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SERIES B

February 20, 1947

This document contains 86 pages

NUCLEAR EXPLOSION 16 JULY 1945

Health Physics Report on Radioactive Contamination Throughout New Mexico Following the Nuclear Explosion

Report Written By:

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NUCLEAR EXPLOSION 16 July 1945

Health Physics Report on Radioactive

Contamination Throughout New Mexico

Following The Nuclear Explosion

Part A: Physics

Report Written By Joseph G. Hoffman

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ABSTRACT

1. Monitoring activities before and after the nuclear explosion, 16 July 1945, are described briefly. The apparent decay of fission products activity spread across terrain is discussed. Near the crater the decay was approximately as t^{-2} with wide variations while at distances greater than 12 miles the decay went as $t^{-1.3}$.

2. The geometrical effects of the distribution of active material is described. The measurements in the vicinity of Bingham showed that the gamma dose to personnel was due to: a) dosage delivered while the active cloud particles were falling and b) dosage delivered after the particles had settled to the ground. The method for calculating the total gamma dosage is outlined.

3. Examples of town monitoring for gamma radiation are given for White, Bingham and hot canyon south of the Chupadera Mesa. A Table of gamma doses for towns throughout New Mexico is compiled. Estimates of the density of gamma active material on the ground are computed from the gamma-roentgen intensities and tabulated.

4. The region of highest radio-active concentration is shown to have been in a swath 12 miles long, 1 mile wide starting near White Store (on road 380) and extending northward across the Chupadera Mesa. There was a definite "skip" distance of 15 miles between zero and the regions of measurable gamma intensity. It is estimated that one-half of all the activity available was precipitated in the two weeks after the explosion. This activity was 90% in New Mexico. About 7% of all radioactivity was precipitated in the "hot" swath over Chupadera Mesa.

5. Beta ray dosages in the region of the Chupadera Mesa 30 miles north east of zero are computed on the basis of physical measurements in the field and also on the basis of the chemical analysis of soil samples. The gamma and beta doses for cows on the range are computed and found to be biologically significant.

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I. Monitoring Activities Before and After July 16.

a) Preparations for the Shot:

As a result of discussions among all concerned, it was decided that there were two main possibilities as to where the cloud could go after the shot. They were: in the northeast or in the southeast direction. It was deemed necessary to choose a weather condition which would not blow the cloud over the town of Carrizozo, which lies slightly north of due east of zero. Accordingly, the town monitoring plans consisted of three main cases:

(a) The North blow in which the cloud moves in the northeast direction inside a 20° sector whose south side is not less than 6° north of Carrizozo.

(b) The South blow in which the cloud moves in the southeast direction inside a 20° sector whose north side is not less than 6° south of Carrizozo.

(c) The Indeterminate case in which the cloud moves in any direction outside of the sector whose sides are 26° north and south of Carrizozo.

Of these three cases the North blow seemed to be most likely to occur on 16 July.

On the 15th of July a final meeting of radiation monitors was held at Santa Fe for final instructions, for assignment with Lt. D. Daley's G-2 men, and for assignment of radiation detection meters. The final instructions concerned chiefly the matters of recording observations and getting communications with headquarters in Albuquerque where Lt. Col. Friedell was stationed or with the base camp at Trinity where Col. Stafford Warren was stationed. Since the monitors were spread over a large area it was essential for them to maintain constant central communication in

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order to find out which of the three main cases had occurred.

Each monitor was assigned a set of the following instruments:

1. A methane filled proportional counter for detecting alpha particle radiation in the presence of beta and gamma radiation.

2. A Victoreen, model 247, three range, portable gamma ray survey meter. This was the most useful instrument for field work. The three ranges cover the following intensity ranges: 0.01 to 0.1 R/hr, 0.1 to 1.0 R/hr, and 1 to 10 R/hr.

3. The Hallicrafter, Geiger-Müller Tube, Model 5, portable survey meter for gamma and gamma plus beta radiations. The two ranges are 0.00004 to 0.001 R/8 hr, and 0.0008 to 0.02 R/8 hr.

In addition to meters the monitors were supplied large mouthed bottles in which to put earth samples from places where radiation was detected.

The disposition of the monitoring crew was as follows:

Mr. Alfred Anderson with Mr. Julian Bernacci at Nogal.

T/4 Joel Greene with Mr. Charles Mally at Roswell.

T/5 Carl Hornberger with Mr. Richard Foley at Ft. Sumner.

T/3 Robert Leonard with Mr. Wm. J. McElwreath at Socorro.

At Guard Gate 2 in Major T. O. Palmer's bivouac area were:

Mr. Wright Langham with T/4 Philip Levine; Messrs. John Magee and Joseph Hirschfelder; and Joseph G. Hoffman to accompany Major Palmer in event that the evacuation of people was found necessary.

The chief monitor and two crews were stationed at Guard Gate 2 bivouac area in order to get information from Col. Warren at Base Camp as soon as possible. This information concerned the height of the cloud, its velocity and direction of movement. The crews were concentrated at Guard Gate 2 because of the presence of two inhabited localities; the Fite house and the town of Tokay which lie northeast of zero and within the Jornada del Muerto. Fite house is fifteen and Tokay is twenty miles from zero. In case of a northwest blow, these places might have been subjected to intense radiation. From Guard Gate 2 the monitors could also go toward Carthage, Bingham, Claunch, and Carrizozo. Major Palmer carried with him the map (prepared by G-2) having on it the names of inhabitants in the localities within a radius of 40 miles of zero.

I. b) Events Immediately After the Shot, 16 July.

Up to the time of the shot and for one half hour after, the information concerning the direction of movement of the cloud was vague, except that it indicated the cloud would move in a line northwest from zero through Guard Gate 2. This meant that monitors might have to go to Fite's Farm, Tokay, and San Antonio. A 20 mph. ground wind along this direction was experienced at Guard Gate 2 and led to the belief that the cloud would come that way. However, the top of the mushroom did not move in the northwest direction. In the time interval from 6 to 7 AM the wind directions as received over the radio from Base Camp gradually changed from northwest to northeast. And the mushroom top seemed to shift toward northeast. Finally, the most definite information available over the very poor radio communication with Base Camp was that the cloud was going northeast at 15 mph., altitude 35,000 feet, and rising about 14,000 feet per hour. Hoffman requested that Magee go with Lt. Huene along road 380 toward Bingham to look for radioactivity from the cloud. Later Levine and Langham went in the same direction. In the meantime Hoffman tried to go down the road past Guard Tower 2 in order to go to Fite's Farm. The MP refused permission to anyone to travel down that road. An unsuccessful attempt was made to contact Base Camp and get permission for monitors to move in. By 7:30 AM Colonel Warren had secured permission for Hoffman to go in alone, but by that time it was certain that the major part of the cloud was moving northeast. Hence the monitors moved northeast along Highway 380. Later in the day Captain Paul Hageman went to Fite's Farm at 2:30 PM and found no radiation whatever.

Along the road toward Carthage, Hoffman, Palmer, and Hirschfelder met Leonard, who had found readable gamma radiation at 1.7 hrs. after the shot at points 19 miles from zero. This indicated that the active dust falling from higher altitudes had been caught by the northwesterly wind near the ground and blown in the direction of Socorro. As the party moved eastward, they met Levine and Langham, who also had found gamma radiation in increasing intensities of the order of fractions of an R per hour toward Bingham. Levine and Langham were dispatched toward Hanscomburg.

Hoffman's party went beyond Bingham taking Road 161 to Searchlight Station L-8, at which place they arrived at 4 hours after the shot just when the measured gamma intensity at that point had dropped by a factor 2 in 10 minutes, from 2 to 1 gamma roentgens/hr. Magee reported 15 R/hr at a point 3 miles east of L-8. Leaving there, Hoffman returned to Bingham and went to White Store, this route nearly paralleling that of Magee but closer to zero. The highest intensities found were 3 R/hr. Returning from White toward Bingham, measurements were made along the highway near all visible ranches. Alfred Anderson was met on his way from Carrizozo. From Bingham, Hoffman returned to L-8 Station, where Magee had just returned from a trip northeast along 161 and reported readings up to 10 R/hr. This was at about 11:15 AM. The intensities at White, Adobe, Bingham, and L-8 had apparently settled down to their steady decay values

Radio communication with Base Camp was unsuccessful, so Hoffman sent a message by Courier to Warren stating that the gamma intensities were about 90% of allowable value. (Reference: See Section VI. Examples of Town Monitoring, 1. Town of White.

Hoffman's party was joined by Magee at this time and the company went east along 161 from Station L-8 to investigate further the high intensities reported by Magee. At the first place at which measurements were attempted, it was found that Magee's car was heavily contaminated under the fenders and the chassis where road dust could cling. The meters recorded 4 gamma R/hr above the general background when held near the fenders. Moreover, inside the car the intensity was higher than outside. This cast some doubt on the validity of Magee's readings. Hoffman had earlier compared the reading inside and outside the car near Adobe at 10 AM and found a factor of 2 reduction inside the car. It was decided to return to Bingham and eat since it was noon.

At Bingham, the entire monitoring group except Leonard were present. Hempelmann arrived from Base Camp and plans were made for continued monitoring of the region. Briefly, these were as follows:

1. Capt. H. Barnett to go along 161 toward Claunch and Corona.

2. J. G. Hoffman to investigate the ranches and hot regions reported by Magee east and north of Bingham.

3. Levine and Langham to go along 161 and find any roads leading off to the side from it, in the first 15 miles from Bingham.

4. Anderson to measure carefully along 380 and any roads to the south of 380.

At this conference it was decided that alpha particle radiation was negligible as far as measurements up until noon indicated. The major hazard appeared to be gamma and its accompanying beta radiation.

In the afternoon, Hoffman went east from Bingham along 161 and north along 146 using Palmer's map of inhabited localities as a guide. The ranches west of Road 146 were in the midst of a region of intensity of about 0.25 R/hr at 2-3 PM. This was considered to be safe. The ranches named on the map were T. R. Coker, W. Lucero, and Sedillo. In another direction, namely due east from the junction of roads 146 and 161, along 146 the highest intensities were recorded, namely 6.0 R/hr at 2 PM. This high intensity was called to the attention of the military guard accompanying Hoffman. The readings were taken up to a point 3/4 miles from the Raitliff house, whose presence was unknown to the monitors since it was not marked on the G-2 map. At about 2 miles from the 146 - 161 road junction, 146 runs through a steep gorge. In this gorge the high gamma intensities were found which caused the gorge to acquire the name "Hot Canyon".

The swath of high intensity which began at the hot canyon, about 30 miles from zero, is known to have extended north slightly east for about 12 miles. Levine and Langham found where it crossed Highway 161 and took soil samples at a point where a gamma intensity of 7 R/hr was found at 3 PM, 16 July, on the south side of Road 161.

For detailed information on field monitoring in the five months subsequent to the shot we refer the reader to the transcript of field notes of all monitors.

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II The Decay of Precipitated Gamma Activity

The physical picture of events leading to spread of radioactivity over terrain far removed from zero point was as follows:

1. Fine particles of sand would fall from the cloud carrying radioactive materials on them. These particles will be carried in many different directions after leaving the cloud on account of differing wind directions at different altitudes.

2. At a given place on the ground a minimum time must elapse after the shot before radioactivity appears in measurable amounts. This time depends on the cloud velocity and its extension. It also depends on the time it takes for particles to fall from the cloud.

3. After the cloud has passed and the radioactivity has risen to its maximum intensity there will occur a decay of intensity with time. This decay will be due to two main causes; the change in the geometrical distribution of active material and the natural radioactive decay of the elements concerned.

a). Geometrical changes:

The apparent decay of the activity as measured on the ground will be influenced by the rate at which the particles settle. There will be a time at which a fog of particles is hanging in the air just above the ground. At a certain time later these particles will have settled to the ground. If there is wind, these particles will move into the interstices of the ground surface. Furthermore, rain will wash them further into the ground. At each of these stages the geometrical distribution of the active material is different from the preceding stage. There will result an apparent decay of activity because the progressive changes are toward obscuring the active particles. This kind of decay was well demonstrated by the measurements of the searchlight crew at L-8 whose data are shown in Figure 3. In about ten minutes the measured activity dropped by a factor of two, from a maximum of two down to one R per hour.

b). Fission products decay law

The decay of gamma and beta activity in fission products is summarized by Katherine Way, CK-2737. The gamma decay in Mev/sec/fission is as $t^{-1.2}$. See also V. Weisskopf: "Neutron and Gamma Effects After the Nuclear Explosion"-II, LAMS - 250, Figure 5 and: Los Alamos Hdb. Supplement, LA-140 A, p. 10, and : E. P. Wigner and K. Way "Summary and Correlation of Data on the Rate of Decay of Fission Products,"CC-3032, June 13, 1945.

For purposes of health monitoring the 1/t decay is most convenient for estimating intensities and is conservative in estimating integrated doses from measurements made in the first 24 hours after the shot. However, at longer times, for conservative monitoring, it is necessary to assume an inverse power of t larger than unity.

c). <u>Measured decay rates of radioactivity</u>

The decay of radioactivity as measured by gamma roentgenometers varied considerably as can be seen by reference to the decay curves in Appendix I compiled by Richard Watts. Fragments from the crater at zero decayed with time varying from t^{-1} to $t^{-1.5}$. At fixed points around the crater the apparent decay was as $t^{-1.8}$ to t^{-2}. This was assumed to be due to obscuration by dust. In one place the activity actually increased with time. This was interpreted as being due to wind blowing active material toward this place.

At great distances (greater than 12 miles) the activity seemed to follow the law $t^{-1.3}$ as shown in Figs. 1 and 4.

III. Geometrical Effects in the Distribution of Active Material

(a) Settling of the Cloud

In II (a) above, the changes in dose rate due to changes in geometrical disposition of the radioactive material were described in a general way. Following is a detailed discussion of the gamma ray intensity measured by an observer as a cloud of radioactive particles falls to the ground.

Let the gammas under consideration have an average energy 1 Mev with an average mean-free-path, λ , in air of 220 meters. There will be measurable intensities on the ground before the layers of air immediately above the ground are filled with active particles. When the particles start to reach the ground the intensity of gammas is most easily considered as being due to a cylindrical distribution surrounding the observer. The observer is on the axis of a cylinder of radius λ and height h. If the material gives A roentgens /hr/mc/unit solid angle, and if the density of the material is M mc/cc of air, and if we neglect absorption in the air, the intensity of gammas will be:

$$I = AM\pi\left\{h\log_e\left[\left(\frac{r}{h}\right)^2+1\right]+2r\arctan\left(\frac{h}{r}\right)\right\} \quad (1)$$

I = roentgens/hour

For a discussion of this formula see W. W. Mayneord: "Energy Absorption IV: Math. Theory of Integral Dose in Radium Therapy," Brit, Journ. Radiology, January 1945, vol. 18. For a more accurate calculation taking into account the absorption in the air, see Chicago Project Handbook, Chapt. V, section F. Since we have neglected absorption in air we take the height of the cylinder to be λ and the radius also as λ . For an average gamma energy of 1 Mev, A = 4.7 R/hr/mc/unit solid angle. Substituting in (1) one gets:

$$I(air) = 7.35 \times 10^5 \, M \;\; R/hr \quad (2)$$

When the material in the cylindrical volume has fallen to the ground, the observer is standing at the center of a disc of active material of radius λ. The intensity then, I (gnd), is given by:

$$I(gnd) = A \phi \pi \log_e \left[\frac{\lambda^2}{d^2} + 1\right] R/hr \qquad (3)$$

where ϕ = density of active material in mc per cm^2, and d is the height of the recorder above the surface of the disc.

$$\text{for } d = 10\text{cm}, \quad I(gnd) = 105\phi \ R/hr \qquad (4)$$

Note that if an intensity of one R/hr is recorded while the material is in the air then M = 1.36×10^{-6} mc/cc. When this is precipitated $\phi = 2.2 \times 10^4 \times 1.36 \times 10^{-6} = 3.0 \times 10^{-2}$ mc/cm^2 on the ground. And I (gnd) = 3.15 R/hr, if one neglects ground obscuration. Thus the ratio I (gnd): I (air) = 3.2. We shall assume however, that the cylinder height was of the order of 2.5 to 3 λ and that ϕ is increased accordingly. The ratio I (gnd): I (air) becomes 10:1. Note that according to (4) there are 9.5 μc/cm^2 of gamma activity for 1 r/hr. Taking into account the 50% ground obscuration of active material there are 19 μc/cm^2 gamma activity per 1 R/hr. This is an average gamma energy 1 Mev and assumed average mean-free-path in air of 220 meters. The ground to air ratio is useful for estimating concentrations of activity in the air from the measured concentrations on the ground.

(b) Obscuration due to ground interstices

According to the above discussion, the gamma intensity should rise to the level determined by the density of active material when it is finally on the ground. Measurements at Bingham, Adobe, White, and at Searchlight Station L-8 (see Fig. 3) showed that the intensity drops abruptly from a peak value determined by the particular terrain. This abrupt drop is attributed to settling of the active material among the cracks of the ground surface. The density of air is 0.00129 while that of ground is about 2.5 so that obscuration by ground particles is effective. From the data taken at the above named places we estimate that the ground obscuration is about 50%.

(c) "Geometrical Dose," Dg.

The integrated dose under the maximum (see Fig. 3) which precedes the steady decay is called the "geometrical dose." In Fig. 3 it is the area under the flat-top maximum and amounts to 2.5 R total. Attention is called to this type of dose (as distinguished from the integrated dose under the long, low intensity decay that follows it) because it is a high intensity, short duration dose. At hot canyon, for example, the intensity at the maximum was around 15 R/hr giving a value of Dg = 18 R in little over one hour. The geometrical dose can be a severe health hazard because it is delivered in a short time interval. Its maximum tolerable value is set at 50 R.

(d) Practical Importance of the L-8 Measurements

For the purposes of the 16 July shot the data at L-8 served as a guide because there the geometrical dose rate dropped to 50% when the cloud settled (Fig. 3). This supplied the working rule that if the value of I_o at t_o could be computed from any measured values I_1 and t_1 the geometrical dose rate would have been at least 2 I_o. The time over which this dose is delivered in one hour for points that were about 20 miles from zero point (L-8 is 19.5 miles distant).

This working rule was verified, within the accuracy of the measurements, at two other places beside L-8. At Adobe, Leonard observed 6.5 R/hr at 3.3 hrs. Checking this at 4.8 hrs Hoffman found 1.6 R/hr. The indications were that from 3.3 to 4.8 hrs the intensity had fallen off rapidly as it had at L-8. Here, however, the drop was nearly 70% instead of 50%. The other check for the rule was found in the "hot" canyon 7 miles due East of Bingham. Here the L-8 crew verified the reading of 15 R/hr at 3.3 hrs. At 8.4 hrs Hoffman found 3.8 R/hr. If the 15 R/hr had dropped to 7.5 at about 4 hrs and decayed as 1/t, Hoffman's reading should have been 3.7, which is close enough to 3.8 in view of the approximations involved.

It should be noted here that before the Trinity shot of 16 July 1945 there was no field data as to how pronounced the geometrical effect would be. The picture up until after the shot was that the activity at a given place would build up and decay giving a curve like a Gaussian curve skewed toward the left, or a curve resembling that of $y = xe^{-ax}$ with small values of a. Before the L-8 data were taken it was planned to assume that the intensity rose linearly to the value I_o over a time t_o giving an integrated dose $I_o t_o/2$.

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IV. <u>The Integrated Dose</u>

(a) Conference held at Base Camp on 14 July with Col. Warren, Lt. Col. Friedell, and Dr. Hempelmann set the upper limit of integrated gamma ray dose for the entire body over a period of two weeks (336 hours) as 75 roentgens.

(b) Calculation of integrated dose with 1/t decay.

A general formula can be derived relating the intensity I, measured at time t, (after decay has started) with the total integrated dose D over a period P. The 1/t decay law leads to the relation $I_1 t_1 = I_0 t_0$ where I_0 is the initial intensity at time t_0. The time, t_0, is the time at which the 1/t decay starts after the cloud has passed. See Section VII (a) and (b) for detailed discussion of t_0. It follows that the intensity I at any time is:

$$I = I_0 t_0 / t \tag{5}$$

The integrated dose is:

$$D_1 = I_0 t_0 \ln \left[P/t_0 + 1 \right] \tag{6}$$

Let the period P = 2 weeks, or 336 hours. t_0 is the time it takes for the cloud to move from zero point to the place at which monitoring measurements are made. Let this distance be d miles and the cloud velocity be v miles per hours. D_1 is 75 roentgens. Equation (6) is rewritten then as:

$$I_0 t_0 = I_1 t_1 = 75 / \ln \left(\frac{336}{d/v} + 1 \right) \tag{7}$$

[redacted]

where I_1 is the intensity of radiation measured at time t_1 at a point d miles from zero point. See Table I for use of this formula. (7) has two main features: it is relatively insensitive to position, d, or the cloud velocity, v; and the integrated dose, D, at a given position is directly proportional to the measured intensity, I_1.

These features facilitate a monitor's decisions in the field. It should be noted, however, that d/v is an approximation to t_o because t_o excludes the time it takes for the cloud to rise and the time it takes for the radioactive particles to fall. Also it does not account exactly for the time it takes the entire cloud to pass a given point, nor does it account for a cloud which does not move in a straight line from zero point. The use of d/v directly for t_o gives one a kind of safety margin for I_1; it is on the "safe" side for determining whether or not I_1 is high.

(c). Calculation of integrated dose with $1/t^n$ decay.

The discussion of theintegrated dose over time for the 1/t decay law has been presented in some detail because it can be used as a basis of comparison with the case in which the decay goes as $1/t^n$ where $|m|>1$. In the latter case the expression for the integrated dose becomes:

$$D_m = \frac{I_o t_o^m}{m-1}\left\{\frac{1}{t_o^{m-1}} - \frac{1}{(t_o+P)^{m-1}}\right\} \qquad (8)$$

where I_o is the "initial intensity," that is, the intensity at the time, t_o, when the activity commenced steady decay, and P is the period over which the dose is integrated (2 weeks, or 336 hours). Since P is 336 hours equation (8) can be reduced to a good approximation:

$$D_m \cong \frac{I_o t_o}{m-1} \qquad (9)$$

for values of t_o up to 25 hours.

The ratio D_1/D_n is

$$D_1/D_n = (t_o/t_1)^{n-1} C (n-1) \qquad (10)$$

where $C = 2.30 \log (336/t_o + 1)$ (See Table I or Fig. 6)

Figure 6A gives the values of $(t_o/t_1)^n (n-1)$ as function of $(t_o/t_1)^{n-1}$ which is used with the values of Figure 6 to compute the ration of doses D_1/D_n.

The integrated dose using equation (8) for the time $t_o = 4$ hrs has been computed for values of n = 1.229, 1.3, 1.5 as shown in Fig. 7. For comparison is shown the integrated dose for the 1/t law. Note that for all practical purposes the 1/t law dose diverges whereas for all values of n greater than unity the dose approaches some asymptomatic value. The value of $t_o = 4$ hrs was used because the field measurements of largest intensities were found in the region in which t_o was known to be 4 hrs.

Figure 8 shows the build up of dose in the weeks following the first 2 weeks after the shot. The curves give the dosage increment over a two week interval at increasing numbers of weeks after the shot. The purpose of this curve is to serve as a means for estimating dosage rates at long times after the shot.

(d) Determination of exponent n in the decay law.

