at the start of World War II. Collective Protector M1 was used for permanent

[redacted]

fortifications and M2 for field installations. Both types were bulky and awkward to handle. In March 1943, the carbon impregnated filter of the canister of each protector was replaced by an asbestos-impregnated paper. The protection against liquid smoke was markedly improved by this change.

Collective Protector M2A2 was standardized in March 1944. The main difference in the M2 and M2A2 is the position of the canister. The canister in the former is placed above the blower in a vertical position while in the M2A2 the canister is resting in a horizontal position on a steel frame beside the blower. In the vertical position the canister often broke the blower frame. In July 1944, Type ASC charcoal was substituted for Type A charcoal in the canister. The protection against cyanogen chloride was markedly improved by this change.

A small collective protector M3 of the same general design as the original field models was standardized in June 1942 for installation in vehicles such as the Ordnance machine shop truck, laboratory truck and similar vehicles. This protector was designed to purify only 50 cu. ft. of air per minute as compared to 200 cu. ft. of air per minute for the field models.

However, experience has shown that Collective Protector M2A2 is too heavy and cumbersome for field service and the M3 supplies insufficient air to pressurize existing vehicles. The newly developed Field Collective Protector E24R3 dispenses with the frame, using the air purifier itself to support the blower. The complete protector, which may be either electric or gasoline motor driven, is made almost entirely of aluminum,

[redacted]

weighs only 300 pounds and is easily disassembled into eight separate sections which permits easy one or two man carries. Its air-purifying capacity is 300 cu. ft. of air per minute which is sufficient for the comfort of 30 men, and the active air purifying materials are Type ASC charcoal and waterproofed asbestos-bearing filter paper (Type 6), an improved filter material. Field Collective Protector E24R3 is designed for the removal of chemical and BW agents and radioactive dusts from air entering all types of mobile and portable shelters, dugouts, barracks, trucks and trailers. The protector may be installed either inside or outside of the structure for which it is furnishing purified air. It is necessary that leaks in the shelter be minimized so that a positive pressure of approximately 0.5 inch of water can be maintained within the shelter.

The authority for the work on this project was contained in the letter of 22 December 1947 from Headquarters Joint Task Force SEVEN to Director of Plans and Operations Division, Subject: Chemical Corps Participation in Atomic Energy Activities. In addition to the Chemical Corps who have prime interest, this project has been sponsored by the Corps of Engineers, Bureau of Yards and Docks, and the Armed Forces Special Weapons Project.

III. Experimental:

A. Materials and Equipment:

1. Field Collective Protector E24R3:

The units used for test X-Ray were gasoline motor driven while those used for Tests Yoke and Zebra were electric motor driven.

The floor space required by the unit is 5 sq. ft., and the overall height is about 39 inches. One end of a flexible metal hose, approximately 8 feet long, was connected to the intake plemm of the Collective Protector, while the other end of the hose was fitted with an adapter for attaching to the 6-inch air inlet pipe to the concrete structure. Photographs of the gasoline-driven unit showing its construction are given in Figures 1 and 2, Appendix A.

2. Pitot Tube:

A pitot tube was used to measure the rate of flow of air through the Field Collective Protector.

3. Draft Gage:

An Ellison draft gage (0 to 1.5 inches of water) was used to indicate the pressure attained within the concrete structure while the protector was in operation.

4. Radioactivity Detecting Equipment for Penetration Measurements.

The equipment for measuring the radioactive material penetrating the collective protector consisted of an Eck and Krebs self-quenching Geiger tube with a thin window (30 mg./cm.^{2}) for measuring Beta activity. This was connected to a counting-rate meter (General Radio Co.) which in turn was connected to an Esterline-Angus recorder (Figure 3, Appendix A). The Geiger tube was placed in the effluent air stream from the Field Collective Protector and surrounded by at least 4 inches of lead in the form of bricks.

5. Electric Generators:

A gasoline driven 115 volt generator producing 1-1/2 kw. was used to operate the radioactivity detecting equipment in the concrete structure, while one producing 5 kw. was used on the LCVP boat for test X-Ray. One 5 kw. electric generator was used to operate both the radioactivity detecting equipment and the electric motor driven Field Collective Protector on the LCM boat during tests Yoke and Zebra.

B. Procedures

1. Test X-Ray:

One Field Collective Protector E24R3 with a gasoline motor was installed in a Corps of Engineers Type A structure at 1500 feet from Zero. The inside dimensions of the structure were 15 ft. x 8 ft. x 8 ft. and contained one door with an anti-back draft valve and no windows.