Of greater use to the monitor is a quick means for judging the value of n in $1/t^n$. The first and obvious method is to plot intensity vs time on a log - log graph and estimate the slope which gives n directly. The second method is to prepare a graph beforehand of $(t_2/t_1)^{n-1}$ where t_2 and t_1 are the times at which intensities at a given spot are measured and use the relation $I_2 t_2^n = I_1 t_1^n$ which can be written as:

$$\frac{I_1 t_1}{I_2 t_2} = \left(\frac{t_2}{t_1}\right)^{n-1} \quad (11)$$

The two sets of measurements and the known ratio of t_2 to t_1 give n from the prepared graph of $(t_2/t_1)^{n-1}$. This method is quicker and easier for use in the field than the first method of plotting log - log graph. However, the log - log plot allows one to estimate I_o by an extrapolation. backward to t_o.

TABLE 1

Table for determining integrated dose, D_1 where $D_1 = C\,I_1\,t_1$ assuming 1/t decay law. Taking D = 75 Roentgens the tolerable values of initial intensity I_1 at time t_1 are computed from $I_1\,t_1 = 75/c$

		d = distance from zero point		max. tolerable value of $I_1\,t_1$
t_o	C*	v = 7 mi/hr	v = 18 mi/hr	$D/C = 75/C = I_1\,t_1$
1 hrs	5.82	7 miles	18 miles	12.9
2	5.13	14		14.6
3	4.73	21	54	15.8
4	4.44	28		16.9
5	4.22	35	90	17.8
6	4.04	42		18.6
7	3.89	49	126	19.3
8	3.76			20.0
9	3.65			20.5
10	3.54	70	180	21.2
11	3.45			21.7
12	3.36			22.3
13	3.29			22.8
14	3.22			23.3
15	3.15	105	270	23.8
20	2.88	140	360	26.1
24	2.71	167	378	27.7
36	2.34			32.1
48	2.08	386	864	36.1

* $C = 2.303 \log\left(\frac{336}{t_o} + 1\right)$ See Fig. 6

Integrated dose D is taken over a period of 336 hours after t_o.

[redacted]

V. Procedure for Determining Safe Dosage Rates of Gamma Radiation

(a) A monitor coming to a spot where the cloud has passed has two items of information about the radiation there: (1) he can measure rate of dosage at times up to about 48 hours after his arrival and (2) he has a rough estimate as to when the cloud precipitated the activity at that point. (if the rate of dosage is too high his sojourn at the spot may be limited to a period considerably less than 48 hours.) From these two items he has to judge whether the integrated dose over 336 hrs after the cloud passed will exceed 75 roentgens or not.

The first measurement of intensity I_1 at t_1 permits the use of equation (3). The product I_1t_1 should be less than or at most equal to the constant on the right hand side of the equation. Various values of $t_o = d/v$ should be chosen to allow for possible inaccuracies in guessing at the time, t_o. If the product I_1t_1 is too large to satisfy the equation it means that according to the 1/t law the integrated dose will be excessive. The next step is to determine whether the decay differs from the 1/t law. This is accomplished by the two methods outlined in the preceding section for determining n in $1/t^n$. Once an estimate of n is gotten, equation (5) is used. Here one has to compute back to estimate I_o and then calculate Dn. If the log I vs log t plot is made, the straight line can be extrapolated back to time t_o and I_o is determined from the graph.

Fig. 5 shows a log - log plot of $y = x^n$ in the form where $x = (t_1/t_o)$. This curve is useful for two purposes. First, it permits the computation of I_o from the general formula : $I_o = (t_1/t_o)^n$ where I_1 and t_1 are measured values in the field and n is any exponent one chooses to assume. Secondly, Fig. 5 allows one to estimate what the intensity I_1 at a place would have been if it had decayed with an exponent one instead of with any other value, n.

[redacted]

This uses the formula:

$$I = I_1(t_1/t_0)^{n-1}$$

where I_1 and t_1 are measured at a point and I is the intensity which would have existed if the exponent of decay had been unity instead of n.

Wherever possible the procedure is to determine the integrated dose, D_1, under the 1/t decay curve and refer to equation (6) for possible values of D_n when a value of n has been estimated.

(b) Determination of Geometrical dose, Dg.

The geometrical dose has been discussed in section IV (c). The conservative estimate of this doseis made by assuming that $I_1t_1 = I_ot_o$. Once I_1t_1 are measured, a guess is made as to t_o and the value of I_o is obtained. This value of I_o is then multiplied by 2 (or by 3 if a very conservative estimate is desired) to get the dosage rate while the cloud of particles was settling. For example, if I_o turns out to be of the order of 15 R/hr at $t_o = 4$ hrs it follows that the geometrical dose will have been at the tolerance level of 30 R, moreover the integrated dose D_1 will be excessive, namely $4.4 \times 4 \times 15 = 265$ R.

(c) Effect of House Walls on Gamma Dosage.

The intensity of gamma radiation inside a house which is located on terrain which is covered with gamma active material must be considered in calculating the dosage received by personnel over a long period of time. Measurements made at Site Y on 19 July at T 825 indicated that there is at least a 50% reduction of gamma intensity inside a light wooden frame house. Outside the reading was 0.0065 R/8 hr while inside it was 0.0026 R/8hr. For a heavy adobe (about 15" thick) house at Bingham, the intensity outside was 0.0025 R/hr at waist level while inside it was less than 0.0001 R/hr (August 17th measurements of Dr. L. H. Hempelmann). At another stone house in hot canyon, Dr. Hempelmann measured 0.023 R/hr outside and 0.0035 R/hr inside. Thus for an adobe house, the gamma dose is reduced by a factor of 8.

Thus if one takes the reduction of 50% for a light frame wooden house and assumes that people spend 12 hours per day indoors, the integrated dose is reduced by 25%. If one takes the factor of 8 for a stone house and 12 hours per day indoors, the integrated doseis reduced by 44%.

It should be noted that the protection afforded by an automobile was of concern to the monitors. It was found that the gamma intensity inside an auto was 50% that outside. This was no longer true in the car that had picked up material which stuck to it (under chassis and under the fenders). The car became contaminated and the intensity inside was at times greater than that outside.

(d) Variation of Gamma Intensity With Height Above Ground

It was soon found that the intensity of gammas varied markedly with height above the ground. The following table gives data on this variation:

TABLE II

Place Observed	Time	Ground Reading	Air Reading: Height, Intensity	Air As % Of Ground Reading	Remarks
Searchlight	ca. 3-4 hrs	-------	------ --------	75%	Gamma radiation
Crew at L-8	4	5 R/hr	3 ft., 1 R/hr	20	Gamma & beta radiation
Hoffman, 1 mi. east of L-8	8	0.9	1 meter, 0.5	55	Gamma radiation
2 mi E of L-8	8.2	3.2	1 meter, 2.3	72	Gamma radiation
3 mi E of L-8	8.5	6.0	1 meter, 3.8	63	Gamma radiation
Hoffman, Bingham	3.3	3.3	1 meter, 1.7	51	Gamma radiation
Friedell & Hempelmann at Hot Canyon	37	.7	"Waist High", 0.5	71	Gamma radiation
Fulbright & Mallinckrodt, 14 mi N of Bingham	550	0.027	1 meter, 0.0[illegible]9	70	Gamma radiation

The data indicate that for gamma radiation, the average value of the intensity at torso level (1 meter) is 55% of the intensity at ground level. Ground level readings were made by setting the meter on the ground. The average position of the center of the ionization chambers was 10 cm above the ground surface. Since the meters were made in such a manner as to prevent the ionization chambers from reaching ground level, it was decided that the intensity at torso level could be safely taken as 50% that at ground level.

The importance of the variation of intensity with height above ground is shown in Table II A below. According to measurements the major fraction of human body mass is at a height of over 1 meter above grounding (for standing position). Table II A shows average heights and masses of the parts of the average man. These data are taken from W. V. Mayneord; Brit. Journ. of Radiology XVII, pp. 151-182, (1944); "Energy Absorption II Part I: Integral dose When the Whole Body Is Irradiated".

For comparison with the case of uniform intensity with height Table II A shows the effect of variation which is 50% at 1 meter above ground. The distribution of intensity shown gives a total dosage which is 54% of the case of uniform intensity over the body. In the discussions of dosage (secs VI, VII) a factor of two is introduced to account for the variation with height. The correction applies only to adults of at least normal stature.

<u>Table II A</u>

Part of Body	Avg. Height Above Ground	Mass	Distribution Radiation Intensity	Mass X Intensity
Foot	1.8 cm.	1.388 Kg	1.0 R/hr	1.388 Kg-R
Lower leg	26.7	8.180	0.9	7.362
Thigh	63	11.332	0.6	6.799

Table II A (cont'd)

Part of Body	Avg. Height Above Ground	Mass	Distribution Radiation Intensity	Mass X Intensity
Lower torso	95 cm	19.000 Kg	0.5 R/hr	9.500 Kg-R
Upper torso	125	19.100	0.45	8.595
Arms	125	4.254	0.45	1.914
Shoulder	135	0.792	0.4	0.317
Neck	144	1.292	0.4	0.517
Head	157	4.330	0.3	1.299
		69.678 Kg		37.691

100(37.691/69.678) = 54%

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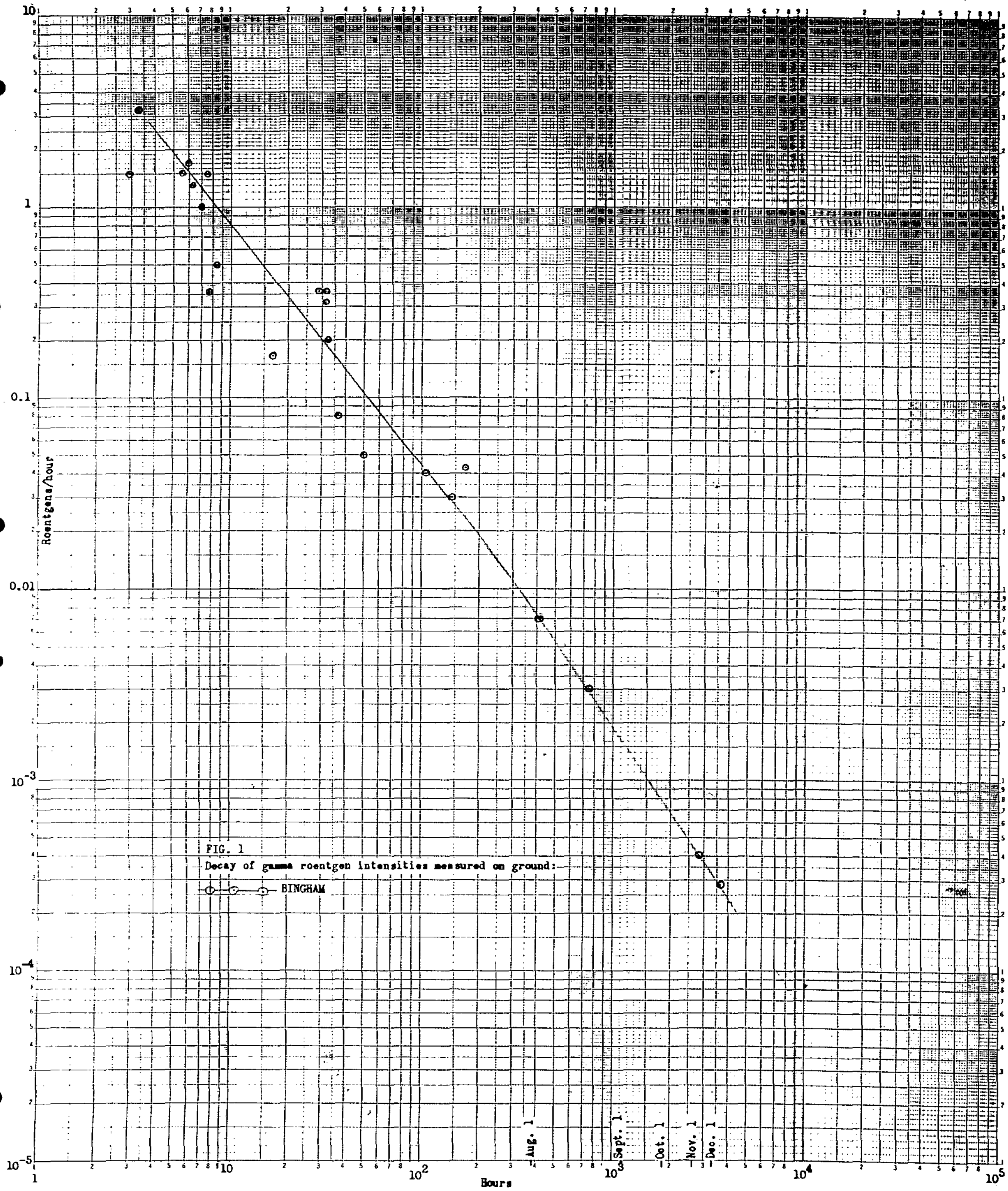


FIG. 1

Decay of gamma roentgen intensities measured on ground:

UNCLASSIFIED Figure 2

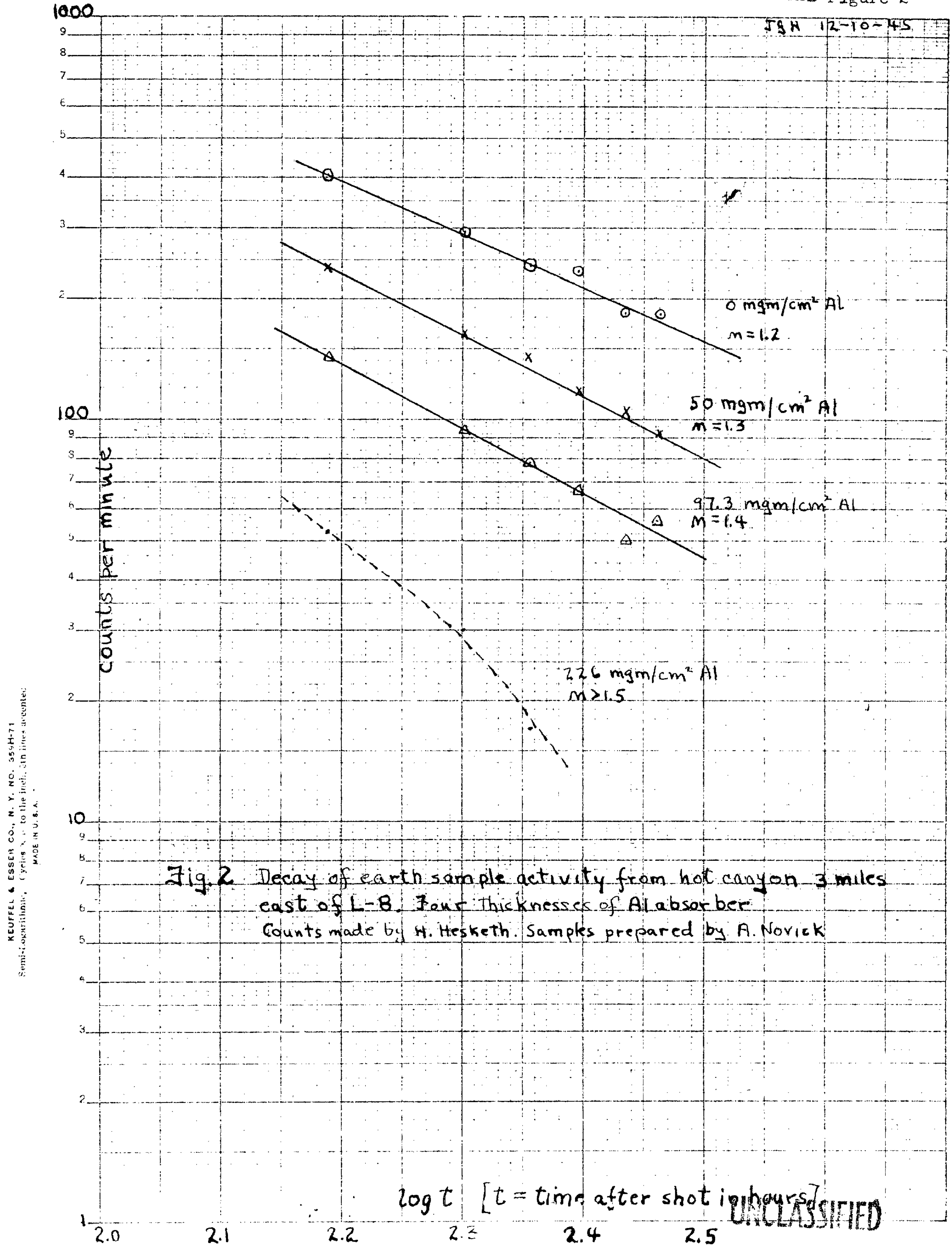


Fig. 2 Decay of earth sample activity from hot canyon 3 miles east of L-B. Four Thicknesses of Al absorber
Counts made by H. Hesketh. Samples prepared by A. Novick

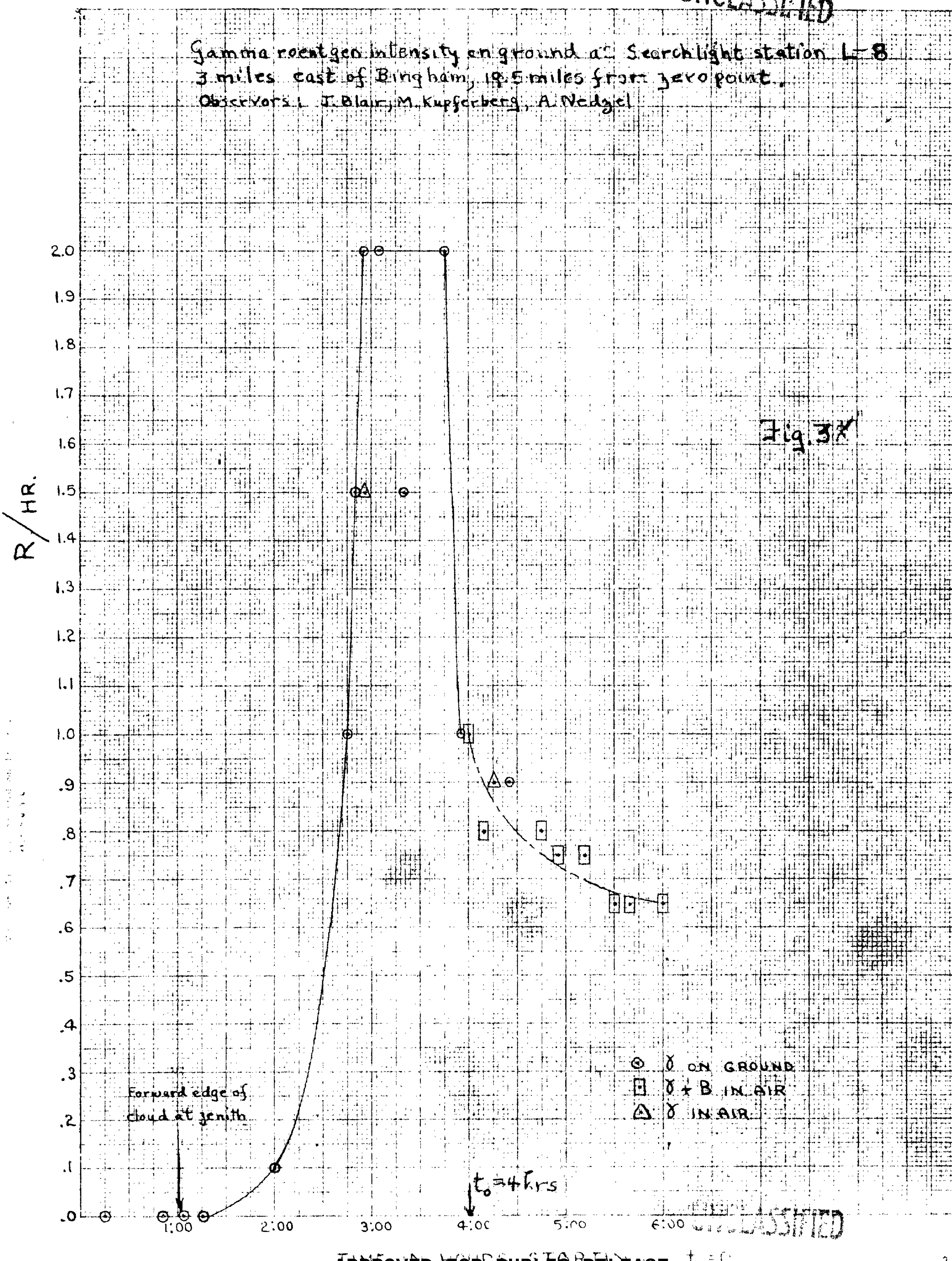
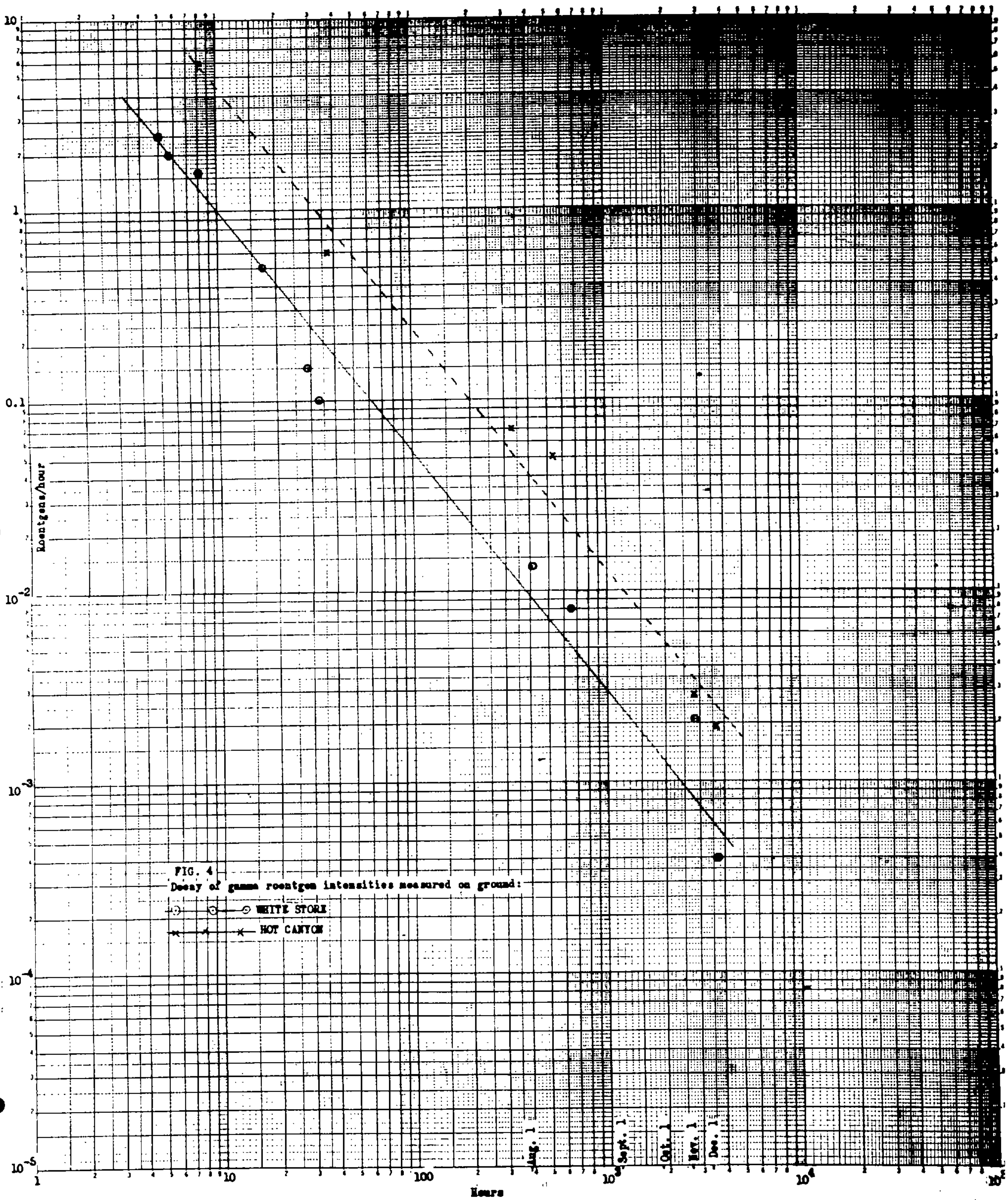

Gamma roentgen intensity on ground at Searchlight station L-8
3 miles east of Bingham, 18.5 miles from zero point.
Observors: J. Blair, M. Kupferberg, A. Nedzel
R/HR.
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0
Fig. 3X
Forward edge of cloud at zenith
t_0 = 4 hrs
⊙ γ ON GROUND
⊡ γ + B IN AIR
△ γ IN AIR
1:00
2:00
3:00
4:00
5:00
6:00

Figure 4



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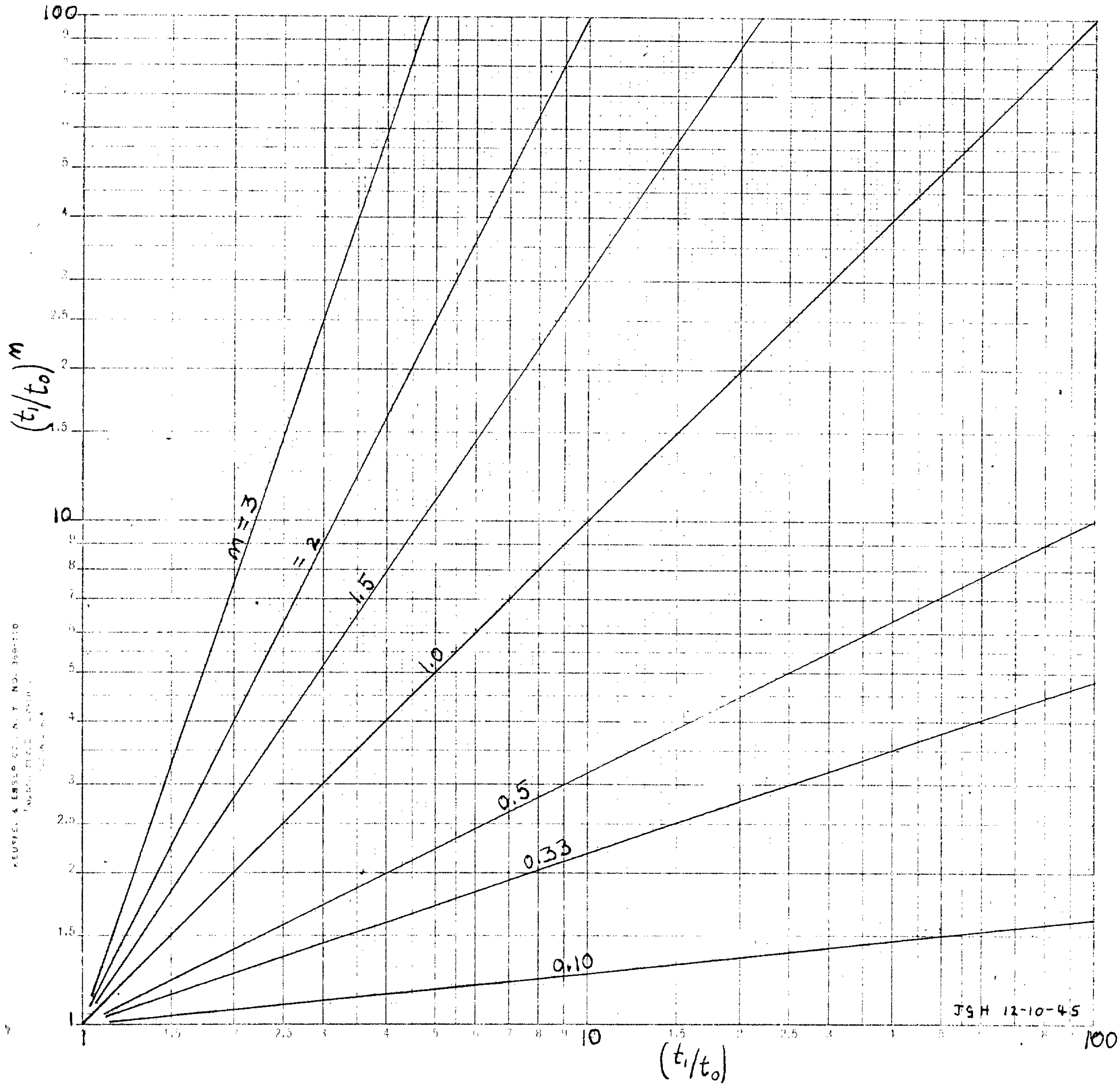

Fig. 5

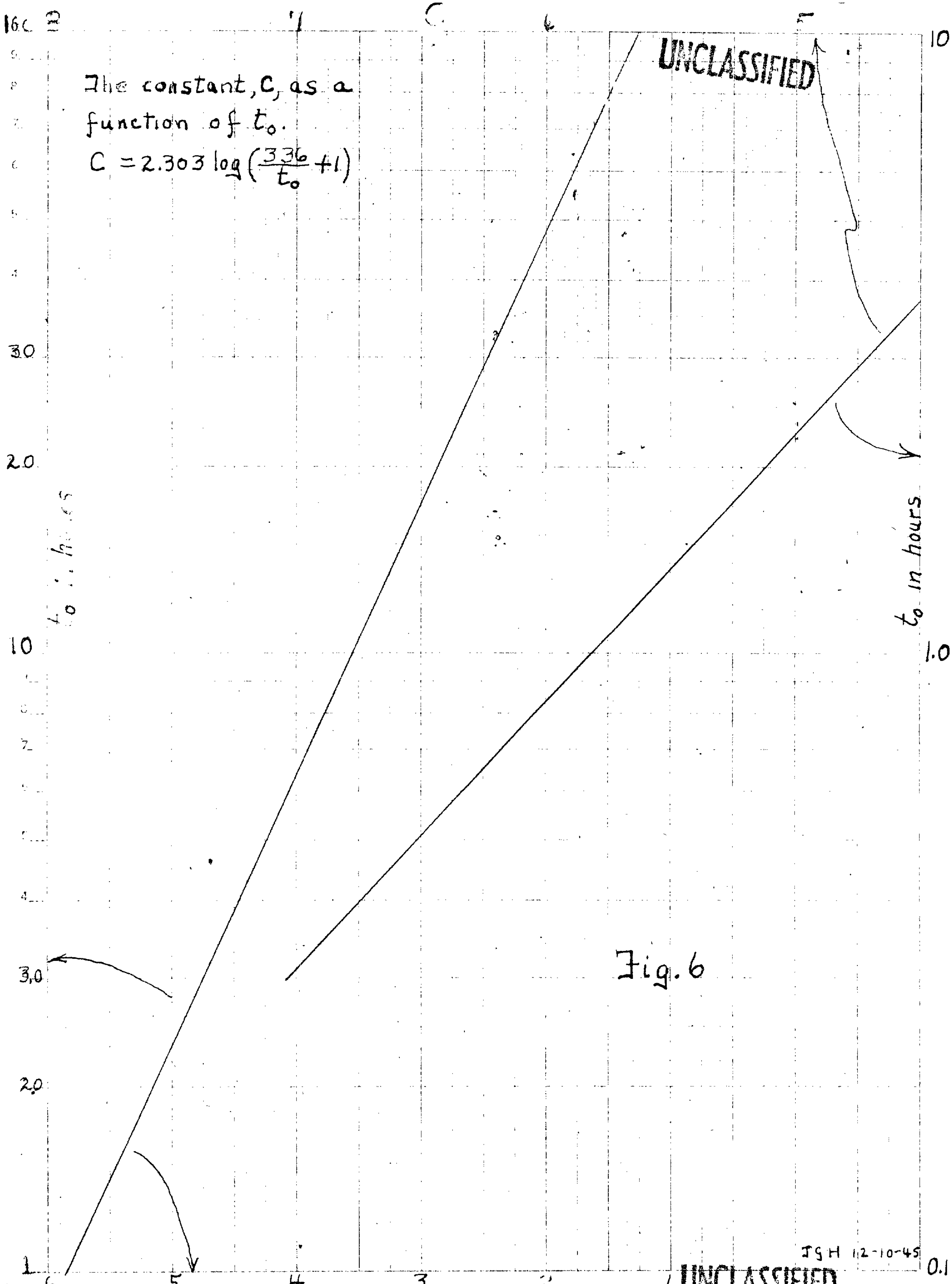

Fig. 6

JSH 12-10-45

27-6.

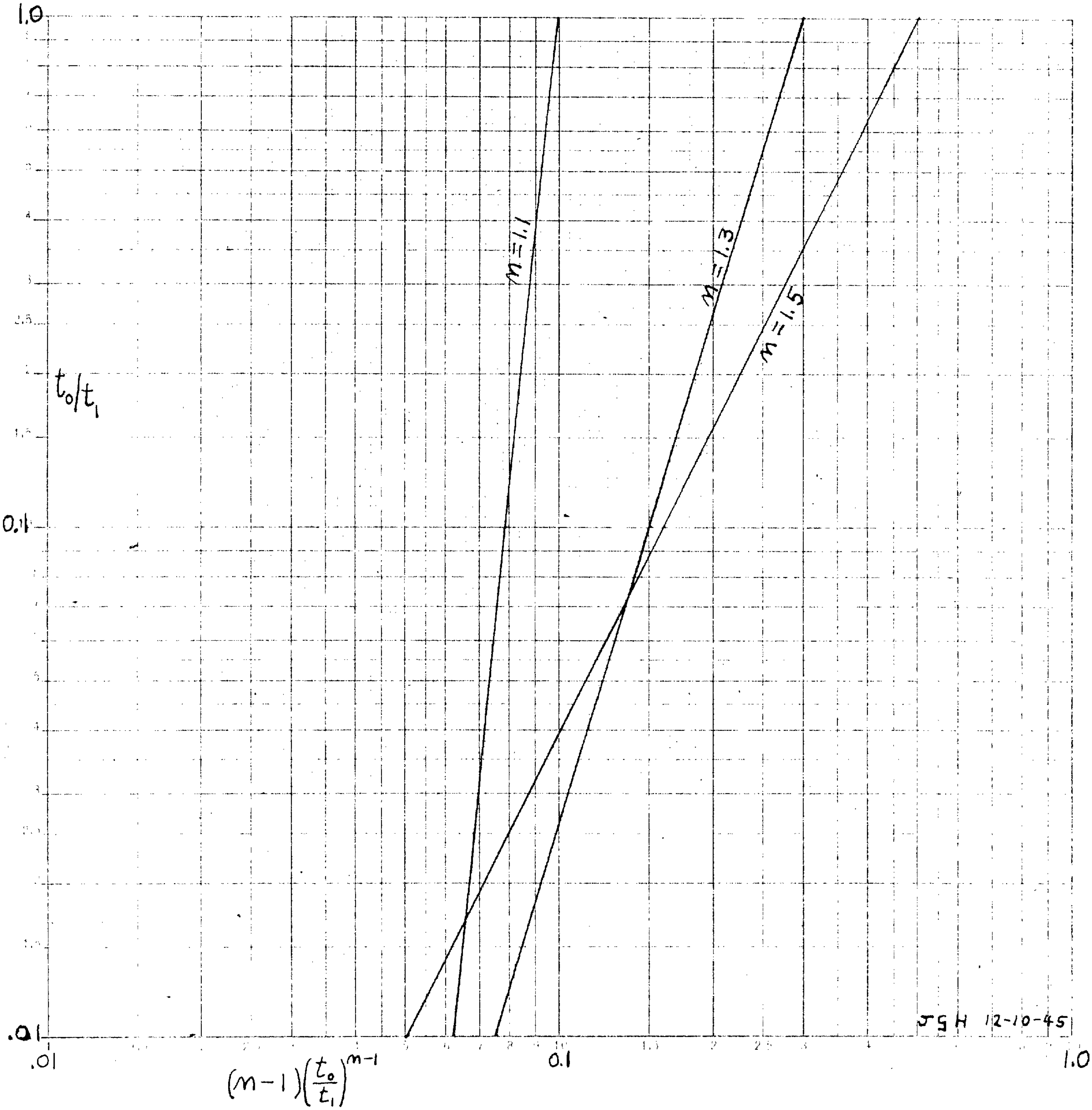

Fig. 6F.

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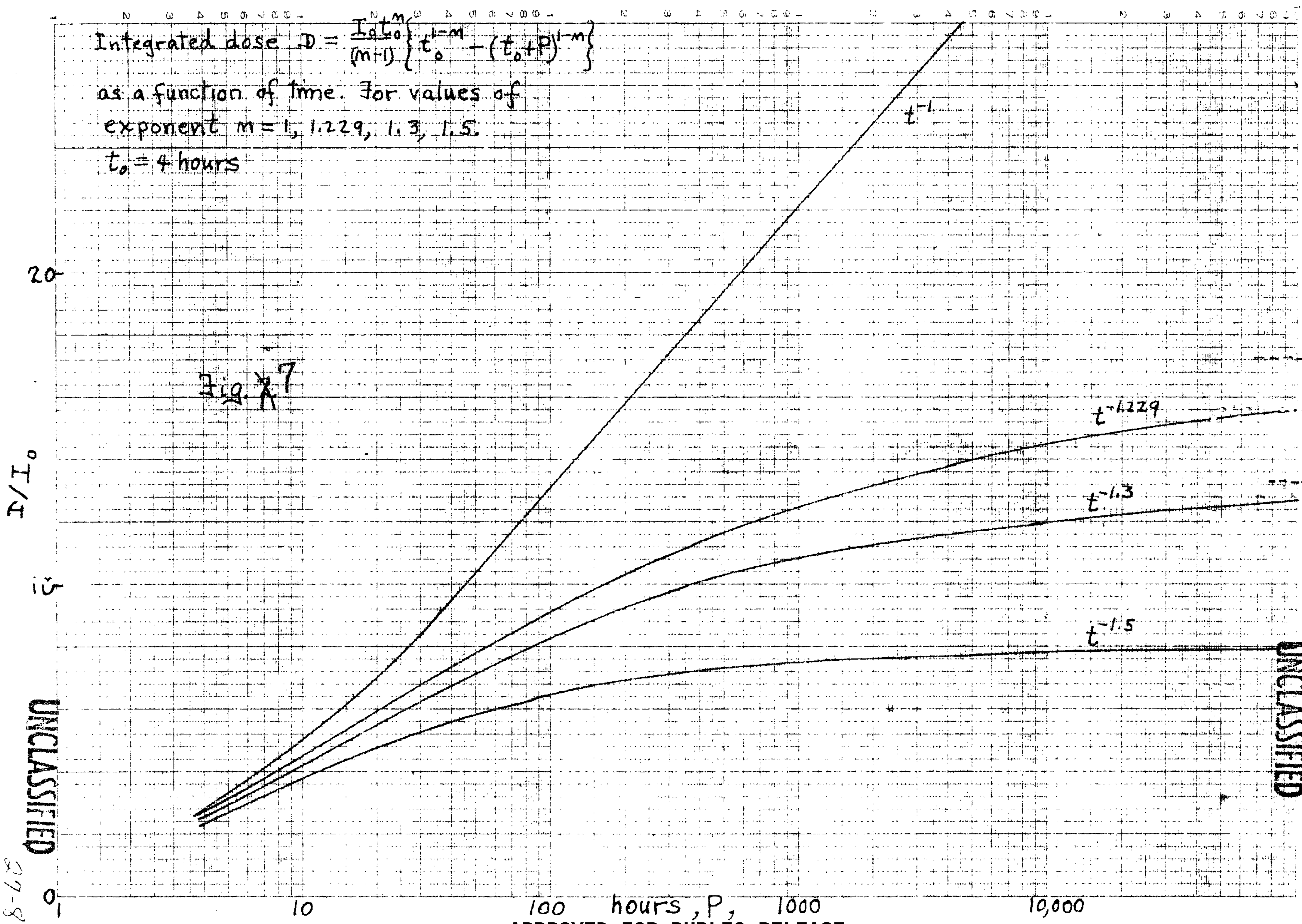

Integrated dose $D = \frac{I_o t_o^m}{(m-1)}\left\{t_o^{1-m} - (t_o+P)^{1-m}\right\}$
as a function of time. For values of
exponent m = 1, 1.229, 1.3, 1.5.
t_o = 4 hours
Fig. 7
t^{-1}
$t^{-1.229}$
$t^{-1.3}$
$t^{-1.5}$
∞
D/I₀
20
10
0
1
10
100
hours, P,
1000
10,000
UNCLASSIFIED
UNCLASSIFIED

Figure 7

Millimeters, 10th lines heavy

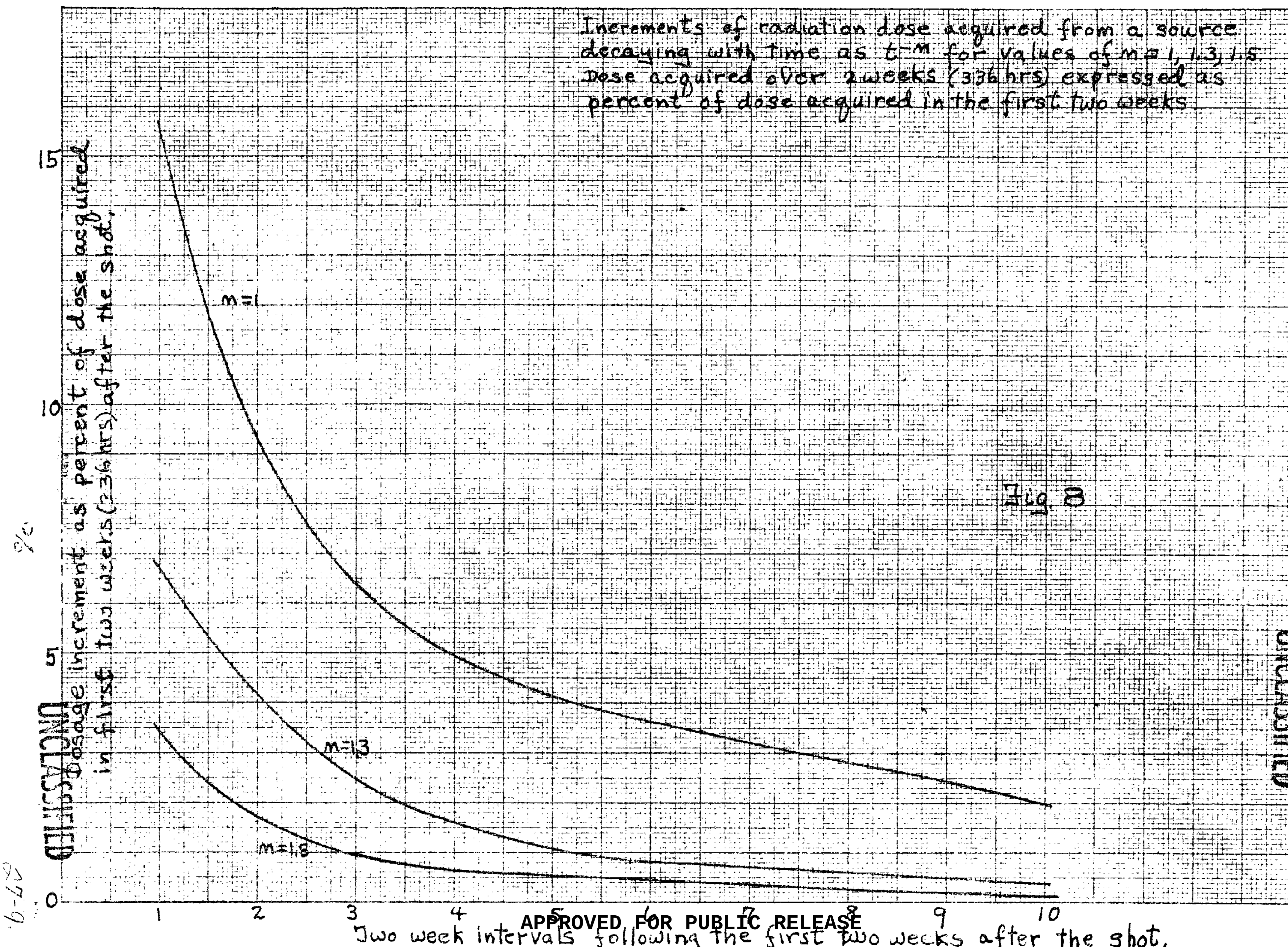

Figure 8

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VI. Examples of Town Monitoring

1. Town of White. One building on road 380, 6 mi. East of Bingham.

Figure 4 shows the measured intensities made at White Store. The air measurements were multiplied by 2 to correct them to the corresponding ground values. Hoffman had been called to Adobe, 2 mi West of White, to verify a reading of 6.5 R/hr at 3.3 hrs. By the time he arrived at Adobe the intensity dropped to 1.6 R/hr. This is assumed to be due to the settling of the cloud around 4 hrs. Hoffman then went on to White and there found 2.5 R/hr at 5 hrs. Having just come from L-8 and seen the rapid drop there at 4 hrs and found that it apparently had occurred similarly at Adobe it was natural to assume that it had already occurred at White by 5 hrs time.

To calculate the dose at White one extrapolates the line back to $t = 4$ hrs at which $I_o = 4.2$ R/hr. Table I gives for $t_o = 4$ hrs a value of $C = 4.44$. Hence the integrated 1/t law dose is $D_1 = 4.44 \times 4.2 \times 4 = 74.5$ R on ground. To get the geometrical dose multiply $I_o = 4.2$ by 3 and multiply this by 1 hour and get $Dg = 12.6$ R. This is over estimated on the safe side; for comparison with the L-8 station decay one should multiply I_o by 2, this gives 8.4 instead of 12.6. The total dose is 74.5 plus 8.4 R or 83 R. Allowing 25% reduction for the change in dose with height above ground one has $83 \times .75 = 62$ R. The first conservative guess as to the dose at White was to take $I_1 t_1 = 2.5 \times 5$ (this is 2.5 R/hr measured at 5 hrs) and assume that the cloud velocity was 18 mph and that $t_o = 1$ hr. The value of C from Table I is 5.82. Hence $D_1 = 5.82 \times 5 \times 2.5 = 73$ R. From the L-8 data at the time it was known that t_o could not be as small as 1 hr, but since no specific data was on hand it was guessed that D_1 was at most 90% of tolerance. This is the bases of the estimate sent to Col. Warren at 11:00 AM from L-8, signed by Hoffman, that 90% of tolerance integrated dose was the value for one of the localities in that region.