The Collective Protector unit was placed on the floor in approximately the center of the building. One end of a 4-inch diameter flexible metal hose, about 8 feet long, was connected to the intake plenum of the Collective Protector, and the other end, with a special adapter, was welded to the 6-inch air intake to the structure. (Figures 4 and 5, Appendix A).

An Eck and Krebs beta-sensitive Geiger tube was placed in a right angle duct which was then attached to the Collective Protector blower outlet (Figure 6, Appendix A). A shield of lead bricks was built around the duct to prevent outside radiation from reaching the Geiger tube, so that only the radioactive particles penetrating the Collective Protector unit would be recorded. Then the Geiger tube was connected to a Counting-Rate Meter which in turn was connected to an Esterline-Angus recorder (Figures 7 and 8, Appendix A).

The counting tubes were calibrated with a Cobalt 60 standard

[redacted]

prepared by the National Bureau of Standards. Dir ct calibrat on of the activity per liter of effluent air was difficult because of the complicated geometrical factors in l ed in measuring t e activity of air flowing hrough a duct. A rough estimate, which was prob bly sufficiently accurate o hat purpose, indicated that the efficiency of the counting set up was about 25%. The oun ing rate meter was operated on the 6000 counts per minute rang.. With this range accurate measurements can be made from 100 to 6000 cpm. Since the volume of air measured at one time is about o e liter, and since the tube is only 25% efficient, this is quivale to 400 to 24,000 cpm per liter of effluent air. At an average inhalation rate of 20 liters per minute, this is equivalent to the inhalation of 8,000 to 480,000 cpm or 0.004 to 0.2 microcuries per minute.

A 1-1/2 kw. gasoline-drive electric generator wa also placed in the structure t operate the detection equipment (Figure 9, Appendix A). An ov rall vi w of th generator and Coll cti e Protector unit installed in the building is shown in Figure 10, Appendix .

The flow rate through the Collec ive Protect r during i s opera io was determined by attaching a straight 4-1/8 inch diameter metal tube, about 10 feet l ng, to the effluent end of the blower, and measuring the pressure differential with an impact type pitot tube connected to a draft gage.

The sitive pressure maintained within the OCE str cture under operating conditions was measured by attac ing one end of a dr ft gage to a ne-inch pipe which led to th outside, while the other end of the draft gage w s open to the inside of the struc ure.

[redacted]

A second field Collective Protector E24R3 with a gasoline motor was set up in an LCVP boat which was anchored in the lagoon at approximately 2500 yards from Zero. The same type of radioactivity detecting equipment as used in the OCE structure was assembled on the boat. A 5 kw. gasoline-driven electric generator was used to operate the detection equipment.

On X-Ray minus two days the gasoline tanks on the Collective Protectors and electric generators were filled and the operation of the equipment checked. The electric generator was allowed to continue operating the counting rate-meter in the OCE structure to keep the meter warm thus preventing moisture from collecting inside the meter.

On X-Ray minus one day the gasoline tank on the generator in the OCE structure was refilled. At H-hour minus six hours, the engine on the Collective Protector unit was started. It was also planned to start the Collective Protector and radioactivity detecting equipment on the LCVP boat on X-Ray minus one day, but the boat sank in the lagoon on that morning with all the equipment aboard.

2. <u>Test Yoke:</u>

A Field Collective Protector with an electric motor was set up on an LCM boat, which was anchored downwind in the lagoon at approximately 2500 yards from Zero (Figure 11, Appendix A). The same radioactivity detecting equipment as described under Test X-Ray was assembled on the boat. The 5 kw. generator was used to operate both the detection equipment and Collective Protector. On Yoke minus one day the gasoline tank on the generator was filled, and the generator, Collective Protector and radioactivity detecting equipment were started.

UNCLASSIFIED

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3. Test Zebra:

The same LCM boat and equipment that was used during Test Yoke was used for this test. However, during this test the boat was anchored at approximately 4000 yards from Zero. The same procedure was followed in starting the equipment as in the previous tests.

IV. Test Results:

A. Test X-Ray:

With the Field Collective Protector completely assembled and installed in the OCE Type A structure at 1500 feet from Zero, the rate of flow of air through the unit was determined.

Diameter of metal tube =	4.125 inches
Area of metal tube, A -	0.092 sq. ft.
Temperature, t =	32° C
Barometric pressure, $\overline{Bar}$ =	29.85 in. Hg
Reading on draft gage with pitot tube in center of air stream, D =	0.93 in. H_2O

$$\text{Flow Rate } Q = A \times 3435 \sqrt{D \times \frac{273 + t^{o}}{273} \times \frac{29.92}{\overline{Bar}}}$$

$$= 0.092 \times 3435 \sqrt{0.93 \times \frac{273 + 32}{273} \times \frac{29.92}{29.65}}$$

$$= 316 \text{ cubic feet per minute}$$

With the door on the structure closed and the Field Collective Protector operating, a positive pressure of 0.8 inch water was maintained inside the building.

[redacted]

During a pre-test check the electric generator operating the radioactivity detecting equipment performed satisfactorily for 24 hours. After refueling on X-Ray minus one day, the generator would not start apparently due to a burned out magneto. Since insufficient time remained before the test to fix or replace the generator, the radioactivity detecting equipment was removed from the structure to prevent it from becoming damaged during the test. However, the Field Collective Protector was started as scheduled and allowed to operate in order to determine the effect of the explosion on the unit.

As a result of the explosion the OCE structure was thrown approximately 30 feet from its original position and turned upside down. An inspection of the inside of the building showed that the Field Collective Protector had turned over, but the air purifier unit was still in good condition. The electric generator had fallen against the flexible metal inlet hose and had broken it away from the air intake pipe to the building. The Collective Protector apparently did not operate after the explosion as no radioactivity was detected on the filter units. Figures 12 and 13, Appendix A, show the condition of this equipment inside the structure after the explosion.

The only conceivable damage to the Field Collective Protector was the crushing of the enlarged gasoline tank on the engine. A close visual examination of the Collective Protector showed that there were no cracks in the aluminum castings. The air purifier was disassembled, and a visual inspection of the filter units revealed no damage to the paper. The absorbents in the chemical units were still

[redacted]

compactly packed, and no looseness of the charcoal was apparent upon shaking.

As stated in the previous section, all of the equipment set up on the LCVP boat was lost when the boat sank in the lagoon on the morning before the test.

B. <u>Test Yoke:</u>

As a result of the explosion the electric generator, which was operating both the Field Collective Protector and the radioactivity detection equipment, stopped. The wires connecting the equipment to the generator were torn loose. The record on the Esterline-Angus recorder indicated that the equipment functioned up to the time of the explosion and then stopped. Therefore no results were obtained on the efficiency of the Field Collective Protector in removing radioactive particulates. However, upon starting the generator again all of the equipment operated satisfactorily, so the same apparatus was used for the next test.

C. <u>Test Zebra:</u>

For this test the LCM boat on which the equipment was assembled was anchored at a distance of 4000 yards instead of 2500 yards from Zero as in Test Yoke. The boat was placed downwind in the predicted "fall-out" area. However, no "fall-out" occurred in the vicinity of the boat, and although the equipment functioned satisfactorily throughout the test, no results were obtained in this test on the efficiency of the Field Collective Protector in removing radioactive particulates.

[redacted]

V. Discussion:

In the original plan of test X-Ray one Field Collective Protector E24R3 was to be installed in each of two Corps of Engineers Type A structures, one at 1000 feet and the other 1500 feet from Zero. However, a late estimate of the pressure that would probably exist at the 1000 feet structure as a result of the explosion clearly indicated that this structure would be badly damaged or destroyed. Therefore it would be impractical to set up the Field Collective Protector equipment inside this building. It was decided to assemble this apparatus on an LCVP boat anchored downwind in the lagoon, while leaving the second Field Collective Protector apparatus in the OCE structure at 1500 feet from Zero as originally planned. All of the equipment assembled on the LCVP was lost when the boat sank in the lagoon on the day prior to test X-Ray. However the equipment would have been of no value if it were left in the OCE structure at 1000 feet since this building was thrown over 100 feet from its original position, turned upside down and the door blown inside the structure.

In the pre-test runs prior to test X-Ray some trouble was experienced with the blower units on the Field Collective Protectors. After operating for several hours the impellor blades broke loose from the blower wheel, scraped against the inside of the blower casing, and caused the engine to overheat and stop. Apparently the spot welds holding the blades to the blower wheel were not strong enough for operation of the blower at 3400 revolutions per minute. The blowers were repaired by riveting the impeller blades to the blower wheel. After reassembly the blower units operated satisfactorily.

Although no results were obtained on the efficiency of the Field Collective Protector in removing radioactive particulates, the tests did show that the Field Collective Protector would withstand the blast effects of an atomic explosion when placed within a suitable building at least as close as 1500 feet from the center of the explosion. The OCE type A structure at 1500 feet from Zero was turned upside down by the explosion, but the Field Collective Protector was still in good condition. The only visible damage to the unit was a crushed gasoline tank on the engine. There were no cracks in the aluminum castings, the charcoal units were still compactly packed, and there was no visible damage to the paper in the filter units. It may logically be assumed that if the Field Collective Protector were in a building that would withstand the effects of the blast from an atomic explosion, the unit would operate satisfactorily.