Actually, this dose can be considerably reduced with our present information. The line in Fig. 4 has a slope 1.3 indicating a decay according to $1/t^{1.3}$. From Fig. 8 when $n = 1.3$ the value of $Dn/I_o = 9.6$, where I_o is 4.2 , so that $Dn = 40.3$ R. The geometrical dose is $Dg = 8.4$ R so that the total integrated dose is $8.4 + 40.3 = 48.7$ R. on ground. Note that Dg is 20% of Dn. Allowing a 25% reduction for the house effect and 25% for the decrease in intensity with height the dose is 24.3 R per person. The 25% reduction for the house effect at White is on the safe side. Actually it should be a 46% reduction on the basis of measurements made by Dr. L. H. Hempelmann, 12 August 1945. These measurements gave 0.005 R/hr outside, on ground, with 0.0005 R/hr inside White Store. With the 46% reduction for house effect only (neglecting the variation with height) the integrated dose is 26.2 R on ground.

2. Town of Bingham, 18 miles North of zero point.

The firstreading at Bingham was made by Leonard at 2.9 hrs, intensity 1.5 R/hr. At $t_1 = 3.1$, $I_1 = 3.3$ R/hr as measured by Hoffman. Apparently the intensity had built up in the interval between these readings and according to the findings at L-8, 2 miles East, the reading 3.3 R/hr may be assumed to have been the maximum at Bingham. At the time 3.1 hrs, however, it was not known how the intensity would behave and accordingly the most conservative computation of dose was made. A cloud velocity was assumed that would make $t_o = 1$ hr, so that from Table I, $C = 5.82$ and $D_1 = 5.82 \times 3.1 \times 3.3 = 59.4$ R.

After returning from L-8, Adobe, and White it was realised that $t_o = 4$ hrs was more accurate. At $t_1 = 6$ hrs the average intensity had fallen to 1.5 R/hr, and thus $D_1 = 4.2 \times 1.5 \times 6 = 37.8$ R. Dg is $3.3 \times 1 = 3.3$ R

Making $Dg \neq D_1 = 41$ R.

There is a correction for the exponent n being 1.3. Fig. 1 shows data plotted beyond 336 hours. The line has slope 1.3 making the decay law $1/t^{1.3}$. According to Fig. 1, the dose, $I_o = 2.5$ R/hr, $t_o = 4$ hrs, and from Fig. 7 $Dn = 9.6 \times 2.5 = 24$ R. The total dose now becomes 27.3 R. Allowing a 46% reduction for house effect one has for the final dose 14.7 R per person, on ground.

Note: the readings at Bingham are scattered, Fig. 1, more than those at White, Fig. 4. This is attributed to the fact that there was heavy traffic there before, during, and after the 6 hr measurements were made. Cars were coming and going at the road junction, presumably bringing in active dust on wheels and fenders or burying activity already precipitated there.

3. Hot Canyon, 7 miles due East of Bingham.

At 3.3 hrs the Searchlight Crew checked and found correct the earlier measurement of about 15 R/hr at waist height by Magee in the region known as "hot canyon". The computations for this canyon are presented because sufficient data are available for computing dose and also because Levine and Langham found a spot on road 161 Northeast of Bingham which had a comparable radiation dosage and which were nearer to known ranches than was the hot canyon. A swath of comparable intensities lay across the Chupadera Mesa. At 8.4 hrs Hoffman measured 3.8 R/hr 1 meter off ground (6 R/hr on ground) which gives a value of $I_o = 7.6$ R/hr at $t_o = 4$ hr if one assumes the 1/t law. The 1/t law dose is $D_1 = 4.4 \times 7.6 \times 4 = 134$ R. The geometrical dose is $Dg = 15$ R. And the total dose in air at torso level is 149 R.

The value of I_o is very close to that expected by dividing 15 R/hr by 2 according to the observations at L-8. In a conservative approximation we may put $I_o = 8$ R/hr at $t_o = 4$, this makes $D_1 = 142$ R. Since the canyon was hot extensive measurements could not be made there on account of instrument contamination. Data on the exponent n are available from an earth sample taken by Hoffman. The data on this sample are shown in Fig. 2 where the counts are plotted against time for various thicknesses of Al absorber. (We are indebted to Mr. Aaron Novick for preparing the sample and to Mr. Harry Hesketh for the counting measurements.) With thick absorbers the exponent rises to 1.4. The sample was not strong enough to go to 800 mgm/cm^2 Al which is the case of interest to us for comparison with the gamma measurements in the field, but the meager data indicated that the exponent is at least 1.3.

Under the circumstances that n was 1.3 at Bingham and at White and in view of the laboratory data in Fig. 2 it is reasonable to assume that the exponent at hot canyon will be at least 1.3. According to Fig. 7 the dose Dn is found to be 9.6 x 8 = 76.8 R. The geometrical dose is 15 R making the total dose 91.8 R in the air at torso level. (On the ground Dn = 9.6 x 12 = 115 R.) To correct for the wooden house effect, reduce 92 R by 25% making 69 R, or, for an adobe house the reduction is 46, making the dose 50 R. At 535 hrs Fulbright and Mallinckrodt measured 0.07 r/hr on the ground at hot canyon. For a 1/t decay in the interval between 336 and 535 hrs the integrated dose, on the basis of the 0.07 R/hr reading, is 15 R on ground for the 200 hours following the 336th hour. This figure is to be reduced for house effect.

Doses on ground were Dg = 24 R, Dn = 115 R making the total dose D_t = 139 R, without house correction.

4. <u>Discussion</u>

The methods of computing dose illustrated in the preceding examples lead to doses summarized in Table IV a. The doses shown are conservative in that the house wall effect reduction is not applied to the geometrical dose. It is assumed that a person was standing in open terrain and received the full dose that occurred during the falling time of the cloud material. A person inside an adobe house would have been subjected to only 1/8 of the geometrical dose. It should be noted that in the examples discussed in the preceding sections the house effect reduction was applied to the total dose, Dg + Dn.

The correction of dosage from ground level to torso level is applied only during the first 336 hours. After that time interval the field measurements indicate that the dosage on the ground and at torso level were essentially the same.

Table IV a: Summary of Examples of Town Monitorning: Gamma Roentgen Doses.

Location	Geometrical Dose, Dg.	Integrated Dose, Dn.	Total Dose After 336 hrs. Dg ≠ Dn	Increment of dose during 2 week Intervals after the shot. 3 - 4 weeks	5 - 6 weeks	7 - 8 weeks	19 - 20 weeks
White							
a) Dose on ground*	8.4 R	21.8 R	30.2 R	1.5 R	0.9 R	0.54 R	0.087 R
b) Dose on ground corrected for house wall effect **	8.4	11.8	20.2	0.81	0.48	0.29	0.045
c) Dose (b) corrected to torso level dose***	4.2	5.8	10	0.81	0.48	0.29	0.045
Bingham							
a) Dose on ground *	3.3	24	27.3	1.7	1	0.6	0.096
b) Dose on ground corrected for house wall effect **	3.3	.3	17.3	0.91	0.54	0.32	0.052
c) Dose (b) corrected to torso level dose***	1.7	6.5	8.1	0.91	0.54	0.32	0.052
Hot Canyon							
a) Dose on ground *	24	115	139	9	4.8	2.8	0.46
b) Dose on ground corrected for house wall effect **	24	62	88	4.3	2.6	1.5	0.25
c) Dose (b) corrected to torso level dose ***	15	41	56	4.3	2.6	1.5	0.25

* 10 cm above ground.

** Adobe house, reduces gamma dosage to 54%

*** Dose at torso level is 50% of that 10 cm above ground level. Applies only to the dosage During the first 336 hours after the shot. After that time ground and torso doses are the same, see Section VII

[redacted]

VII. Method for Calculating Doses

a. There are on hand a large body of data on the measurement of gamma ray intensities at many localities along the swath laid down by the cloud. The computation of integrated doses for these localities can be made according to three main considerations as follows:

1. For localities 20 plus 3 miles from zero point the method as described in section VI for White, Bingham, and Hot Canyon can be used with appropriate approximation depending on the deviation from 20 miles distance. Summarizing it briefly, this method consists first in determining D_1 from the known value of $t_o = 4$ hrs at 20 miles. D_1 is then revised for decay according to $1/t^n$ law where the data shows the revision to be justified. Dg is then computed as being 2.1_o since the time is one hour for the dose rate of Dg at 20 miles. The total dose is then D_1 plus Dg exclusive of any corrections for the height above the ground effect or the house effect.

2. <u>First approximation: For localities other than those at 20 ± 3 miles from zero point</u> the most conservative method of computing integrated dose is to assume a cloud velocity, 18 mph, take $t_o = d/v$ and assume that the intensity decays as $1/t$. This is a rough approximation and suitable only for field estimates. A refinement used in computing the doses of Table V is given in (3) below.

3. <u>A second approximation based on field data: For localities other than those at 20 ± 3 miles frm zero point</u> it is assumed that insofar as gamma activity on the ground is concerned the apparent drift velocity of the cloud of particles was 18 mph. Moreover, the length of time required for the gamma activity to settle down to a steady decay after its initial appearance is assumed to be not less than 2.8 hrs for values of $d \geq 17$ miles.

As a first approximation for values of $D < 17$ miles subtract 10% per mile from 2.8 hrs.

For example, at $d = 28$ miles the value to t_o is $(28/18 + 2.8) = 4.4$ hrs. The basis for selecting these values for the apparent drift velocity and the time for settling of the cloud is given in the following discussion.

b. Discussion of t_o

The value of t_o is determined by the rise time, the drift velocity, and the falling time of the cloud of particles. For purposes of calculating dose the rise time is considered negligible. This is a conservative approximation as far as doses are concerned in that it over-estimates dose.

1. The apparent drift velocity: Hornberger observed measurable gamma intensity in the school yard at Vaughn at 7.6 hrs. Vaughn is 96 miles from zero point. Hence the cloud of particles could not have traveled slower than 12.9 mph. At L-8 first measurements of gamma radiation were made at 1.4 hrs, and since L-8 is 19.5 miles from zero, the cloud could not have traveled less than 13.9 mph. It should be noted here that the measurement of gamma radiation does not necessarily imply that the cloud particles have fallen at a given point. The radiation may be coming from the cloud before it has settled at that point. At L-8 the leading edge of the visible cloud was at the zenith at 1.1 hrs indicating a drift velocity of 17.7 mph. This is more closely the actual drift velocity of the cloud aloft in contrast to the apparent drift velocity associated with the appearance of measurable gamma radiation.

Table III shows the winds aloft at the time of the shot. These data were submitted by the meteorologist, J. M. Hubbard. Inspection of Table III shows that the winds between 20,000 and 35,000 feet five a resultant in the Northeast direction with a velocity above 15 mph. This figure agrees with the velocities quoted above in that it is not smaller than 13.9 mph.

It is assumed that 18 mph for the apparent drift velocity of the cloud of particles is a "safe" value for computing doses in that it will over-estimate rather than under-estimate the dose. In special cases one may make estimates with lower velocities but in no case can the velocity be taken as less than 12.9 mph.

2. Falling time of the cloud of particles is defined here as the interval between the time of first measurable gamma radiation and the time at which the steady decay of gamma radiation sets in. Figure 3 shows the best data

TABLE III

The following are the winds aloft at the time of the operation July 16, 1945:

Winds Aloft: Composite of 0545 base camp pibal, 0400 outpost pibal and 0200 Point P Rawin

Surface-500 ft.	Wind from 110°	3-5 mph
720	160°	7 mph
1380	200	6
2040	230	7
2670	250	8
3300	250	10
3900	240	8
4500	230	7
5100	220	8
5700	220	12
6300	220	11
6900	200	8
7500	190	7
8100	170	9
8700	170	12
9300	160	12
9900	150	13
10,500	140	13
11,100	130	16
11,700	120	16
12,300	140	12
12,900	160	10
13,000	150	13
14,000	150	12
15,000	180	4
16,000	250	4
17,000	240	8
18,000	220	11
19,000	220	12
20,000	220	15
25,000	230	16
30,000	230	27
35,000	240	19
40,000	290	18
44,000	280	11

J. M. HUBBARD

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available for measuring the falling time at d = 19.5 mi. Activity was first measurable at 1.4 hrs, passed thru a maximum, and settled to a slow decay at about 4 hrs. The falling time is taken as (4.2 - 1.4) or 2.8 hrs.

Indirect evidence verifying the abrupt settling of activity was found at Adobe which is about 3 miles nearer to zero than is L-8. Leonard measured 6.5 R/hr, at 3.3 hrs; Hoffman found 1.6 R/hr at 4.8 hrs, indicating that between 3.3 and 4.8 hrs an abrupt change of intensity had occurred. This effect was also found at hot canyon.

From these data we infer that the falling time for distances greater than 17 mi was at least 2.8 hrs. For lack of specific information about its increase with distance and because it over-estimates doses we shall use the figure 2.8 hrs for computing dose for $d \geq 17$ miles.

For distances less than 17 mi the best approximation is to assume that the falling time decreases 10% for each mile less than 17 mi. This reduces the falling time to zero at d = 7 mi. The nearest distance at which measurements were made was 13 miles. The 10% reduction per mile has no justification other than that the falling time should be redused in order to avoid under-estimation of doses.

3. <u>Examples of the calculation of t_o</u>

The examples given in section VI show the basis for arriving at $t_o = 4$ hrs and illustrate the method of VII a.1 above. The methods of VII a.2 and a.3 will be illustrated below:

Cedarvale, New Mexico 65.5 miles from zero point.

t_o, according to the first approximation is 65.5/18 = 3.64 hrs.

t_o, according to the second approximation is 65.5/18 + 2.8 = 6.4 hrs.

For a comparison of the effects of these two values on the integrated dose under the 1/t decay curve, take the measured value of $I_1 = 0.11$ R/hr at $t_1 = 11.25$ hrs:

First approximation: $D_1 = 5.6$ R integrated dose over 336 hrs.

Second approximation: $D_1 = 4.8$ R integrated dose over 336 hrs.

Vaughn, New Mexico, 96 miles from zero point.

t_o, in the first approximation 96/18 = 5.3 hrs.

t_o, in the second approximation 96/18 + 2.8 = 8.1 hrs.

The doses D_1 for the two cases above are:

First approximation: D_1 = 1.6 R, integrated dose over 336 hrs.

Second approximation: D_1 = 1.7 R, integrated dose over 336 hrs.

The values of t_o are lower than the evidence indicates. Hornberger found first measurable gamma radiation at 7.6 hrs and consistent readings at 8.6 hrs. No information is available as to when theintensity started to drop. It is reasonable to assume that the 2.8 hrs falling time is too small for Vaughn. It is to be increased for two reasons: the cloud extension increased and the cloud increased its altitude in the time after it passes L-8.

VII. C. The geometrical dose, Dg

Since nothing is known about the falling time at distances beyond 23 miles the geometrical dose will have to be computed on the basis that it has an intensity Ig = 2 I_o and a time interval of at least one hour. This will be under-estimating Dg because the time interval will probably be longer. On the other hand, at large distances, such as at Vaughn, the value of Ig will not be as large as 2 I_o. The over-estimation in D_1 will partly compensate for possible under-estimation in Dg.

For values of d < 17 miles it is reasonable to take Dg = 2 I_o, over a 1 hour interval. This will give an over-estimate of Dg since I hour is the known time interval at 20 miles.

VII. d. Doses computed in Table IV

There are two dose calculations in Table IV, one on the basis of 1/t the other on the $t^{-1.5}$ decay of gamma activity. Examination of Figs. 1 and 4 indicates that the maximum exponent of t was 1.5; theoretically n is 1.2 for gamma decay of fission products. It seems reasonable that the presence of neutron activated sodium, the gradual obscuration of the active particles in the soil and weather wearing should raise the apparent rate of decay. Hence it is believed that the gamma doses should lie between the integrated doses for n = 1 and 1.5. Doses are at ground level unless otherwise indicated.

Following is an outline for the procedure of calculation beginning with the intensity I_1 measured at any time t_1 after t_o :

a. Estimate t_o according to sec. VII b. t_o = (d/18 + 2.8) hrs for d ≥ 23 miles, and t_o = 0.28 (d - 7) for d 17 miles. t_o was measured and found to be 4 hours for d = 20 ± 3 miles.

b. Compute (t_1/t_o) and $(t_1/t_o)^{0.5}$.

c. Compute $I_{o1} = I_1 (t_1/t_o)$, which is the value of I_o according to the 1/t decay law.

d. The geometrical dose on the basis of 1/t decay is $2I_{o1}$. Here we assume that the time interval under the maximum is one hour.

e. The value of $D_1 = CI_{o1}t_o$, where C is the constant appropriate to t_o as shown in Fig. 6.

f. The ratio $D_1/D_{1.5}$ is given by equation (6) with reference to Fig. 6 A. By means of this ratio and the value of D_1 one computes $D_{1.5}$.

g. The ratio of the geometrical doses: $D_{g1.5}/D_{g1}$ is given by $(t_1/t_o)^{0.5}$ which is computed in (b) above. Hence with the value of $D_1 = 2I_{01}$ one computes $D_{g1.5}$.

h. The total doses for the two decay laws are then (D_{g1} D_1) and ($D_{g1.5} + D_{1.5}$) roentgens integrated over 336 hours after t_o.

Estimates of the concentration of gamma (1 Mev) active material on the ground at t_o are made for the two cases n = 1 and n = 1.5. For the 1/t decay the concentration is given by: 19 I_{01} microcuries/cm^2 and for the $1/t^{1.5}$ decay it is 9.5 $I_{01.5}$ microcuries/cm^2, where $I_{01.5}$ can be replaced by $D_{g1.5}$ because the time interval is $D_{g1.5}$ is one hour.

The doses computed in Table IV are conservative in that they over-estimate doses because the value of t_o is based on a cloud velocity of 18 mph. The exceptions are the cases where t_o was determined directly along with I_o as at Bingham and L-8.

 TABLE II Sheet 1

Location in New Mexico	d Distance in mi. from zero	I_1 Measured gamma roentgens per hr	t_1 Time after shot in hrs.	t_0 Time after shot in hrs.	t_1/t_0	$(t_1/t_0)^{\frac{1}{2}}$	I_{01} Initial intensity according to 1/t decay law	c Characteristic constant from Fig. 6	$cI_{01}t_0$ Integrated 1/t dose = I_1	$D_1/D_{1.5}$ Ratio of integrated doses	$D_{1.5}$ Integrated dose according to $t^{-1.5}$ decay	D_{g1} Geom. dose according to 1/t decay	$D_{g1.5}$ Geom. dose according to $t^{-1.5}$ decay	$D_{g1}+D_1$ Total dose according to 1/t decay	$D_{g1.5}+D_{1.5}$ Total dose according to $t^{-1.5}$ decay	Gamma microcuries per cm² on ground at time = t_0: 1/t decay $= 19\,I_{01}$	Gamma microcuries per cm² on ground at time = t_0: $t^{-1.5}$ decay $= 4.5\,I_{g1.5}$	Monitor
Adobe	17	1.5	4.87	4.0	1.22	1.10	1.83	4.44	32.45	2.01	16.14	3.65	4.03	36.10	20.18	34.71	38.32	Leonard
" (2)	17	6.5	3.3	4.0	.83	.91	5.36	4.44	95.23	2.45	38.87	10.72	9.74	105.95	48.61	101.88	92.50	"
Albuquerque (1)	95	.001	28.9	8.1	3.57	1.89	.0036	3.73	.11	.98	.11	.0071	.013	.12	.12	.068	.13	Hornberger
Aurora	116	.003	54.6	9.2	5.93	2.44	.018	3.61	.59	.74	.80	.036	.087	.63	.89	.34	.82	-
Barton	98.5	.001	29.2	8.3	3.52	1.88	.0035	3.71	.11	.98	.11	.0070	.013	.12	.12	.067	.13	-
Bingham (3)	17	1.5	4.86	4	1.21	1.10	1.82	4.44	32.36	2.01	16.10	3.64	4.02	36.0	20.12	34.62	38.15	Leonard
"	17	.08	31.75	4	7.94	2.82	.63	4.44	11.28	.79	14.28	1.27	3.58	12.55	17.85	12.07	33.99	Barnell
Canoncito	136	.0002	59.5	10.4	5.72	2.39	.0011	3.49	.04	.73	.057	.0023	.0055	.044	.062	.022	.052	Hoffman
Carthage	17	.03	38.5	4	9.63	3.10	.29	4.44	5.13	.72	7.13	.58	1.79	5.71	8.92	5.49	17.03	[illegible]
"	16.5	.01	32.3	4	8.07	2.84	.081	4.44	1.43	.70	2.05	.16	.46	1.60	2.51	1.53	4.36	Burnett
"	17	.003	11.8	4	2.95	1.72	.0088	4.44	.16	1.29	.12	.018	.03	.17	.15	.17	.29	Anderson
" (4)	17	.11	3.0	4	.75	.87	.083	4.44	1.47	2.56	.57	.16	.14	1.63	.71	1.57	1.36	[illegible]
Claunch (5)	42	.18	30.7	5.1	6.02	2.45	1.08	4.2	23.22	.86	27.0	2.17	5.32	25.30	32.32	20.60	50.54	Barnett
"	42	.19	38.3	5.1	7.51	2.74	1.43	4.2	30.57	.77	39.70	2.85	7.82	33.42	47.52	27.11	74.29	[illegible]
Carrizozo (6)	34	.0003	10.5	4.7	2.23	1.49	.00067	4.28	.013	1.44	.0094	.0013	.002	.015	.011	.013	.019	[illegible]
"	34	0	29	4.7	6.17	2.48	0	4.28	0	.86	0	0	0	0	0	0	0	Jorgensen
Clines Corner	120	.003	29.8	9.5	3.14	1.77	.0094	3.5	.31	1.01	.31	.019	.033	.33	.343	.18	.32	Hornberger
"	120	.002	30.5	9.5	3.21	1.79	.0064	3.5	.21	.99	.21	.013	[illegible]	[illegible]	.24	.12	.22	"

(1) 11 miles East of Albuquerque at Carne
(2) $t_1 < t_0$, integrated doses are too high
(3) 4 miles west of Bingham on highway 380.
(4) 1/4 mile west on [illegible] note $t_1 < t_0$.
(5) $t_1 < t_0$
(6) Activity did not appear at Carrizozo before 10 hrs. hence t_0 should be 10 hrs.

Location in New Mexico	d	I_1	t_1	t_0	t_1/t_0	$[t_1/t_0]^{1/2}$	I_{01}	c	$cI_{01}t_0$	$I_1/I_{1.5}$	$I_{1.5}$	I_{g1}	$I_{g1.5}$	$I_{g1}+I_1$	$I_{g1.5}+I_{1.5}$	E r/cm² on grd. at time = t_0 (1/t decay)	E r/cm² on grd. at time = t_0 ($t^{-1.5}$ decay)	Monitor
Corona	64	.02	29.6	6.3	4.70	2.17	.094	3.9	2.31	.91	2.54	.19	.41	2.50	2.95	1.79	3.87	Barnett
Cedarvale	65.5	.11	11.25	6.4	1.76	1.33	.19	3.9	4.82	1.50	3.21	.39	.51	5.20	3.72	3.67	4.86	"
Chavez	120	.0015	30.7	9.5	3.23	1.80	.0049	3.6	.17	.99	.17	.0097	.017	.18	.19	.092	.17	Greene
Dilia	142	.006	34.7	10.7	3.24	1.80	.019	3.44	.72	.96	.75	.039	.07	.76	.82	.37	.67	Hornberger
Duran	83	.07	28.9	7.4	3.91	1.98	.27	3.8	7.68	.96	8.0	.55	1.08	8.22	9.08	5.19	10.25	Barnett
Encino	87	.024	56.3	7.7	7.31	2.70	.17	3.8	5.12	.69	7.42	.35	.95	5.47	8.37	3.33	8.99	Hornberger
" (At RR Depot)	89	.06	10.4	7.7	1.35	1.16	.081	3.8	2.37	1.63	1.46	.16	.19	2.53	1.64	1.54	1.79	"
"	89	.65	13.4	7.7	1.74	1.32	.087	3.8	2.55	1.43	1.78	.17	.23	2.72	2.01	1.65	2.18	Barnett
Espanola	160	.0001	61.4	11.7	5.25	2.29	.00053	3.4	.021	.73	.029	.0011	.0024	.022	.031	.01	.023	Hoffman
Gran Quivira	46	.035	36.5	5.4	6.76	2.60	.24	4.15	5.31	.79	6.72	.47	1.23	5.79	7.95	4.50	11.7	Allen, Humphries
" "	46	.005	150	5.4	27.78	5.27	.14	4.15	3.11	.39	7.99	.28	1.46	3.39	9.45	2.64	13.42	" "
[illegible]	133	.0002	58.9	10.2	5.77	2.40	.0012	3.5	.041	.73	.057	.0023	.0056	.044	.062	.022	.053	Hoffman
Las Vegas	140	.001	35.5	10.6	3.35	1.83	.0033	3.47	.12	.95	.13	.0067	.012	.13	.14	.064	.12	Hornberger
Long Horn Ranch	40	.001	29.6	5.0	5.92	2.43	.0059	4.2	.12	.88	.14	.012	.029	.14	.17	.11	.27	"
Lucy	76	.01	12.8	7	1.83	1.35	.018	3.89	.50	1.44	.35	.037	.049	.53	.39	.35	.47	Barnett
Moriarty	94	.001	24.5	8	3.69	1.92	.0037	3.74	.11	.97	.11	.0074	.014	.12	.13	.07	.13	Hornberger
Monte Prieto	30	.19	32	4.5	8.00	2.83	1.52	4.3	29.41	.77	38.20	3.04	8.60	32.45	46.79	28.88	81.67	Barnett
Negra	86	.04	13.2	7.6	1.74	1.32	.069	3.8	2.01	1.44	1.39	.14	.18	2.15	1.57	1.32	1.74	"
Palma	50	.001	30.7	5.6	5.48	2.34	.0055	4.1	.13	.86	.15	.011	.026	.14	.17	.10	.25	Hornberger
Pojoaque	160	.0001	53.4	11.7	4.56	2.14	.00046	3.3	.018	.79	.022	.00091	.0019	.018	.024	.0087	.019	Hoffman
Progreso	66	0	12.5	6.5	1.92	1.39	0	3.95	0	1.42	0	0	0	0	0	0	0	Barnett
Ramon	98	.0011	321	8.2	39.15	6.26	.043	3.72	1.31	.30	4.38	.086	.54	1.40	4.92	.82	5.12	Greene

Table IV Sheet 2

Location in New Mexico	d	I_1	t_1	t_0	t_1/t_0	$(t_1/t_0)^{\frac{1}{2}}$	I_{01}	c	$C I_0 t_0$	$D_1/I_{1.5}$	$I_{1.5}$	I_{g1}	$I_{g1.5}$	$I_{g1}+D_1$	$I_{g.5}+I_{1.5}$	µc/cm² on grd at time t_0: $t^{-1.2}$ decay	µc/cm² on grd at time t_0: $t^{-1.5}$ decay	Monitor
Roswell	125	.0001	29	9.7	2.99	1.73	.0015	3.57	.052	1.02	.051	.003	.0052	.055	.056	.029	.049	Greene
Roswell	154	.0005	36.4	11.3	3.22	1.79	.0016	3.4	.062	.95	.065	.0032	.0058	.065	.071	.031	.055	Hornberger
"	132	.0002	56.1	10.1	5.55	2.36	.0011	3.51	.039	.74	.053	.0022	.0052	.042	.058	.021	.050	Hoffman
San Antonio	26	.003	11.5	4.2	2.74	1.66	.0082	4.4	.15	1.33	.11	.016	.027	.17	.14	.16	.26	Leonard
San Marcial	30	.005	30	4.5	6.67	2.58	.033	4.3	.65	.84	.77	.067	.17	.71	.94	.63	1.63	"
Santa Rosa	136	.005	31.6	10.3	3.07	1.75	.015	3.49	.55	1.00	.55	.031	.054	.58	.60	.24	.51	Hornberger
" ditto	98	.001	29.1	8.2	3.55	1.88	.0035	3.72	.11	.99	.11	.0071	.013	.11	.12	.067	.13	"
Socorro	55	0	11															Jorgenson
Sokay	[illegible]	.0001	57.6	4	14.40	3.79	.0014	4.44	.026	.57	.043	.0029	.011	.028	.054	.027	.10	Leonard
"	[illegible]	0	10	4	2.5	1.58	0	4.44	0	1.4	0	0	0	0	0	0	0	Jorgenson
Torrance	10.3	.05	29.4	6.7	4.39	2.09	.22	3.9	5.72	.93	6.15	.44	.92	6.16	7.07	4.16	8.72	Barnett
Vaughn	76	.04	9.8	8.1	1.21	1.10	.046	3.73	1.46	1.71	.85	.097	.11	1.56	.96	.92	1.01	Greene
"	76	.025	13.8	8.1	1.70	1.31	.043	3.73	1.24	1.44	.89	.085	.11	1.37	1.01	.81	1.05	Barnett
"	76	.025	28.5	8.1	3.52	1.88	.088	3.73	2.46	.97	2.69	.18	.33	2.83	3.02	1.67	3.13	"
"	76	.013	8.4	8.1	1.10	1.05	.02	3.73	.60	1.80	.33	.040	.041	.64	.37	.38	.39	Greene
"	76	.012	8.1	8.1	1.01	1.04	.013	3.73	.39	1.81	.21	.026	.027	.42	.24	.25	.25	Hornberger
Villanueva	126	0	54	9.8	5.51	2.35	0	3.6	0	.76	0	0	0	0	0	0	0	"
Willard	68	0	12.5	6.6	1.89	1.38	0	3.9	0	1.43	0	0	0	0	0	0	0	Barnett
"	68	0	150	6.6	22.73	4.77	0	3.9	0	.41	0	0	0	0	0	0	0	Allen, Humphries
Zamora	98	.0012	29	8.1	3.58	1.87	.0043	3.7	.13	.98	.13	.0086	.016	.14	.15	.082	.15	Hornberger
(1)(2) in or near Bingham	18	1.5	2.73	4	.73	.86	1.10	4.44	19.5	2.59	7.53	2.20	1.88	21.70	9.41	20.86	17.86	Leonard
(1) " " "	18	3.2	3.33	4	.83	.91	2.75	4.44	48.77	2.43	20.07	5.49	5.01	54.26	25.08	52.17	47.19	Hoffman

(1) on ground
(2) $t_1 < t_0$

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 Sheet 4

Location in New Mexico	d	T_1	t_1	t_0	t_1/t_0	$(t_1/t_0)^{\frac{1}{2}}$	I_{01}	c	$cI_{01}t_0$	I_1/I_{15}	I_{15}	I_{g1}	I_{g15}	$I_{g1}t_1$	[illegible]	Exposure in [illegible] at time to: 1.2 decay	Exposure at time to: $t^{-1.0}$ decay	Moniter
In or near Bingham [illegible] 4 miles east	18	1.5	4.3	4	1.20	1.09	1.80	4.44	31.97	2.02	15.83	3.60	3.94	35.57	19.77	34.20	37.45	Leonard
" " "		1.6	4.8		1.20	1.09	1.92		34.10	2.02	16.88	3.84	4.21	37.94	21.09	36.49	39.95	Hoffman
"		1.55	5.5		1.37	1.17	2.13		37.35	1.84	20.03	4.26	5.00	42.02	25.02	40.49	47.49	"
"		1.7	6.0		1.50	1.23	2.55		45.29	1.81	25.02	5.10	6.25	50.39	31.27	48.45	59.36	Levine, Langham
" 1 meter off ground		.65	6.16		1.54	1.24	1.00		17.78	1.79	9.93	2.00	2.48	19.78	12.42	19.02	23.60	Search light crew
" in car		.25	7.00		1.75	1.32	.44		7.78	1.67	4.66	.88	1.16	8.65	5.82	8.32	11.01	Barnett
" in car		.09	7.75		1.94	1.39	.17		3.09	1.59	1.94	.31	.48	3.44	2.43	3.31	4.60	"
" 4 mi east		.5	8.08		2.02	1.42	1.01		17.94	1.56	11.50	2.02	2.87	19.96	14.37	19.19	27.27	Hoffman
"		1.5	7.5		1.87	1.37	2.81		47.94	1.61	18.60	5.62	7.70	55.57	26.30	53.43	73.14	Levine, Langham
"		.5	8.5		2.12	1.46	1.06		18.86	1.52	12.41	2.12	3.10	20.99	15.51	20.18	29.42	Anderson
" meter off ground		.08	16.8		4.20	2.05	.34		5.97	1.09	5.47	.67	1.38	6.64	6.85	6.38	13.08	Search light crew
1 mi east " meter off gnd		.15	17.7		4.43	2.10	.66		11.79	1.06	11.13	1.33	2.79	13.12	13.92	12.62	26.54	Barnett
"		.08	31.75		7.94	2.82	.65		11.68	.79	14.28	1.27	3.58	12.55	17.85	12.07	33.99	-
"		.08	36.2		9.05	3.01	.72		12.86	.74	17.38	1.45	4.36	14.31	21.73	13.76	41.38	Hemp. & Friedel
" 4 mi east		.15	36.3		9.07	3.01	1.36		24.17	.74	32.66	2.72	8.20	26.89	40.86	25.86	77.89	- -
" in car		.09	29.0		7.25	2.69	.65		11.58	.82	14.12	1.30	3.51	12.88	17.63	12.39	33.36	Breslau
" in car		.092	32.7		8.17	2.86	.75		13.36	.78	17.12	1.50	4.30	14.86	21.42	14.29	40.85	-
" on jeep seat		.10	32.5		8.13	2.85	.81		14.42	.78	18.49	1.62	4.63	16.05	23.12	15.43	43.97	Allen, Humph.
"		.05	50		12.50	3.54	.63		11.10	.63	17.62	1.25	4.42	12.35	22.04	11.87	41.99	Lennor
"		.043	170		42.50	6.52	1.83		32.47	.34	95.49	3.66	23.83	36.12	119.32	34.54	226.41	"
" on jeep seat		.02	105		26.25	5.12	.52		9.32	.43	21.68	1.05	5.38	10.37	27.06	9.97	51.10	Allen, Watts
" on jeep seat		.015	144		36.0	6.00	.54		9.54	.37	25.92	1.08	6.48	10.67	32.40	10.26	61.56	Allen, Humph.
(1) Ranch with windmill, just [illegible] mi W of White Store	16	3.[illegible]	5.[illegible]		1.27	1.13	4.21		74.73	1.69	44.32	8.42	9.50	83.15	53.72	79.95	90.27	Hoffman

(1) On north side of road 380

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Table IV Sheet 5

Location in New Mexico (Ranches & locations near Bingham)	d	I_1	t_1	t_o	t_1/t_o	$[t_1/t_o]^{1/2}$	I_{01}	C	$C I_{01} t_o$	$D_1/D_{1.5}$	$D_{1.5}$	D_{g1}	$D_{g1.5}$	$D_{g1}+L$	$D_{g1.5}+L_{1.5}$	r uc/c r/angrd at time = t_o, 1/t decay	r at time = t_o, $t^{-1.5}$ decay	Monitor
(1) Sec. ranch west of Wh. Store on road 380	16	3.2	5.2	4	1.30	1.14	4.16	4.44	73.88	1.69	44.72	8.32	4.49	82.20	54.20	79.04	90.11	Hoffman
Ranch 0.5 mi E of Bingham on road 380	17	1.3	5.4	4	1.35	1.16	1.74	4.44	31.17	1.90	16.41	3.51	4.08	34.68	20.48	33.35	38.75	"
3 mi E of Bingham on road 161; on ground	18	0.9	8	4	2.00	1.41	1.80	4.44	31.97	1.52	21.03	3.60	5.09	35.57	26.12	34.20	48.35	"
3 mi E of Bingham on road 161; 1 meter off gnd.	18	0.5	8	4	2.00	1.41	1.00	4.44	17.76	1.52	11.68	2.00	2.83	19.76	14.51	19.00	[illegible]	"
T. R. Coker Ranch – 300 yards east	23	.27	9	4	2.25	1.50	.61	4.44	10.80	1.48	7.30	1.22	1.82	12.01	9.12	11.55	17.33	"
at T. R. Coker Ranch	23	.22	9.2	4	2.30	1.52	.51	4.44	8.97	1.46	6.14	1.01	1.53	9.98	7.68	9.61	14.58	"
T. R. Coker Ranch – 300 yards west	23	.26	9.3	4	2.33	1.53	.60	4.44	10.73	1.45	7.40	1.21	1.84	11.93	9.24	11.48	17.50	"
W. Lucero Ranch	22.5	.24	9.4	4	2.35	1.53	.56	4.44	10.02	1.44	6.96	1.15	1.73	11.15	8.69	10.72	16.42	"
Hennoming (Bursum) Ranch	12.5	.45	3.2	1.5	2.13	1.46	.96	5.42	7.81	1.86	4.20	1.92	2.80	9.73	7.00	18.24	26.63	Levine, Langham
1/2 mi S of Ranch	12	.80	4.5	1.4	3.21	1.79	2.57	5.5	19.80	1.53	12.94	5.14	9.22	24.94	22.16	48.85	87.59	" "
White Store (1) (2)	15	.10	33.5	4	8.37	2.89	.84	4.44	14.88	.64	23.25	1.68	4.85	16.56	28.11	15.92	46.07	Allen, Humph.
"	15	2.5	5.0	4	1.25	1.12	3.13	4.44	55.50	1.68	33.04	6.25	6.99	61.75	40.02	59.37	66.39	Leonard
" , 1 mi east of	15	1.6	8.1	4	2.03	1.42	3.24	4.44	57.54	1.32	43.59	6.48	9.22	64.02	52.81	61.56	87.60	Anderson
"	15	.2	56	4	14.0	3.74	2.80	4.44	49.73	.50	99.46	5.60	20.95	55.33	122.41	53.20	199.06	Breslan
"	15	.15	29	4	7.25	2.69	1.09	4.44	19.32	.69	28.00	2.18	5.86	21.50	33.86	20.67	55.67	"
"	15	2.8	8	4	2.00	1.41	5.60	4.44	99.46	1.32	75.35	11.2	15.84	110.66	91.18	106.40	150.45	Levine, Langham
"	15	.25	17	4	4.25	2.06	1.06	4.44	18.86	.90	20.96	2.12	4.38	20.99	25.34	20.18	41.61	Search light crew
Arroya, 2 mi due S of Bingham	15	.068	53.6	2.2	24.36	4.94	1.66	5.04	18.37	.51	36.03	3.31	16.36	21.69	52.39	31.48	155.43	Lerner
Road junction, 4 mi due S of Bingham	13	.11	54	1.7	31.77	5.64	3.49	5.3	31.48	.46	68.44	6.99	39.38	38.47	107.82	66.39	374.15	"
N. H. Wrye Ranch on rd 1 mi S of McDougal	22	.20	5.2	4	1.30	1.14	.26	4.44	4.62	1.94	2.38	.52	.59	5.14	2.97	4.94	5.63	Levine, Langham
On road 1 mi S of McDougal	22.5	.50	5.0	4	1.25	1.12	.63	4.44	11.10	1.99	5.58	1.25	1.40	12.35	6.98	11.87	13.28	" "
Search light Stat. L-8	19.5	1.0	4	4	1.00	1.00	1.00	4.44	17.76	2.21	8.04	2.00	2.00	19.76	10.04	19.00	19.00	Blair, Kupferb.
Fite's farm & rd 161 back to Broadway	14	0	29	2	14.50	3.81	0	5.13	0	.60	0	0	0	0	0	0	0	Hageman

(1) see Text sec VI.1. for discussion of white store doses.
(2) t_o = 4 hrs as observed. If calculated would be 2 hrs.

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VIII. Particle Sizes and Air Concentrations of Radioactive Material

(a) Particle Sizes. The evidence available leads to the conclusion that the sand particles which fell within the first 40 miles of the swath laid down by the cloud could not be less than 50 microns in diameter, and probably not less than 75 microns. The actual cloud of dust which rose from the shot was not a clearly defined puff but rather a continuous column which extended upward from 6000 feet. The lower limit of 6000 ft. is selected for two reasons:

(1) There must have been a lower limit to its height because no radioactivity in health hazard quantities was found within 12 miles of zero. In November there was found evidence that at 12 miles there may have been a hot spot near Julian Tank because cows that drank there had received beta ray burns. The few scattered physical measurements do not support this idea: they indicate a uniform very low intensity of radiation. It is possible, however, that a hot spot existed somewhere among the Oscuro Mountains.

(2) The lowest cloud material was seen by Hoffman and his monitors floating over the Oscura Mountains in a northeast direction toward Chupadera Mesa. At 8 AM this lowest mass took on the appearance of a long brown cloud 20 miles in extent along the eastern horizon as seen from Carthage on road 380. A third argument should be added here which is based on subjective judgement, namely, that the blue glow associated with the heavy ionization from the radioactive fission products was seen to be confined to the region 12,000 ft. and upward at about 1 minute after the shot. This supports the idea that the major fraction of all activity went up to at least 12,000 ft. It also supports the finding that no large amount of activity was precipitated within 12 miles of zero.

At Searchlight Station L-8 measurable activity of gamma radiation

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appeared at 1.2 hours and continued rising until 3 hours. In order to estimate the particle sizes that fell from these known times, we refer to Table V giving particle diameters and falling times. For altitudes up to 12,000 feet we use the falling times in the first column (1) to estimate particle size; for altitudes greater than 12,000 feet we use column (2). If the particles at L-8 fell from 6,000 feet they were of the order of 75 microns and greater in diameter. From 12,000 feet they were about 110 microns in diameter, and so on. The observers at L-8 associated the appearance of gamma radiation with the high altitude cloud at 50,000 feet. If this is the case, then the particles were of the order of 150 microns and greater. It is likely that large particles from all altitudes contributed. But the evidence is that none of the particles could have been smaller than 50 microns and probably not less than 75 microns.

The size of particles at L-8 is representative of the sizes that fell over the Chupadera Mesa where the highest gamma ray intensities were recorded. The swath of high activity is estimated to be about 15 miles long. If the particles had a northeast component of velocity of 13 mph. this would mean about one hour's difference in time along the swath. Referring to Table V, it is seen that at 110 microns one hour increase in time takes the particle size from 1.08 to 2.08 hours or about 85 microns.

Note by Dr. Louis H. Hempelmann:

Information available in the medical literatures indicates that few dust particles larger than 10 microns reach the alveolar air sacs, the only part of the lung where they are likely to remain for more than a few hours. (Reference: F. J. Wampler, "Industrial Medicine," Chapt.XXII, p. 348, Williams and Wilkins, 1943.) Most particles larger than 10 microns are deposited on the "mucous sheet" - a continuous blanket of mucous extending from bronchioles to larynx - and are carried out of the lungs with the mucous into the esophagus. Such particles should be considered as ingested rather than inhaled. It is quite probable that very large dust particles of the type mentioned above are trapped chiefly in the nasopharynx and are then transferred to the gastro-intestinal tract.

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b) Air Concentrations and Inhalation Tolerances

In order to estimate the concentration of activity in the air during the precipitation of the active dust, it is necessary to know how thick the cloud trail was. An examination of Fig. 3 shows that at 20 miles from zero the build up time of activity was 1.5 hours. For conservative purposes of calculation we take it to be 1 hour. For particles 100 microns in diameter (the larger the diameter, the more conservative our estimate) the distance of fall in our hour is 2.7×10^5 cm.

If there are 19 microcuries of gamma (1 Mev.) activity per cm^2 per roentgen per hour reading on the ground we can compute the concentration in the air before the 19 microcuries were completely precipitated =

$$19 / 2.7 \times 10^5 = 7 \times 10^{-5} \mu c/cc \text{ of air } /R/hr$$

(1 Mev gammas)

The total fission products present for each gamma curie is 1/.79 = 1.26. Hence we get total fission products:

0.078 μc/liter air/R/hr on ground.

For tolerance concentrations we refer to the Met. Lab. Hdb. Ch. XII, Table 3 where the tolerances for mixed fission products are given as -

94×10^{-3} μc/liter air for 8 hr day, one day only

0.26×10^{-6} μc/liter air for 8 hr day, continuously.

For the case under consideration we use tolerance figure for the 8 hr. day, one day, only, it being assumed that the cloud material settled within the day, particularly in the region of the Chupadera Mesa. It is possible to assume that since theknown measurements at L-8 indicated precipitation to be completed at 4 hours after the shot, the active material was in the air for at most 4 hrs. and that the tolerance concentration of .094 μc/L for 8 hrs. could be doubled. However, in the interests of conservative estimation we will use the figure

.094 μc/L. The gamma roentgens reading on the ground corresponding to the concentration of tolerance for mixed fission products becomes:

$$(0.078)\ (0.094) \cong 0.83\ \text{R/hr. gammas on ground.}$$

According to this result the places which had 7 R/hr at t_o had had a concentration of fission products in the air which was $7/.83 \cong 8.4$ times tolerance for a single dose. While this may seem excessive, there are two aspects to remember: (1) The calculation is the most conservative possible and (2) the large particle sizes as described in (a) above prevent this material from being breathed into the alveolar sacs.

c) Ingestion of Cloud Materials

As was pointed out in the preceding section the inhalation of cloud materials is an ingestion problem since the materials are transferred from the mucous lining of the trachea to the gastro-intestinal tract. It turns out that the amounts ingested are considerably less than the stated tolerances for mixed fission products. Referring to the concentration found above 0.078 μc/liter air/ R /hr on the ground and assuming 8000 liters air inhaled per 8 hour day, one gets (on assuming 100% retention in lungs) 0.624 mc. retained per R/hr on ground. For an intensity of 7 R/hr., for 4 hours, one has 2.2 mc. ingested. A tolerance dose for one dose only as quoted in the Met. Lab. Hdb., Ch. XII, Table 2, is 14.6 mc. We conclude that for the most conservative case the amounts of active material ingested were of the order of, or less than, tolerance for one dose only.

This estimate is supported by the lack of active materials in cows which grazed on ranges on which sufficient materials fell to produce beta burns on the backs of the cows. Apparently even under these conditions, amounts of active material failed to be ingested and become lodged in tissues and bones.

Table 7

Particle Size and Falling Times

Diameter Particle Size	(1) Time to fall 12,000 ft.	(2) Time to fall from 48,000 to 36,000 ft.
840 microns	0.110 hours	0.091 hours
500	0.139	0.116
250	0.208	0.173
200	0.325	0.271
149	0.585	0.488
110	1.08	0.90
74	2.37	1.97
60	3.61	3.01
33	12.0	10
22.6	25.5	21.2
16.0	50.8	42
11.3	102	85
8.0	204	170
5.65	408	340

(1) Computed from $v = 0.00592\ D^2P$ feet/min. From Hirschfelder and Magee, memo of June 16, 1945 to Bainbridge. See LAMS 277, p. 5. P = density, D = diameter of particle in microns (10^{-4}cm)

(2) Velocity of fall corrected for change of air viscosity with altitude. Average velocity is 20% higher than that calculated by Hirschfelder and Magee for 48,000 ft. altitude.