In connection with project 7.1-17/RS(CC)-9, Particle Size of Material in cloud, a gas mask canister M11 was used on the effluent end of the cascade impactor equipment. This canister utilizes the same Type 6 paper as used in the filter units of the Field Collective Protector. Some information was obtained on the efficiency of Type 6 paper in removing radioactive particulates by measuring the radioactivity on various thicknesses of the paper after drawing a sample of the cloud through the cascade impactor and canister. Details of these tests are given in the report on the project.

VI. <u>Conclusions:</u>

It is concluded that:

(1) The Field Collective Protector E24R3 would probably operate

satisfactorily during an atomic explosion if placed in a building which could withstand the blast effects of an atomic explosion.

(2) The Field Collective Protector E24R3 would withstand the rough handling that would be expected with field usage, as indicated by the absence of mechanical failures in the unit placed in the OCE structure which was thrown about 30 feet and turned upside down by the explosion.

(3) Satisfactory operation of the Field Collective Protector's blower unit for long periods of time could not be assured with the impeller blades spot welded to the blower wheel.

VII. Recommendations:

It is recommended that:

(1) The impeller blades be riveted instead of spot welded to the wheel of the blower units on the Field Collective Protector. This is already being done in the assembly of subsequent units.

(2) Further laboratory tests be conducted on the efficiency of the filter material and absorbent in the Field Collective Protector in removing radioactive particulates and gases. The particle size information obtained from Project 7.1-17/RS(CC)-9, Particle Size of Material in Cloud, could be used in generating a simulated cloud.

(3) In future tests of atomic weapons, a more practical site be selected for the installation of a Collective Protector, i.e. one in which the effects of blast and radiation would not render the building uninhabitable even if furnished with purified air.

APPENDIX A

Figures 1 through 13

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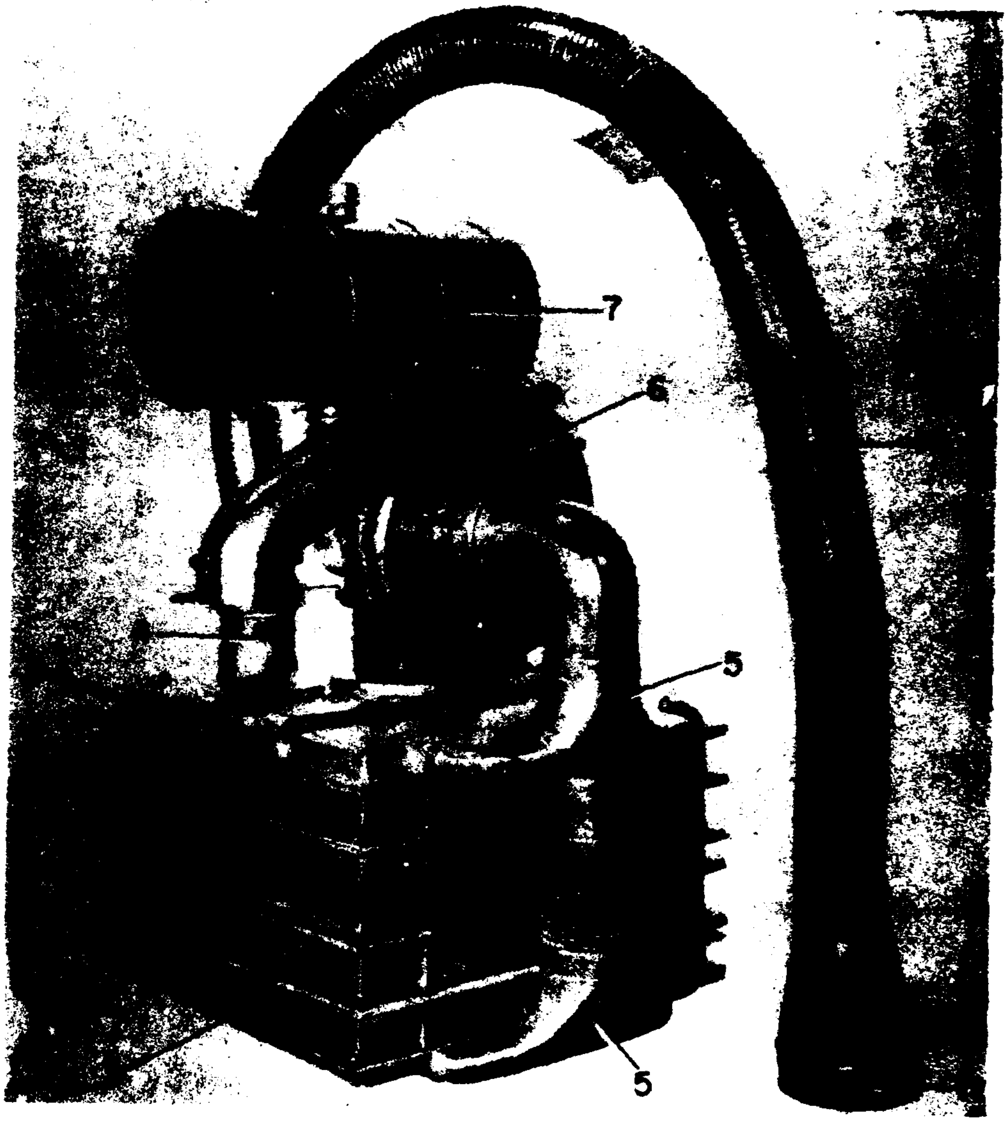