VIII d) Alpha Active Substances

At no inhabited locality or any place farther than 10 mi from the crater was there found an alpha particle count which could be easily distinguished from the natural background. The counts ranged from 2 to 7 counts per minute. This order of magnitude in counting rate is expected from the known amounts of fission products and Plutonium. (For details see Anderson and Sugarman's report on fission products analysis, LA 356). Taking 6×10^{-12} gms. Pu per cm^2 as the most contaminated case, the total alphas emitted per minute will be $6 \times 0.14 = 0.84$ cpm/cm^2 or 0.42 cpm/cm^2/2π solid angle. The counter window area was 20 cm^2 in area, hence a count of $0.42 \times 20 = 8.4$ cpm would be expected exclusive of corrections for absorption in the counter window and obscuration of the Pu by dust particles and geometry.

While it is possible that a localised "hot spot" might have occurred, none was found, and the actual contamination indicated a uniform distribution at a concentration which is considered not to constitute a health hazard.

[redacted]

IX Distribution of Fission Products Over the Countryside

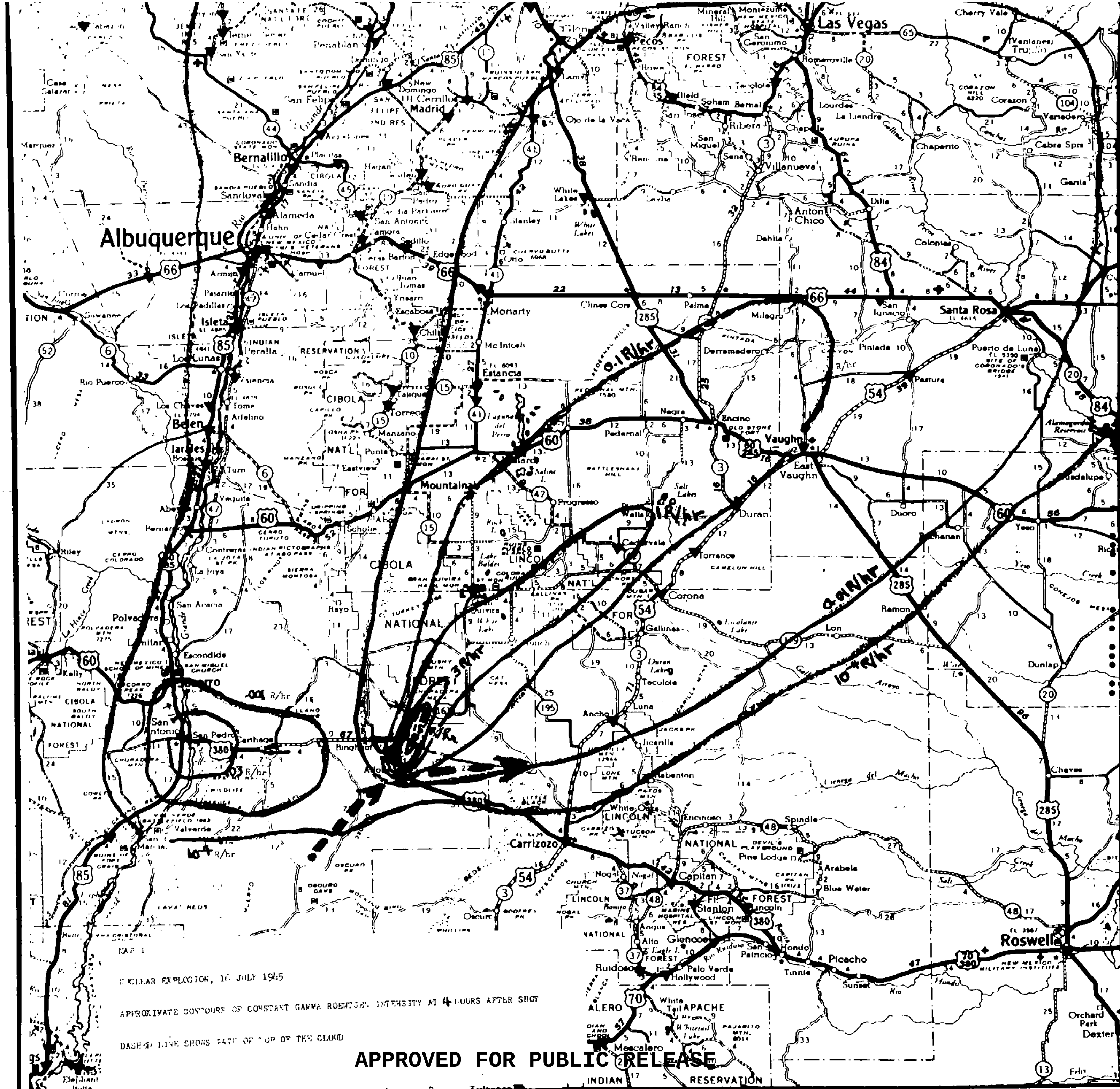
(a) The distribution map

The accompanying Map I shows the distribution of fission products material as measured by the gamma radiations on the ground. The intensities shown are those for time t - 4 hours, the field readings being used to compute the intensity at that time on the basis of the 1/t decay for gammas. The essential features of the distribution are as follows:

1. There was a swath of high intensity approximately 12 miles long and 1 mile wide whose southern end started at about 3 miles north of White Store (on road 380). The swath extended north crossing the N.M. road 161-46. While this swath is shown as a fairly well defined region on the map, the measurements show it to have been highly irregular in actual area and intensity. This is to be expected from cloud materials falling from altitudes greater than 6000 feet.

2. The entire distribution is fan shaped with the central axis of the fan pointing north slightly east. This arose from the fact that the path of the cloud (as indicated by the dashed arrows) was northward. When last seen the cloud was moving due east. The higher portions were known to have moved north and slightly east. The lower level winds were toward north west. Hence the cloud materials moving north and east were swept westward on reaching low altitudes. For instance, at Carrizozo the gamma intensity was zero until 4 PM of 16 July. At 3:26 PM the wind abruptly rose from the east and brought some active particles with it. This activity reached its maximum after about 1 hr., maintained a steady value for about 12 hours and then started to decay. For this reason the contours do not include Carrizozo it being assumed that the activity was due to very small particles which were easily windborne and not likely to settle definitely as precipitated activity.

3. There was a definite "skip" distance between zero



NUCLEAR EXPLOSION, 16 JULY 1945

APPROXIMATE CONTOURS OF CONSTANT GAMMA ROENTGEN INTENSITY AT 4 HOURS AFTER SHOT

DASHED LINE SHOWS PATH OF TOP OF THE CLOUD

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Map I

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point and regions of significant activity. The contour shows a distance of about 22 miles north to the hot swath described in (1) above, and about 24 miles to the active areas west of zero around San Antonio and San Marcial. It should be noted that there may possibly have been very small areas of great activity in the socalled skip interval. None were found, for instance, in the region north of zero by monitors moving along the network of roads west and north of the Oscura Mts.

4. The isolated regions of activity at San Antonio, west of zero were due to the low ground winds which were fast, of the order 20-25 mph and apparently carried part of the explosion column west slightly north. The activities in these regions were very low and did not constitute any radiation hazard.

5. The major area of northern New Mexico was covered by very low activity which is attributed to smaller particles falling out at times greater than 10 hrs. Monitoring trips throughout the region showed a remarkable uniformity of gamma intensity over the terrain. Gamma activities were measurable at Trinidad, Colorado after 13 days (Fulbright and Mallinkordt, monitors). It is assumed that the small particles (1 micron or less) fell very slowly and particularly during the day were kept in a state of suspended animation by "thermals".

IX (b) Total activity precipitated

An integration of the isodose contours shown in the map of contours leads to the result that 50% of all the available activity fell to the ground after two weeks. The rate at which this fell is not known. This estimate is based on the efficiency reported by Anderson and Sugarman (LA-356) according to which 2.95×10^{24} total fissions occurred. According to Weisskopf's data (LA-250 fig. 5) this leads to 1.11×10^{15} micro-curies of gammas at 4 hrs time. When the concentration of material on the ground is 19 gamma micro-curies per cm^2 the roentgen reading is 1 R/hr intensity. It turns out that at 4 hrs the available gamma curies would have covered an area of 2250 sq. miles to give a uniform intensity over that area of 1 R/hr. Thus the hot swath described above in IX a.1 had an area of 12 sq. mi and an intensity of 15 R/hr at 4 hrs. This activity corresponds to about 7% of the total. It is known that this swath was precipitated by the end of 6 hrs.

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Section X: BETA DOSAGE IN TISSUE FROM CLOUD MATERIALS

The material in this section was completed as a separate report December 15, 1945. It is included here as a part of the general monitoring report for purposes of unity. However, it should be remembered that the notation of equations is that of a separate report and has no continuity with that of the other sections. Also, there is a slight repetition of material discussed in previous sections.

ABSTRACT

A computation of beta dosage arising from fission products which fell from the cloud of the nuclear explosion of 16 July 1945 is made on the following lines:

1. Since extensive gamma measurements were made in the region 18 to 40 miles from the shot, it is necessary first to compute the ratio of beta to gamma curies in fission products. This ratio permits one to estimate the beta curies/cm^2 that fell on any biological object. The ratio varies with time as $3.24\ t^{-0.03}$.

2. The measurement of gamma intensities in roentgens per hour (R/hr) are interpreted in terms of gamma curies per cm^2 on the ground. There are 19 gamma micro-curies/cm^2 per roentgen/hour.

3. An alternative estimate of the beta curies/cm^2 on ground is made from the fission products found on the ground. The fission-products assay was made chemically by Anderson and Sugarman from a dirt sample taken eight hours after and 30 miles from the shot: there were 297 beta micro-curies/cm^2 at 8 hours in the region of the Chupadera Mesa (about 30 miles northeast of zero).

4. Field measurements made 9 November corroborate the other estimates of radioactive intensities: they lead to 120 beta micro-curies/cm^2 at 8 hours in the region of the Chupadera Mesa.

5. The beta dosages in the region where 12 gamma roentgens per hour were measured at 4 hrs after the shot were as follows: 18,400 rep were delivered to the tissue surface and 1224 rep to the 2-3 mm depth below the surface by the end of 4 hrs after the shot. In the following 336 hrs there were delivered an additional 60,000 rep to the surface, and 2940 rep to the 2-3 mm depth. The total dose to the 2-3 mm depth is 4164 rep. No correction is made here for mechanical removal of fission products from the skin surface.

6. Gamma doses due to material on a cow's back are estimated and compared with the gamma doses from materials on the ground. At hot canyon where the dose due to ground materials was 106R the materials that fell on the cow's back contributed 32R making a total body radiation of 138R.

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1. Ratio of beta to gamma curies in fission products:

a. Chicago measurements are summarized by Katherine Way, CK-2737, p.31, as

$$\left.\begin{array}{l}\text{Gamma energy in Mev/sec}\\ \text{at t seconds, per fission}\end{array}\right\} = 0.79t^{-1.20} \quad (1)$$

$$\left.\begin{array}{l}\text{Betas/sec per fission at}\\ \text{t seconds, (1.3 Mev/beta)}\end{array}\right\} = 2.56t^{-1.229} \quad (2)$$

The ratio of these expressions is $3.24t^{-0.03}$, or 3.24 slowly decreasing with t.

For a detailed discussion of the decay laws for fission products see CC-3032, Wigner and Way, "Summary and Coorelation of Data on the Rate of Decay of Fission Products," June 13, 1945. We have selected (1) for the gamma decay because the field measurements of gamma decay lead to an exponent for t of -1.3 to -1.5. By taking the laboratory value for the exponent as -1.2 the integrated doses over periods of time will be estimated conservatively.

2. Estimation of activity on ground from gamma roentgen measurement

Gamma ray dosage is measured by an ionization chamber whose height above the ground is 10 cm and use is made of the formula:

$$I = \phi \pi A \log_e \left(\frac{\lambda^2}{d^2}+1\right) \quad R/hr \qquad (3)$$

λ = mean free path of gammas in air

d = distance of the chamber above ground (10cm)

A = R/hr per gamma millicurie per unit solid angle

or A = R/hr/mc/cm^2 at 1 cm distance from a point source

ϕ = density of gamma active material in mc/cm^2

Formula (3) is derived on the basis that the ionization chamber is at the center of a disc of active material whose radius is λ, and is located d cm above the disc. Since the log factor varies slowly with λ we shall assume an average value $\lambda = 220$ meters for gammas in the energy interval 0.3 to 2.1 Mev. Since the actual spectrum in the field was unknown we shall have to assume that the spectra measured in pile operations gives a fair approximation to the field conditions. In Table I are relevant data taken from Met. Lab. Hdb. Chapt. XIC, 1, page 2:

TABLE I

Radiant Energy	"X" conditions % Total Watts	"W" conditions % Total Watts	Factor "A" eq (3)
2.1 Mev gamma	30	7	10.5 r/hr/mc
0.8	8	22	4
0.5	5	5	2.5
0.3	9	3	1.5
0.5 Mev avg. beta	48	63	----

"X" conditions: Metal reacted at 15 kw/ton for 30 days and allowed to decay 25 days.*

"W" conditions: Metal reacted at 2500 kw/ton for 100 days and allowed to decay 60 days.*

The weighted mean values of A for X and W conditions are respectively 7.08 and 4.7 R/hr/mc. It is assumed that the W conditions would most closely approximate the field conditions, hence the value of A = 4.7 will be used in the following calculations. The ratio of 0.5 Mev beta to 1 Mev average gamma curies in the W conditions is 2 x 6 3/37 = 3.4.

Substituting in (3) the resulting simple form is:

$$I = 105\,\phi \quad \text{roentgens/hour} \qquad (4)$$

And for a gamma intensity of 1 r/hr the concentration of gamma curies on the ground becomes:

$$\phi = 0.0095 \text{ mc/cm}^2 \text{ per roentgens/hour}$$

* Met. Lab. Project Hdbk. Chapt. XI, C1 p.2.

The evidence indicates that there is a factor of 2 by which the gamma roentgens should be multiplied to take into account obscuration of the gamma active material. This obscuration is assumed to be due to cracks in ground surface and irregularities of terrain. Taking this obscuration factor into account and assuming according to (1) and (2) that there are $3.2t^{-0.03}$ for each gamma curie one gets.

$$\phi = .019 \text{ gamma mc/cm}^2 \text{ per gamma roentgen/hour} \quad (5)$$

and

$$Q = \frac{.019 \times 3.24}{t^{.03}} \text{ beta mc/cm}^2 \text{ per gamma roentgen/hour} \quad (6)$$

$$Q = .061 \text{ beta mc/cm}^2 \text{ per gamma roentgens/hour at } t = 1 \text{ sec} \quad (6a)$$

The meaning of (5) and (6) is as follows: if a monitor in the field by means of a gamma roentgenometer measures one roentgen/hour when the meter chamber is 10 cm above the ground he will be in the center of a disc of radioactive fission material whose density is 19 gamma $\mu c/cm^2$. According to (6) the density of beta active material will be $(19 \times 3.24/t^{.03})$ beta $\mu c/cm^2$ where t is the time of the gamma measurement in seconds after the shot.

The assumptions underlying this method are summarized as follows: that the fission-products gamma spectrum is given approximately by the "W" condition in Table I, and that the average value of A is 4.7 R/hr/mc/unit solid angle corresponding to about 1 Mev radiation. Also, it is assumed that the average value of λ, the mean-free-path in air for the gammas under consideration, is 220 meters. The log term in (3) is not sensitive to λ's decreasing only by a factor of 2 as λ is reduced to 10 meters and increasing only 16% as λ increases to 500 meters.

The meters usedin the Trinity measurements were calibrated by the gamma rays from radium whose average energy is assumed to be 0.7 Mev.

3. Estimate of beta curies from fission products assay.

An alternative estimate of the beta curies per cm^2 on the ground can be made from the chemical assay of the fission products reported by H. L. Anderson and N. Sugarman, LA-356, 25 September 1945. An earth sample was collected at hot canyon, 30 miles from zero, at 8 hours by Wright Langham on 16 July. The gamma intensity measured at the time was about 6 roentgens per hour.

The fission assay on the dirt sample is listed in Anderson and Sugarman's report, Table VII, p. 34, as "30 mi N. airborne" sample and had 0.64×10^{12} fissions 1 gm dirt (based on Ce). By means of the fission products decay laws given by equations (1) and (2) we compute the beta and gamma curies per cm^2 on the ground at 8 hour (2.88×10^4 secs) assuming a dirt density 2.

$$\text{beta } \mu c/cm^2 = (2.56 \times 2 \times 0.64 \times 10^{12})/(3.67 \times 10^4 \times (2.88 \times 10^4)^{1.229}) = 297 \ \mu c/cm^2 \quad (7)$$

$$\text{gamma } \mu c/cm^2 = (0.79 \times 2 \times 1.28 \times 10^{12})/(3.67 \times 10^4 \times (2.88 \times 10^4)^{1.2}) = 123 \ \mu c/cm^2 \quad (7a)$$

These figures are to be compared with the estimates based on (5) and (6) which when multiplied by the 6 r/hr give 114 gamma $\mu c/cm^2$ and 366 beta $\mu c/cm^2$ respectively. It is to be noted that this estimate is based on the assumption that 3.24 beta per gamma curie exist at 8 hours. According to (1) and (2) the beta to gamma curie ratio is 2.4 at 8 hours which reduces the 366 estimate to 274 $\mu c/cm^2$. The close agreement between the gamma roentgen measurement and the chemical assay methods must be considered fortuitous in view of all the assumption on which the gamma roentgen measurement depends.

4. Measurements of 9 November 1945

Measurements made on 9 November corroborated the estimates of activity made from the July measurements. At hot canyon on the spot where 6 R/hr were recorded at 8 hours, 16 July 1945 the gamma intensity was found to be 3 milli-roentgens/hour. Referring to equation (5) the 3m R/hr corresponds to 0.057 gamma $\mu c/cm^2$ on the ground. The beta to gamma curie ratio at 9 November (10^7 secs after the shot) is 2. Hence the 3m R/hr leads to 0.11 beta $\mu c/cm^2$ on the ground.

Samples of earth taken at the same spot were counted and found to give 84,000 counts/min/4π solid angle per gram of dirt. Assuming a dirt density of 2.5 this leads to 0.1 beta $\mu c/cm^2$ on the ground which is close agreement with the gamma roentgen estimate made above.

By means of equation (2) we compute the beta intensity at 8 hours (2.88×10^4 secs) from the 9 November measurements (10^7 secs) to be 120 beta $\mu c/cm^2$ which in turn is in satisfactory agreement with the other estimates made in part 3 above. The measurements of 9 November can be expected to yield lower concentrations on account of leaching of certain of the fission products from the soil by rain, or displacement by winds.

5. Calculation of beta dosage at depth in tissue

In order to discuss the beta depth dose in tissue it is convenient to compute the energy emitted in ergs/sec and convert to rep units. The computation is $3.67 \times 10^4 \times Q \times E \times (1.6 \times 10^{-6})$ ergs/sec/cm^2, where Q is $\mu c/cm^2$, E is the beta energy in Mev which we shall assume to be 0.5 Mev as an average value for betas coming from a thick source, and 1.6×10^{-6} is the conversion factor from Mev to ergs. Referring to equation (6), the total energy emitted by a 61 beta $\mu c/cm^2$ source is $3.67 \times 10^4 \times 61 \times 0.5 \times 1.6 \times 10^{-6} =$ 1.8 ergs/sec/cm^2. If the active material is deposited on a skin surface only half this energy is delivered to tissue depth. Hence:

$$0.9 \text{ ergs/sec/cm}^2/2\pi \text{ solid angle} \qquad (7)$$

is the total energy delivered to tissue below the skin surface.

The distribution of this energy in the tissue is given by the experimentally determined absorption curves for betas in tissue as measured by Raper, Zirkle, and Barnes ("Techniques of External Irradiation with Beta Rays", CH-3098X). The depth dose rate curve is given by a pseudo-exponential form $I = I_o e^{-9.5x}$ Where I_o is dose rate at the surface of tissue and x is depth of tissue in cm. From these data we compute the following table of the fractions of the total energy incident which is absorbed in the tissue layer between X_1 and X_2 is:

$$F = (e^{-9.5x_1} - e^{-9.5x_2}) \qquad (8)$$

The maximum depth of measurable dose is 0.7 cm.

TABLE II

Tissue Layer between	F	D, average dose rate in 1 mm layer; for 1 beta μc/cm² on skin surface	D, average dose rate in 1 mm layer for 275 beta μc/cm²*
0 - 1 mm	0.633	1.1×10^{-3} rep/sec	0.302 rep/sec
1 - 2	0.218	3.6×10^{-4}	0.101
2 - 3	0.091	1.62×10^{-4}	0.0446
3 - 4	0.036	6.4×10^{-5}	0.0176
4 - 5	0.014	2.43×10^{-5}	6.6×10^{-3}
5 - 6	0.0053	9.4×10^{-6}	2.58×10^{-3}
6 - 7	0.0020	3.55×10^{-6}	9.76×10^{-4}

* Corresponding to 6 gamma R/hr measured at 8 hours around the Chupadera Mesa, northeast of Bingham, New Mexico.

The average dosage rate in the 1 mm layer is calculated as:

$$D = \frac{W \times F}{vol \times 83} \text{ reps/sec}$$

where W is the total energy delivered to the tissue and is 0.9 ergs/sec as calculated above in (7). The tissue vol is taken as 0.1 cc, tissue density ≈ 1, and 83 as the ergs/gm of tissue per rep.

The beta energy has negligible effect on the depth dose. As the beta energy varies from 0.5 to 1.55 Mev the depth dose up to 4mm does not change more than 5%. It should be noted that the significant magnitudes of depth dose extend only to 4 mm depth.

The dose rate, D, in Table II can be compared with the measurements on a P^{32} source reported by Raper, Zirkle and Barnes (loc cit). The P^{32} source was prepared by soaking a filter paper in active phosphates. The source strength was 77 $\mu c/cm^2$ for which the surface dosage rate was 0.127 rep/sec. A 1 $\mu c/cm^2$ source would give a surface dose of 1.65×10^{-3} rep/sec. At 2 mm the depth dose rate is 13% of surface dose, hence the dose rate at 2 mm is 2.14×10^{-4} rep/sec. This compares with the 1.62×10^{-4} rep/sec in Table II for the 2 - 3 mm layer. The value from Table II is lower because it is an average value between 2 and 3 mm whereas the 2.14×10^{-4} rep/sec figure is at the 2 mm level.

In Table II are the calculated depth dose rates for 275 beta uc/cm^2 corresponding to the 6 gamma R/hr measured at 8 hours after the shot on 16 July. The 6 R/hr represents about the highest gamma intensity measured after the active cloud had settled, and is typical of the intensities over the Chupadera Mesa.

6. Calculation of integrated beta dose in tissue.

The calculation of integrated dose due to beta radiation on a tissue surface is based on the decay law given by (2). The dose will be integrated from time 4 hours after the shot because it is known that the cloud material was not settled before that time at 18 miles from zero. The pertinent case applies, for example, to cattle at 18 miles or greater on which the active fission products fell.

The general case in which the exponent of time, t, is n where n is greater than 1 leads to the following expression for integrated dose:

$$D = \frac{I_o t_o^n}{n-1}\left\{ t_o^{1-n} - (t_o + P)^{1-n} \right\} \qquad (10)$$

where t_o is the time at which the integration begins, in our case 4 hours, and P is the period of time after t_o over which the integration is made, and n = 1.229. The function D/I_o is shown in Figure 1 along with the doses D computed for the case of 275 beta $\mu c/cm^2$ on the surface using the intensity I_o at the 2 - 3 mm depth from Table II as 0.0446 rep/sec. The dose has attained 50% of its maximum possible value after 100 hours, or about 4 days.

An important contribution to the beta dose is made during the settling of the active material from the cloud. At a distance of 20 miles from zero it is known that measurable activity started at 1.5 hours (5.4×10^3 secs) and definitely started its natural decay at 4 hours (1.44×10^4 secs). We assume that the active material accumulated linearly with time on the spot as it settled from the cloud and that it decayed as $t^{-1.229}$. From these two assumptions the effective dose rate over an interval between 1.5 and 4 hours is computed as shown in Figure 2. The effective integrated dose at 2 - 3 mm for 275 $\mu c/cm^2$ as measured at 8 hours is computed from Figure 2 as 612 rep.

It should be noted that this dose of 612 rep is delivered in 2.5 hours as compared with, say, 1480 rep (Figure 1 delivered in 96 hours <u>after</u> t_o = 4 hours.

The dose on the skin surface is about 15 times that at the 2 - 3 mm level.

Two items effecting the integrated dose should be mentioned: (1) the presence of 15 hour neutron activated sodium and (2) the sticking of the precipitated cloud materials to any to any tissue surface such as a cow's back. Neither of these items will significantly change the dose received during the falling time. Both items will affect the integrated dose at long times after the precipitation is complete. In view of the apparent agreements among the different methods of estimating activities using equation (1) and (2) it is not likely that more than 50% of the gamma activity was due to sodium. No direct evidence as to the fraction of sodium or its gamma radiation is available. Concerning the question of the fission products clinging to a cowhide one has to guess. Mechanical rubbing is necessary to remove the dust from a pelt. It is known that the cloud dust sticks tenaciously because monitor's autos became heavily contaminated due to the dust sticking to the underside of the chassis and body of the cars. In the computations we have assumed that all the dust

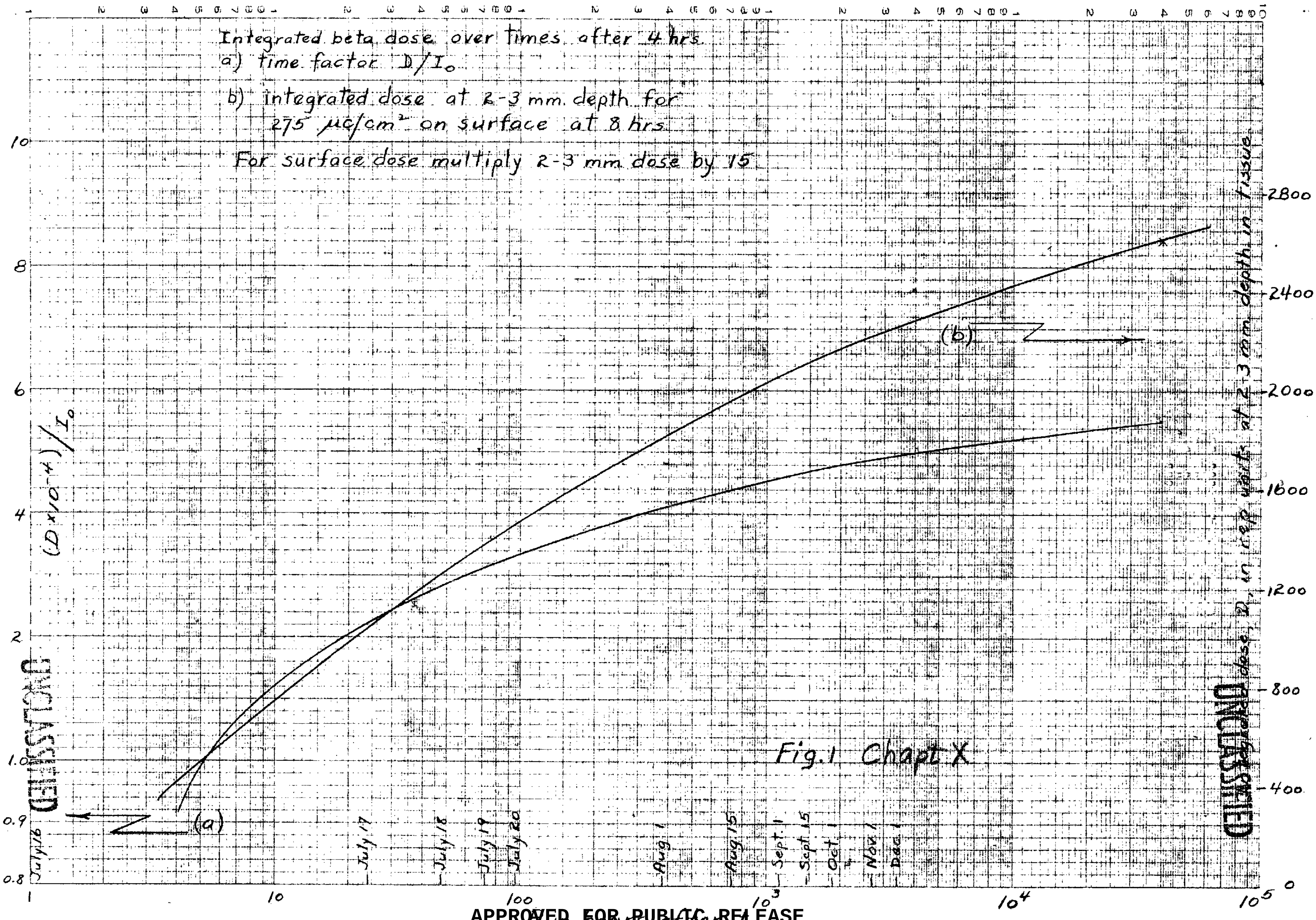

Figure 1, Chapt. X 6/-/.

Computation of beta dose integrated during falling of cloud materials from 1.5 to 4 hrs. - 645 beta $\mu c/cm^2$ have been ppt'd. by 4 hrs, decaying to 275 $\mu c/cm^2$ at 8 hrs.

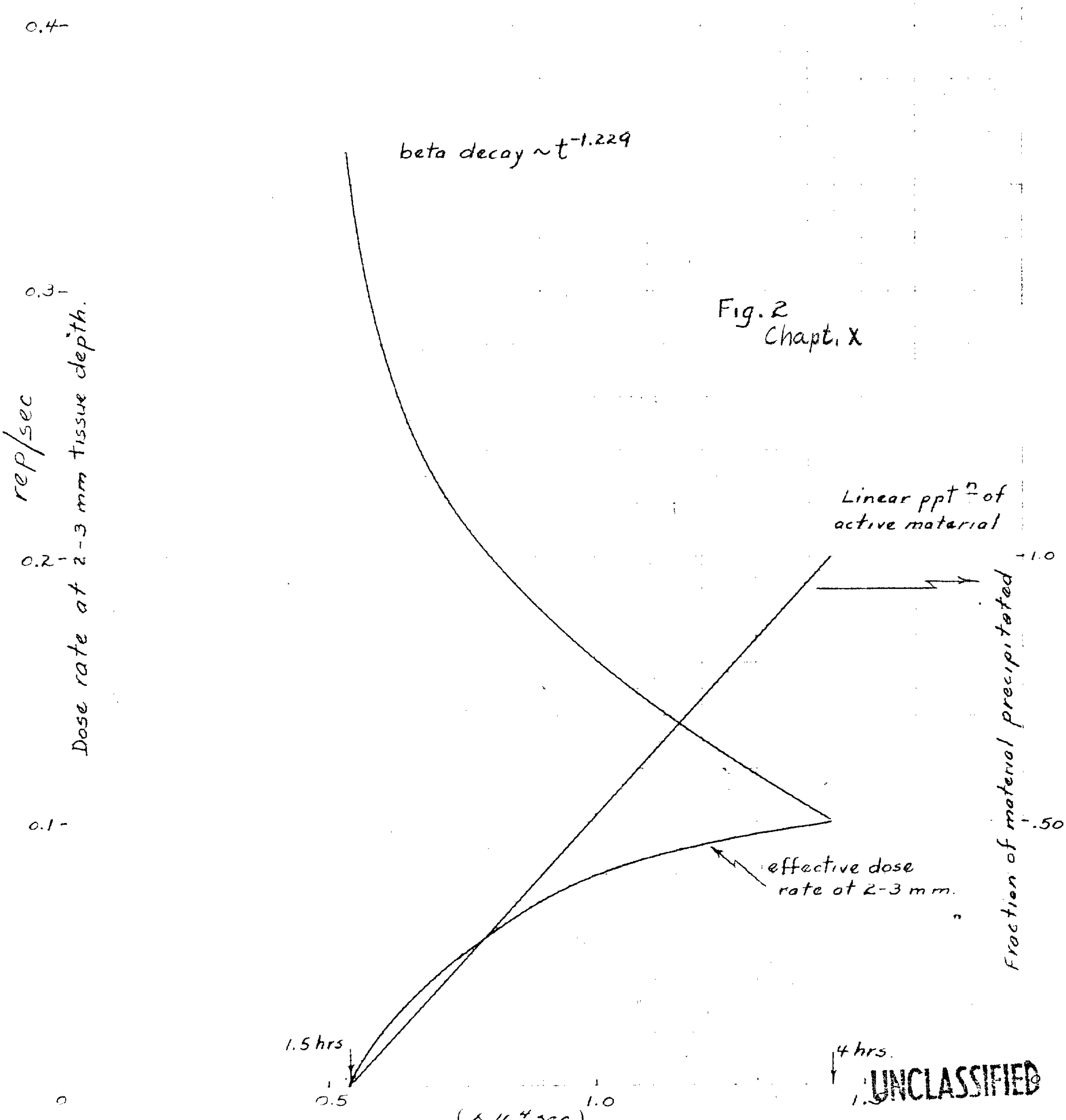

Fig. 2
Chapt. X

Figure 2, Chapt. X

lay in layers immediately on the tissue surface. The doses may have to be reduced by a factor due to the dust particles being distributed on the hairs of the cow pelt. Guesses as to the magnitude of this reduction range from 10 to 80%.

Summarising the beta doses from Figure 1 for the case of 6 gamma R/hr measured on ground at 4 hrs there were about 9200 rep delivered to the skin surface making 612 rep to the 2 - 3 mm depth during the falling of the cloud material up to 4 hours. In the following 2 weeks an additional 30,000 rep were delivered to the skin making 1470 rep to the 2 - 3 mm depth. The total dose at the 2 - 3 mm depth becomes 2000 rep. These figures are not corrected for reduction due to loss of material by mechanical rubbing or weathering from the tissue surface.

For comparison we quote the median lethal dose for external beta ray doses on mice, 4,700 rep, and for rats, 7,500 rep, (Monthly Report of Biol. Section of Research Div., Clinton Labs. Sept. 1945). A single dose of external beta radiation of 4,000 rep will induce tumors in rats (loc cit). No relevant data are available on the possible effects of beta dosage on cows or dogs.

7. <u>Gamma Ray Dosages from materials on tissue surface.</u>

(a) Following is an estimate of gamma ray dose received by a cow on which the radioactive material had precipitated. The method of calculation will aim at finding a gamma dosage rate in air at the tissue surface which will give the same rate of dosage at 1 cm below the surface as that given by the active materials located on the surface. This method is followed in order to have a dosage figure which can be compared with the dosages delivered to the cow by the active materials on the ground surrounding the cow.

Inspection of the cows showed the following two important facts concerning the gamma dosage:

1. On the <u>average</u> the regions of the cow's back affected by

beta radiation were circles whose diameters were not greater than 30 cm in diameter. On each cow there were from 5 to 8 such areas.

2. The active materials covered areas which subtended solid angles over the entire cow which were estimated to be 1/10 of 2π solid angle.

(b) We compute the gamma ray intensity at 1 cm below the skin surface by assuming the active material to be in the form of a disc 15 cm radius. For gammas the absorption coefficient in water is 0.069 cm^{-1} for $h\nu/mc^2 = 2$, which leads to a mean-free-path = 14.5 cm. Applying equation (3) where A = 4.7 R/hr/μc/unit solid angle, and ϕ = 1 $\mu c/cm^2$ we get

$$I = 0.077 \ R/hr/\mu c/cm^2 \ \text{at 1 cm depth}$$

By correcting for the 7% absorption in 1 cm of tissue we shall assume that this gamma intensity at 1 cm can be produced by I = 0.082 R/hr in air at the surface. This assumption is on the conservative side in that it over estimates the total dose delivered to the cow.

To correct for total solid angle subtended we multiply by 1/10 according to item 2 in (a) above:

$$I = 0.0082 \ R/hr/mc/cm^2$$

According to sections 3 and 4 the gamma concentrations at 8 hrs at the place where 6 R/hr ground measurements were made, was 120 gamma $\mu c/cm^2$. Assuming the gamma decay as $t^{-1.22}$ this corresponds to 280 $\mu c/cm^2$ at 4 hrs. The calculation of integrated gamma doses is made with reference to Fig. 1. Curve (a) shows that at P = 336 hrs the value of D/I_o is 4×10^4 secs. The dosage rate $I_o = 0.0082 \times 280/3600 = 6.4 \times 10^{-4}$ R/sec. Thus the integrated dose over 336 hrs after t_o = 4 hrs is

$$D = 4 \times 10^4 \times 6.4 \times 10^{-4} = 25.6 \ R$$

The dose accumulated during the falling of the cloud is found with the aid of Fig. 2 where the ordinates in rep/sec are to be changed to R/sec with the rate at 4 hrs = 6.4×10^{-4} R/sec. The integrated dose from t = 1.5 hrs to t = 4 hrs is 6 R. The sum of the doses from t = 3-6 is then 31.6 or 32 R total.

This dose can be compared with the dose due to the active material on the ground. For instance, in sec VI, 3, of the report on cloud measurements the dose for 1/t decay is given as R = 167 R, for the $t^{-1.5}$ decay as 85 R (doses at torso level) in hot canyon. For 6 R/hr referring to Fig. 1 (a) the $t^{-1.22}$ dose is 106 R. If we assume here that the $t^{-1.22}$ law is fairly representative we get a total dose for the cows of 106 R (ground radiation) plus 32 R (back radiation) making a total of 138 R.

8. Beta doses from active materials on ground

Beta doses delivered to animals or persons walking on terrain which is uniformly covered with beta active materials can be discussed under two separate headings.

Case (a) Dosage delivered to the paws or feet by materials directly in contact with the limbs.

Case (b) Dosage delivered to the leg parts higher than the pediments by betas coming from the ground.

Under case (a) the dosage delivered to persons will be negligible, except for barefoot people. Leather shoes or cow's hoofs absorb the radiation effectively, the mfp of betas having energies from 0.5 to 2 Mev in tissue-like materials being about 1 mm or less. Dogs and cats are more vulnerable to the direct contact dosage because the beta materials can get into the spaces between the toes. Also, the bottom of the paw is probably less than a millimeter thick. There is evidence to indicate that a dog at the Raitliff Farm was effected by beta radiation on his paws.

Under case (b) we refer to dosage curves taken by H. M. Parker (CH-930) "Some Physical Aspects of the Effects of Beta Radiation on Tissue," Sept; 1943, Fig. 9. We will refer to Parker's data on tuballoy for which the betas have a maximum energy E = 2.32 Mev and an energy of 0.7 Mev at the peak of the distribution curve for particles coming from a thick source. This energy range will cover the case of fission products beta materials on the ground as far as dosage to the legs is concerned. Parker shows that if the beta source is covered with 55 mgm/cm^2 of absorber the dosage in air as one moves away from a plane source decreases with a 1/e value of 20 cm. After traversing the air the particles have to penetrate shoes or clothing which we take to be equivalent to 55 mgm/cm^2 as the smallest reasonable estimate. Since 1 mm of tissue is equivalent to 110 mgm/cm^2 there remain 55 mgm/cm^2 penetrating power after 55 mgm/cm^2 have been subtracted. Part of this 55 mgm/cm^2 penetrating power is taken up by air. In the case of cows the presence of heavy hair and a thick hide on the legs precludes the possibility of any betas delivering dose to 1 mm below the hide surface. This is born out by the inspection of cows which received beta burns from materials falling on their backs. The legs showed no signs of radiation effects.

In addition to the fact that clothing is likely to be thicker than 55 mgm/cm^2 in protecting legs from beta radiation there is the further consideration that the effective beta particles must come from the ground around the leg in an area beyond a certain radius. Beta particles approaching the skin surface at a very small angle will expend their energy penetrating the upper skin surface before they reach the vulnerable lower layers. For example, if the angle of incidence is 30° the particles will have traversed 2 mm of skin by the time they have reached the 1 mm depth.

[redacted]

APPENDIX I

HEALTH INSTRUMENTATION AND CRATER ACTIVITY DECAY FOR THE JULY 16TH NUCLEAR EXPLOSION

Written and Compiled by Richard Watts

1.0 General Problem.

2.0 Instrumentation.

- 2.1 Alpha Instruments.
- 2.2 Beta-Gamma Instruments.

3.0 Number of Instruments Needed.

4.0 Distribution of the Instruments.

5.0 Calibration of the Instruments.

6.0 Results of the Shot.

7.0 Gross Activity Decay.

8.0 Conclusions.

[redacted]

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HEALTH INSTRUMENTATION AND GROSS ACTIVITY DECAY AT THE JULY 16TH NUCLEAR EXPLOSION.

1.0 General Problem.

At the request of Dr. Hempelmann the Electronics Group undertook to supply and install the instruments needed for the protection of personnel at the July 16 Nuclear Explosion.

It was recognized that considerable danger would exist, and that specialised instruments not available commercially would be needed to measure and warn of this danger.

This danger could be roughly divided into three parts: (1) Danger at the instant of explosion; (2) Danger from the radioactive cloud that would be formed; (3) Danger from residual activity to people re-entering the area where the bomb exploded.

It was not thought that any serious danger would exist at the moment of explosion. The greatest uncertainty was the amount of light and heat that would be given off. Inasmuch as the personnel would be housed in concrete shelters 10,000 yards from the site of the explosion calculations showed that it appeared extremely unlikely that radiations would reach this distance. Thus at these shelters it was not thought that any instantaneous effects from Gamma, Beta, or neutron radiations would be observed.

A greater uncertainty was the nature of and way in which the radioactive cloud would be formed and moved. If this cloud should stay low and sweep over any of the shelters very serious consequences would result. Then again the cloud might rise high in the air and settle upon a town thirty or more miles away.

Another serious problem was thought to be the alpha activity of that part of the plutonium which was not used in the explosion. Because of the great toxcity of this material, danger from inhalation would exist if it was distributed in the air.

The danger from the residual activity would be largely to those people who would enter the active area after the blast. This danger would consist of total body gamma and beta irradiation and inhalation of active material.

2.0 Instrumentation.

2.1 Alpha Instruments. A universal instrument could not be built that would fill all the varied requirements. In fact, for alpha activity, it was dubious that a satisfactory instrument could be built that would give an instantaneous indication. The problem may be presented in the following manner: The tolerance dose for plutonium is tentatively set at one micro-gram. Assume that a normal man breathes 15 liters of air per minute. For simplicity, assume that none of the plutonium leaves the body after it is ingested. Now then, let us also assume that we would like to measure the tolerance dose for a two-year period, 300 working days per year, 8 hours per day. For this length of time, at 15 liters per minute, a man would breathe 4.32×10^6 liters of air. The product has 1.4×10^5 disintegrations per minute per micro-gram. Thus we must detect in each liter of air $1.4 \times 10^5/4.32 \times 10^6 = .035$ dis/min. per liter of air.

No existing instrument will do this. When one considers that such an instrument should also be portable and non-microphonic it did not seem feasible that such an instrument could be built.

It was possible however, to make a portable instrument that would count one or two counts per minute. Even this was a problem from the microphonic standpoint. It was solved by flowing methane through the chamber. A factor of ten compared to air is easily obtained for the signal to noise ratio. Thus the amplifiers need not have a large gain and the instrument can be simplified. A two-stage battery operated amplifier will suffice to bring the signal to the 10 volt level. The instrument is still bulky however, because of the small methane tank and the batteries needed for the high voltage supply for the chamber.

The thin windows needed were made of collodion and held in place with glyptol. These proved quite sturdy so far as pressures were concerned. To protect them from accidents a wire screen was placed over them. By using this method a window 3/4" x 5" could be obtained. Photograph I illustrates a similar instrument. In this case the counting rate meter was not used.

A far more sensitive method of measuring the alpha activity in the air is to draw the air through a filter paper at a known rate and then measure the activity deposited upon the paper. This method has been worked extensively by the Chicago Group. For our purpose it suffers from two drawbacks. (1) It requires a finite time before an answer can be obtained. (2) The build-up of the natural radioactivity in the air confuses the issue, for this must be allowed to d ecay or corrections must be made before the true activity can be measured. The half-life of this natural radioactive product is of the order of two hours.

Despite these difficulties the method is extremely sensitive to small amounts of contamination. The method developed consists in using a special filter paper with extremely fine fibres. A standard vacuum cleaner (The Filter Queen) commercially available is used to draw the air through this paper. The paper is then counted on a special alpha counter.

It was thought that these instruments should be placed in the surrounding towns as a precautionary measure.

2.2 Beta-Gamma Instruments. It was apparent that certain of the personnel would have to re-enter the active area. A survey indicated that very few of them were willing to take more than 10R/hr. Thus it appeared that intensities of radiation from 10R/hr. down to much less than the tolerance dose would have to be measured. Because of the scarcity of A.C. lines in the remote section where the test took place, it was thought best to rely upon battery operated instruments. It was apparent that the surrounding towns would have to be monitored and instruments for doing this would have to operate a recording meter. These instruments should necessarily be as sensitive as is feasibly possible and well able to record below tolerance dosages.

To cover this wide range of intensities, two different types of instruments were decided upon. The first was a counting rate meter employing a Geiger tube. This instrument is illustrated in Photograph 2.

A thin wall dural G-M tube is used. This has the advantage of eliminating any photoelectric effects common with glass G-M tubes. Drawing # 569 is the schematic for the circuit. The indicating meter is a 0-1 milliameter movement. Provisions are made so that this meter may be disconnected and a 0-1 milliameter Esterline-Angus Recording meter may be put in its place.

This instrument on its least sensitive scale gave a full scale reading for 10,000 counts per minute. This corresponded to $\sim$ .01R/8 hrs. The G-M tubes required about 1000 volts. The batteries for this voltage are contained in the lower box. This made the instrument rather awkward to handle.

To measure the higher intensities the Victoreen Model 427 Ionization Meter was available. Unfortunately the supply was not sufficient for our needs so the one tube meter illustrated in Photograph 3 was designed. The circuit schematic is Drawing 440-B Revised. This meter would cover the range adequately from .04R/hr to 1 R/hr. in three ranges. These meters were also used for monitoring in the tanks. In this case it was necessary to operate them by remote control.

3.0 Number of Instruments Needed.

It was estimated that at least four town, three shelters, and the base camp would need to be monitored. A number of instruments would also be needed for personnel who would try to follow the cloud by automobile. Thus the following list was barely found to be sufficient.