Fig. 1 Field Collective Protector E24R3

1. Charcoal Unit.
2. Filter Unit.
3. Top and Bottom Manifolds.
4. Intake Manifold.
5. Exhaust Manifold.
6. Blower.
7. Gasoline Tank.
10. Flexible Metal Hose.
11. Adapter to 6-inch Pipe.

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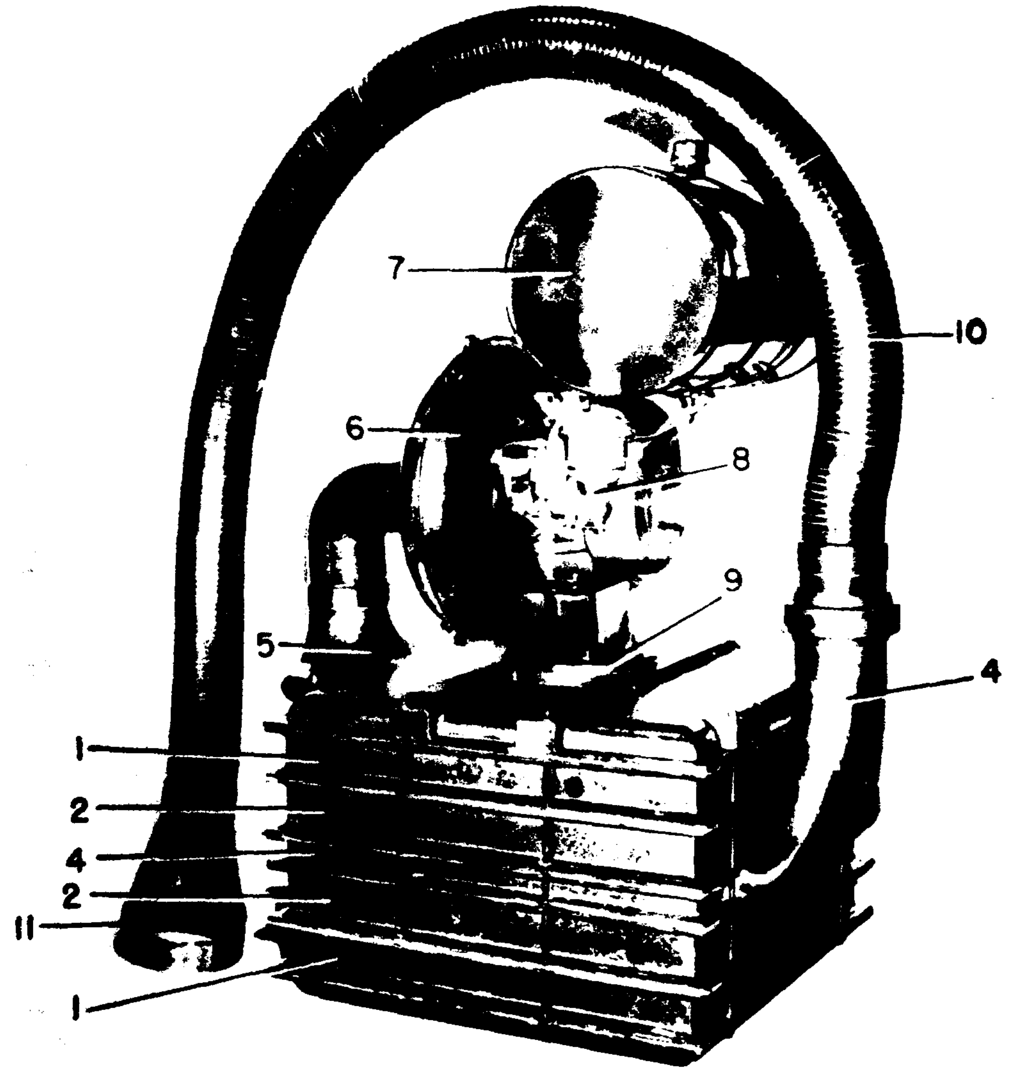

Fig. 2 Field Collective Protector E24R3

1. Charcoal Unit.
2. Filter Unit.
4. Intake Manifold.
5. Exhaust Manifold.
6. Blower.
7. Gasoline Tank.
8. Gasoline Engine.
9. Engine Stand.
10. Flexible Metal Hose.
11. Adapter to 6-inch Pipe.

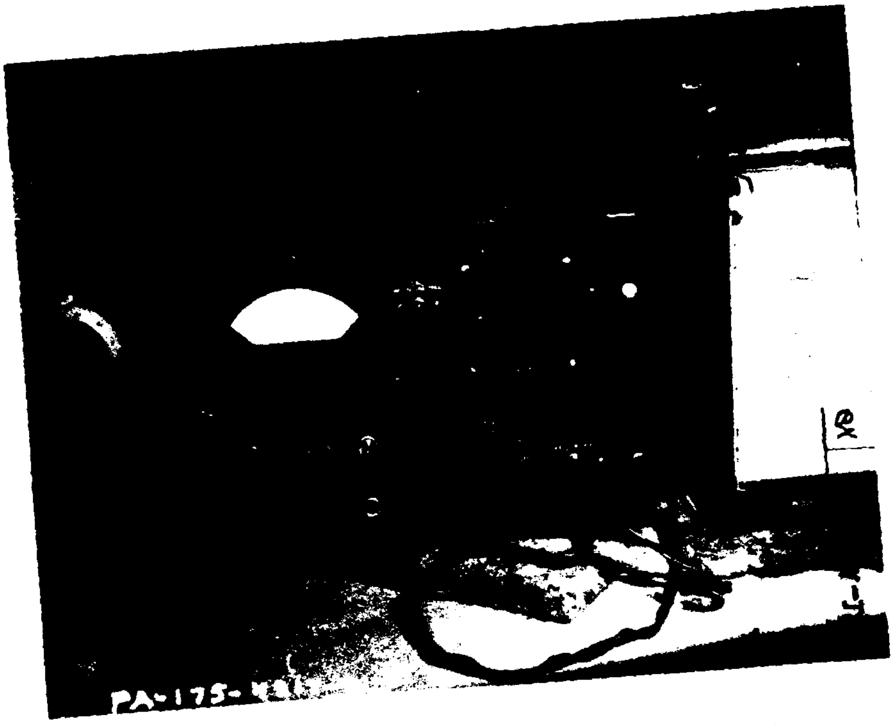

Fig. 3 CU of Counting Rate Meter, Esterin and Angus Recorder, "A" 1500

Fig. 4 Collective Protector Installed in OCE 1500-feet Type A Structure

Fig. 5 Close-Up of Flexible Hose Air Inlet to Collective Protector

Fig. 6 Collective Protector Showing GM Tube Adaptation

Fig. 7 General View of Collective Protector, OCE "A" 1500

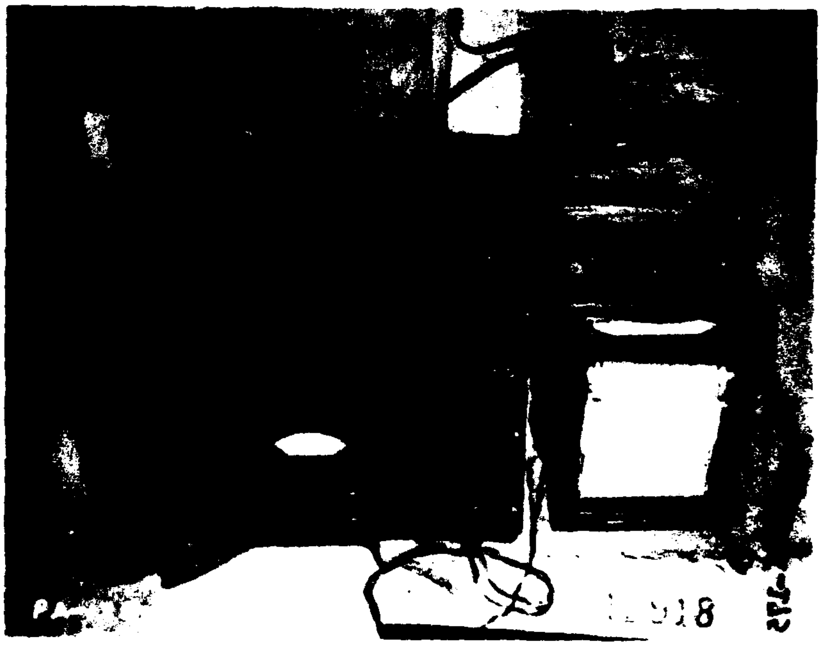

Fig. 8 Radioactivity Detection Equipment, OCE "A" 1500

CONFIDENTIAL

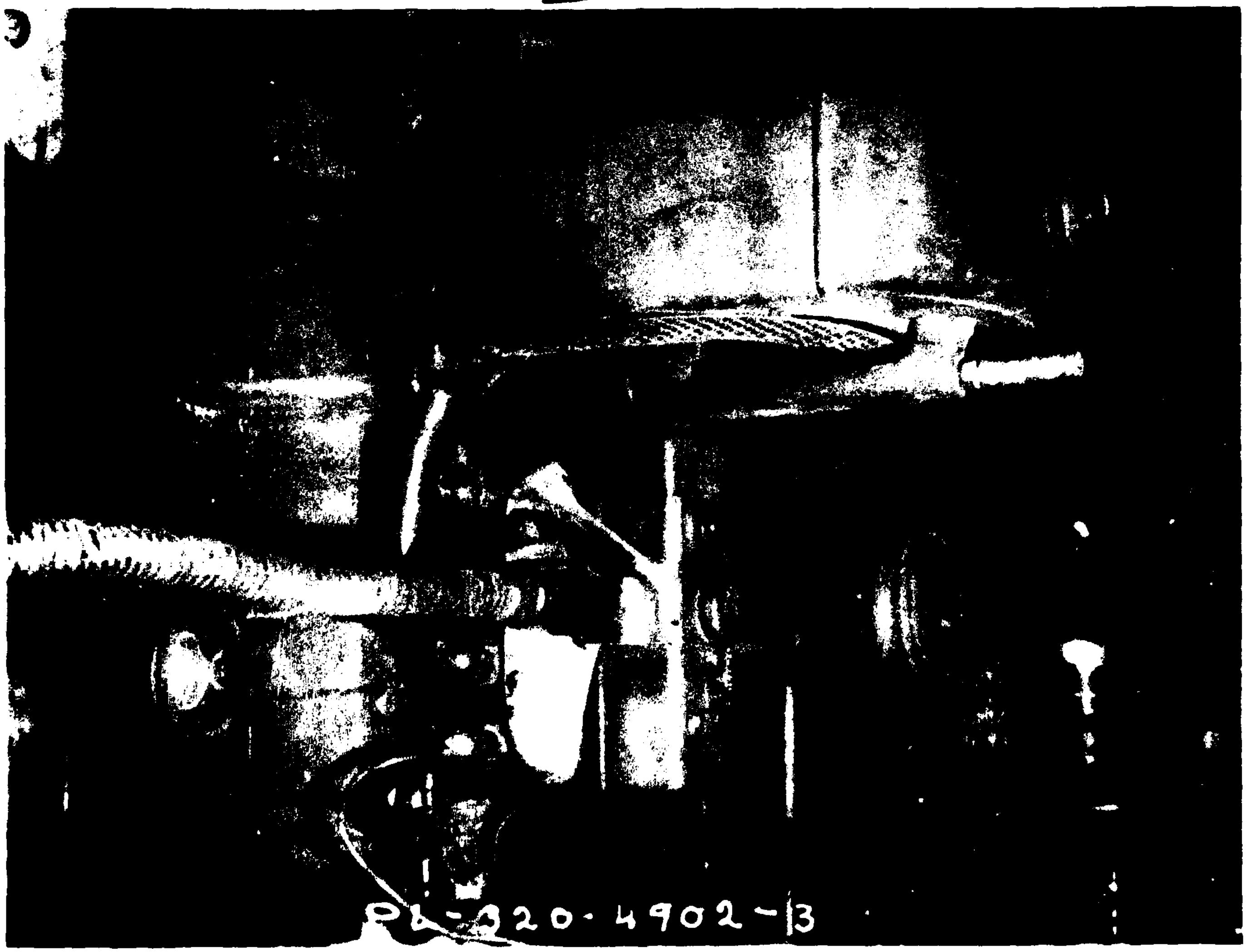

Fig. 9 Generator for Collective Protector Installed in Structure

CONFIDENTIAL

CONFIDENTIAL

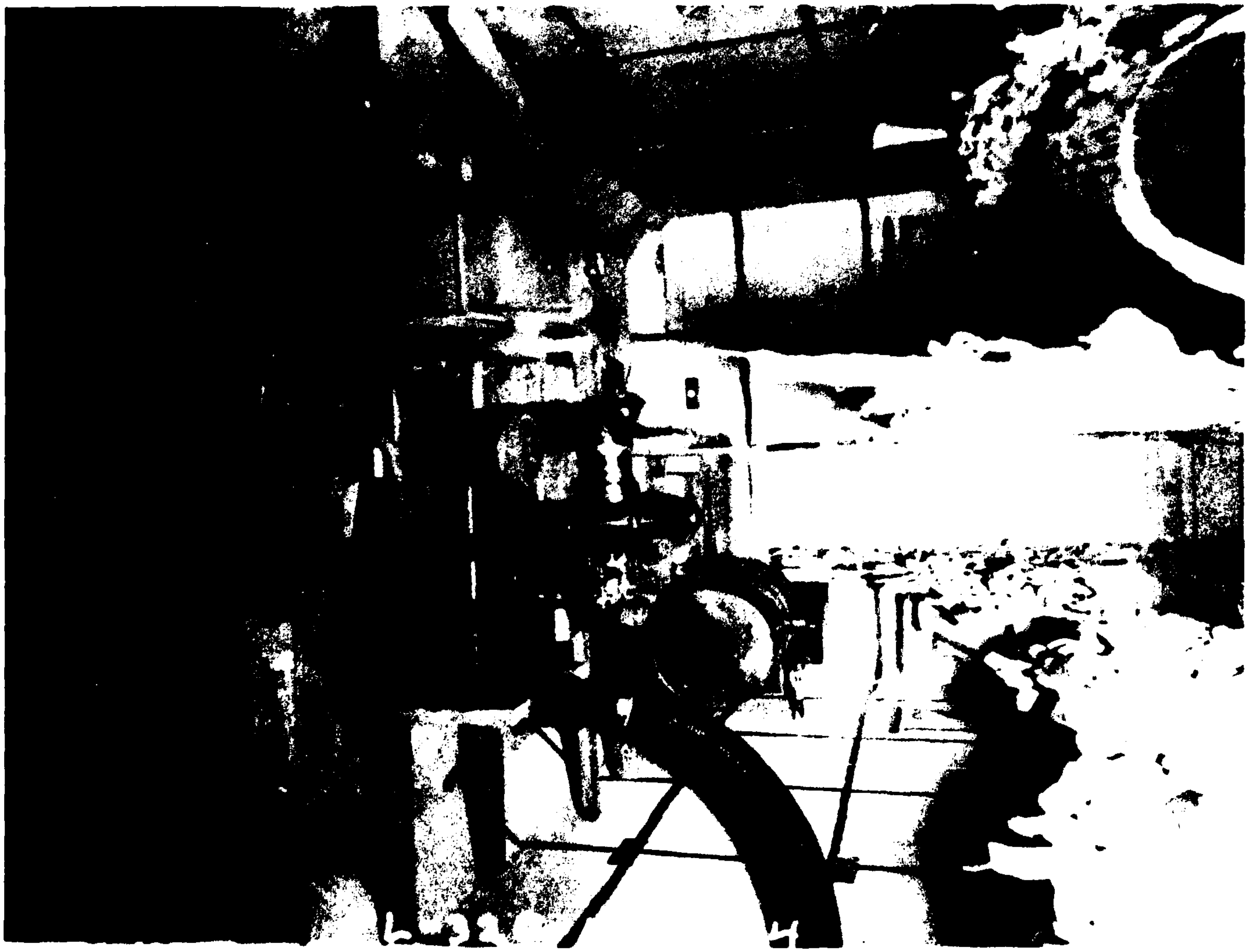

Fig. 10 Generator and Collective Protector Installed in Structure

CONFIDENTIAL

Fig. 11 Generator with Collective Protector in Foreground in LCM Boat

Fig. 12 OCE Structure "A" - 1500-feet - Interior - Collective Protector Unit

Fig. 13 OCE Structure "A" - 1500-feet - Interior - Collective Protector Unit