Filter Queens	10
Gamma-Beta Rec. Meters	15
Alpha Counters	15
Survey Meters	30
Neutron Counter	1
Landsverk Electrometers	10
	81

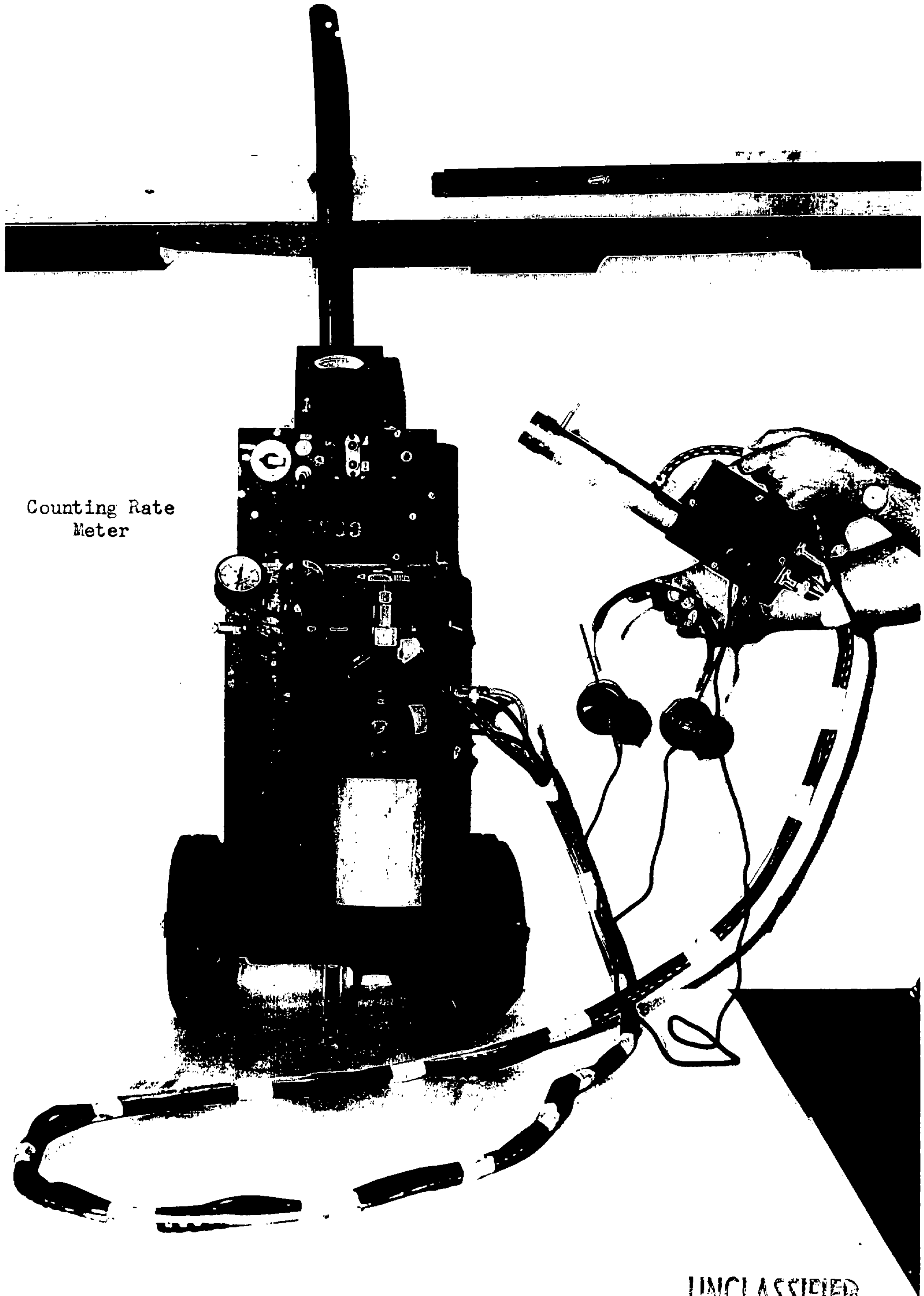
Aside from this a great many pocket electroscopes, film badges, protective clothing, gas masks, etc. were furnished by the health group.

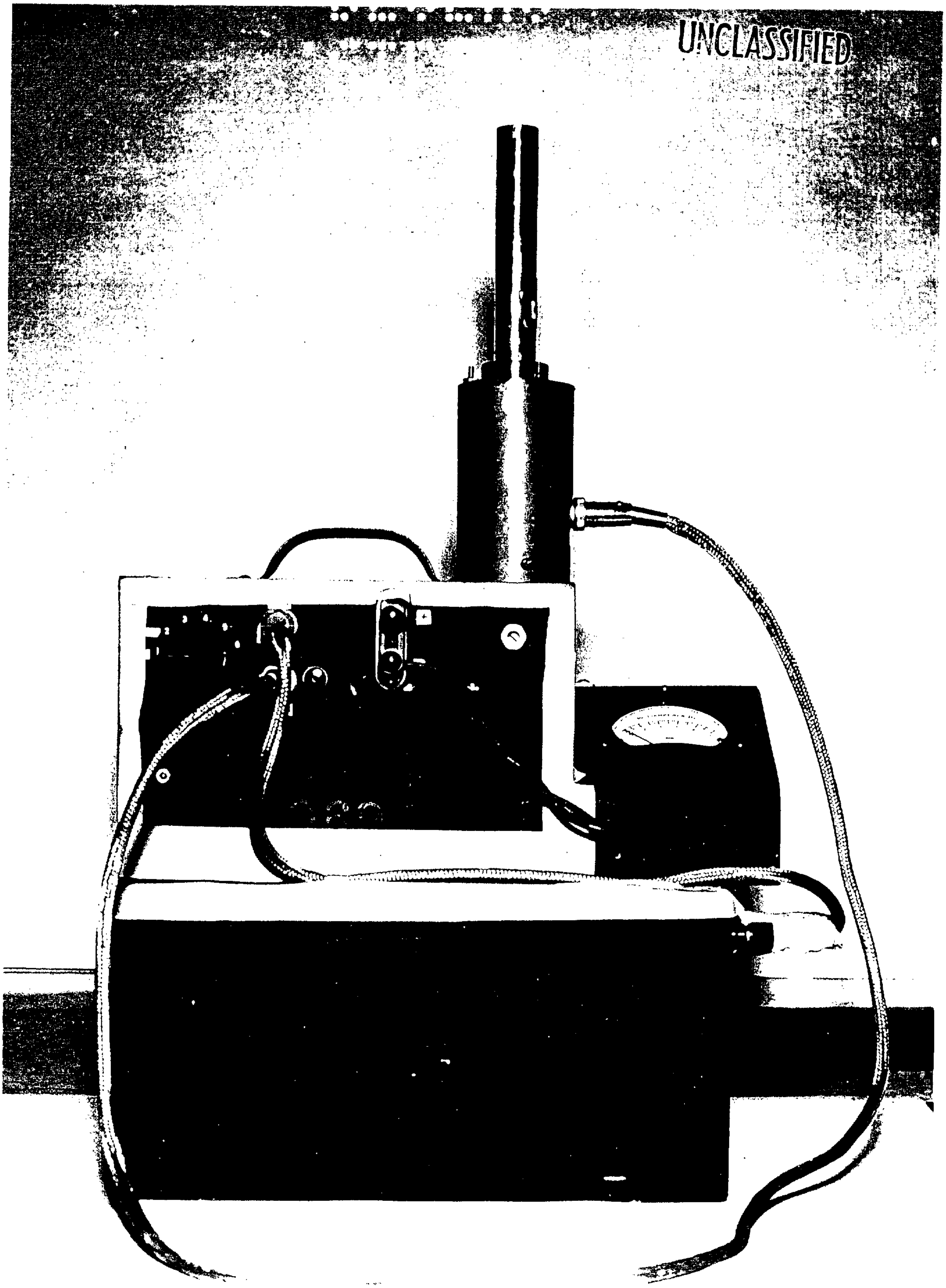
4.0 Distribution of the Instruments.

The three shelters were each equipped with an alpha meter, a Beta-Gamma G-M meter and a survey meter. These instruments were operated by the health personnel. At the Base camp a Filter Queen and a G-M Recording Meter was used. At the towns of Tularosa, Hot Springs, San Antonio, and Carrizozo, a Filter Queen and a Recording Beta-Gamma Meter was set up. These instruments were operated by Mr. Leet's seismograph group who also had instruments at these places.

The automobile group was equipped with alpha meters, Beta-Gamma G-M meters and survey instruments.

Counting Rate Meter





Photograph 2 - Geiger Tube Counting Rate Meter

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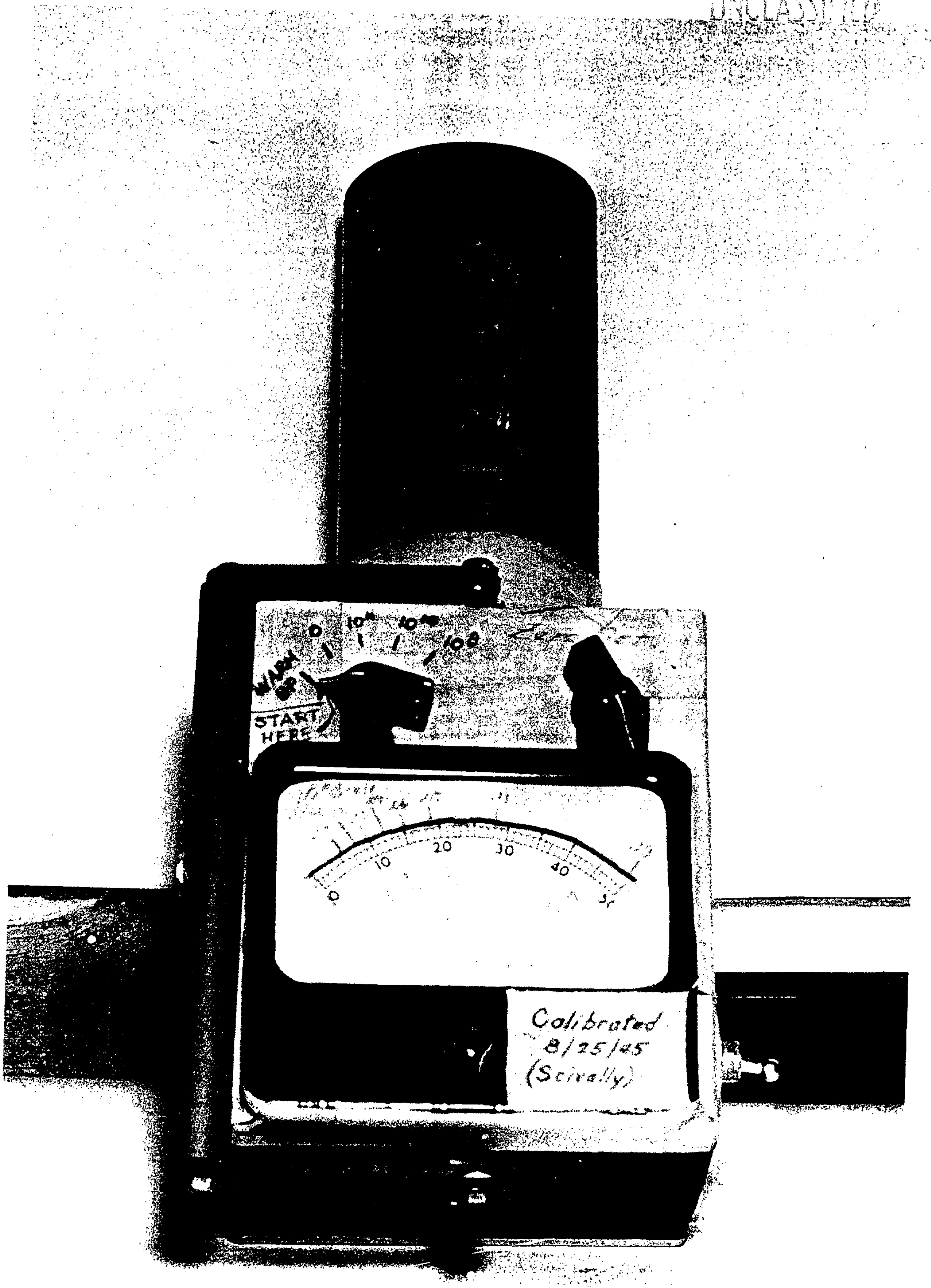

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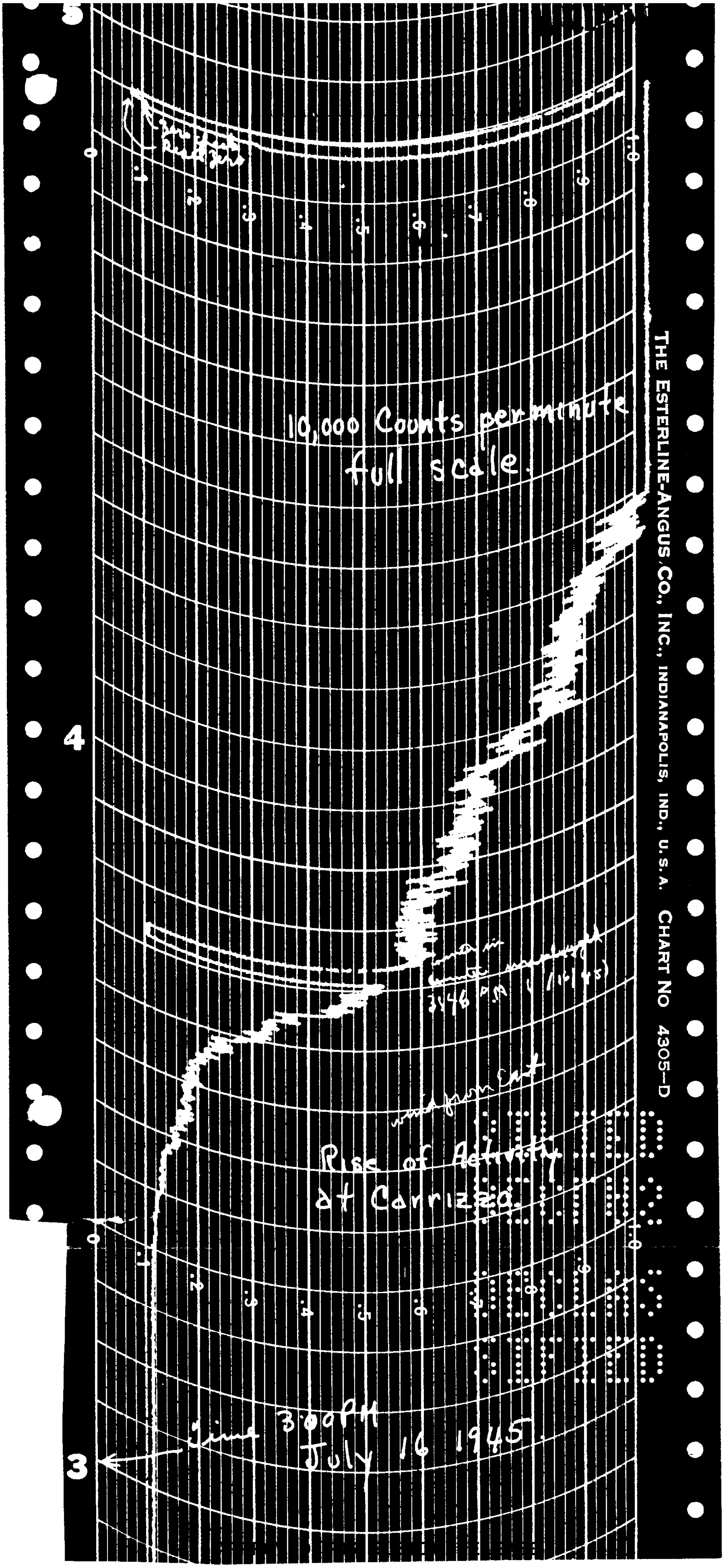
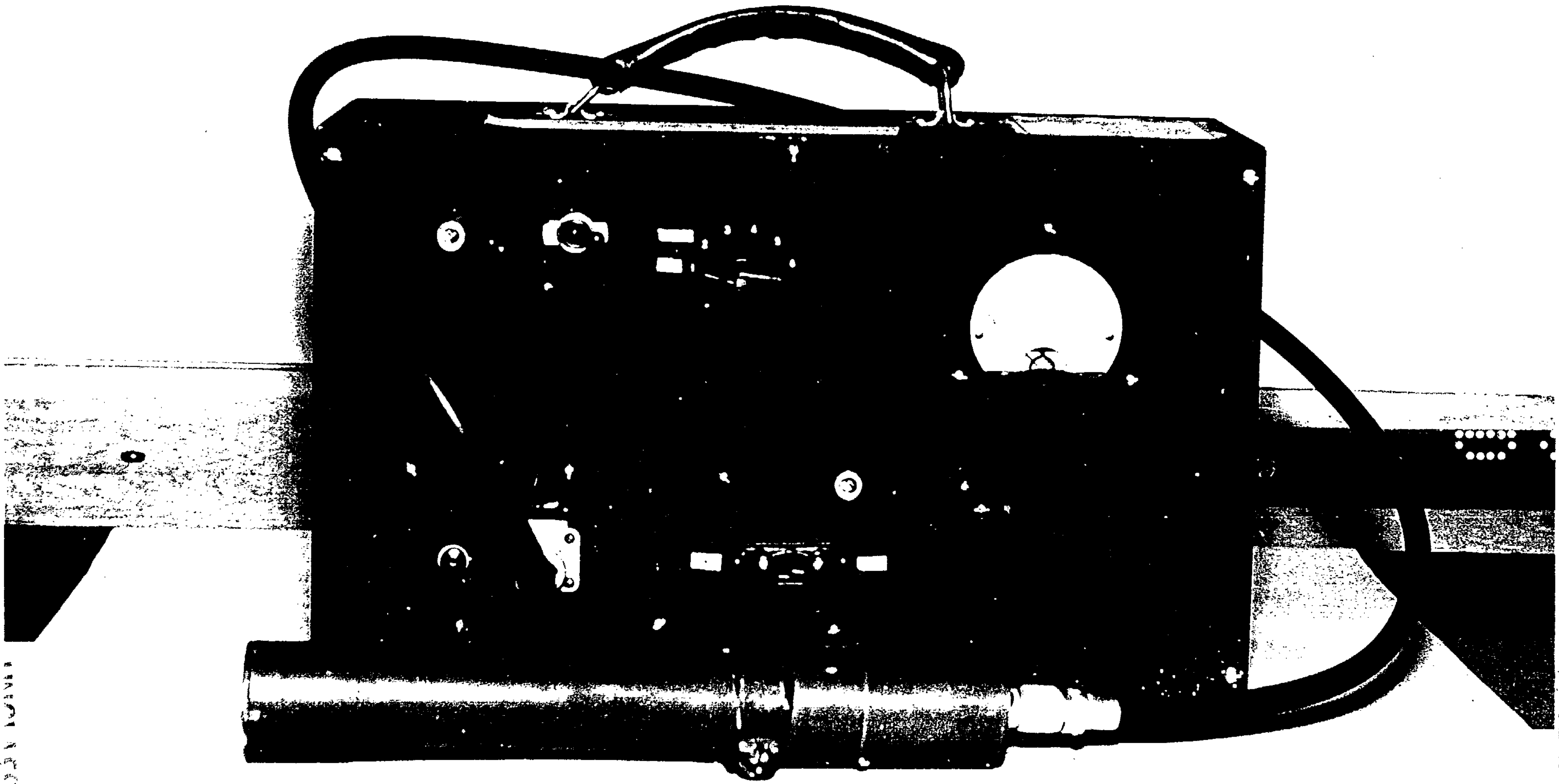

THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A. CHART NO 4305-D
10,000 Counts per minute full scale.
Rise of Activity at Carrizozo.
Time 3:00 PM July 16 1945
3:46 PM (7-16-45)



Photograph 7 - Neutron Counting Rate Meter

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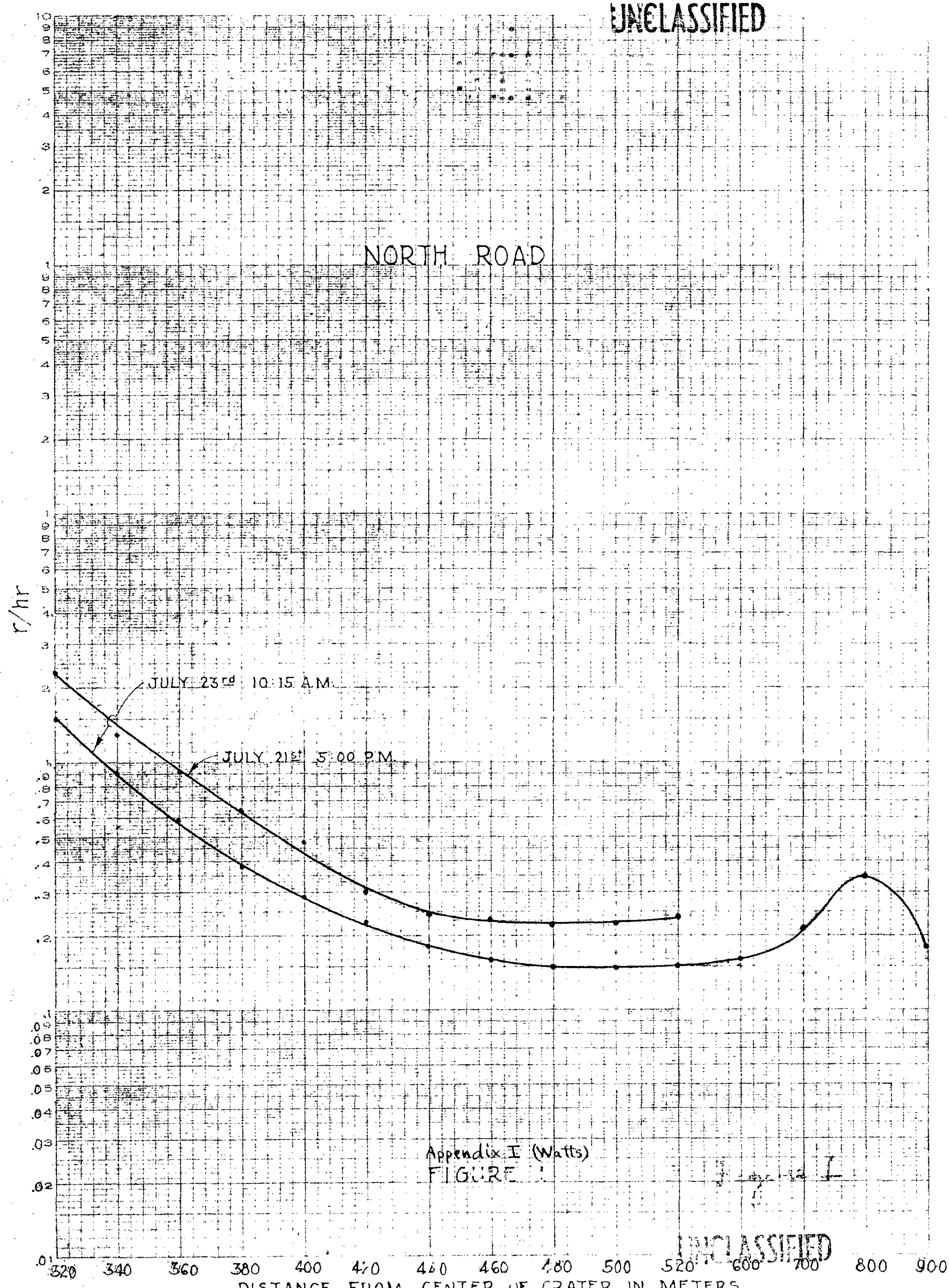
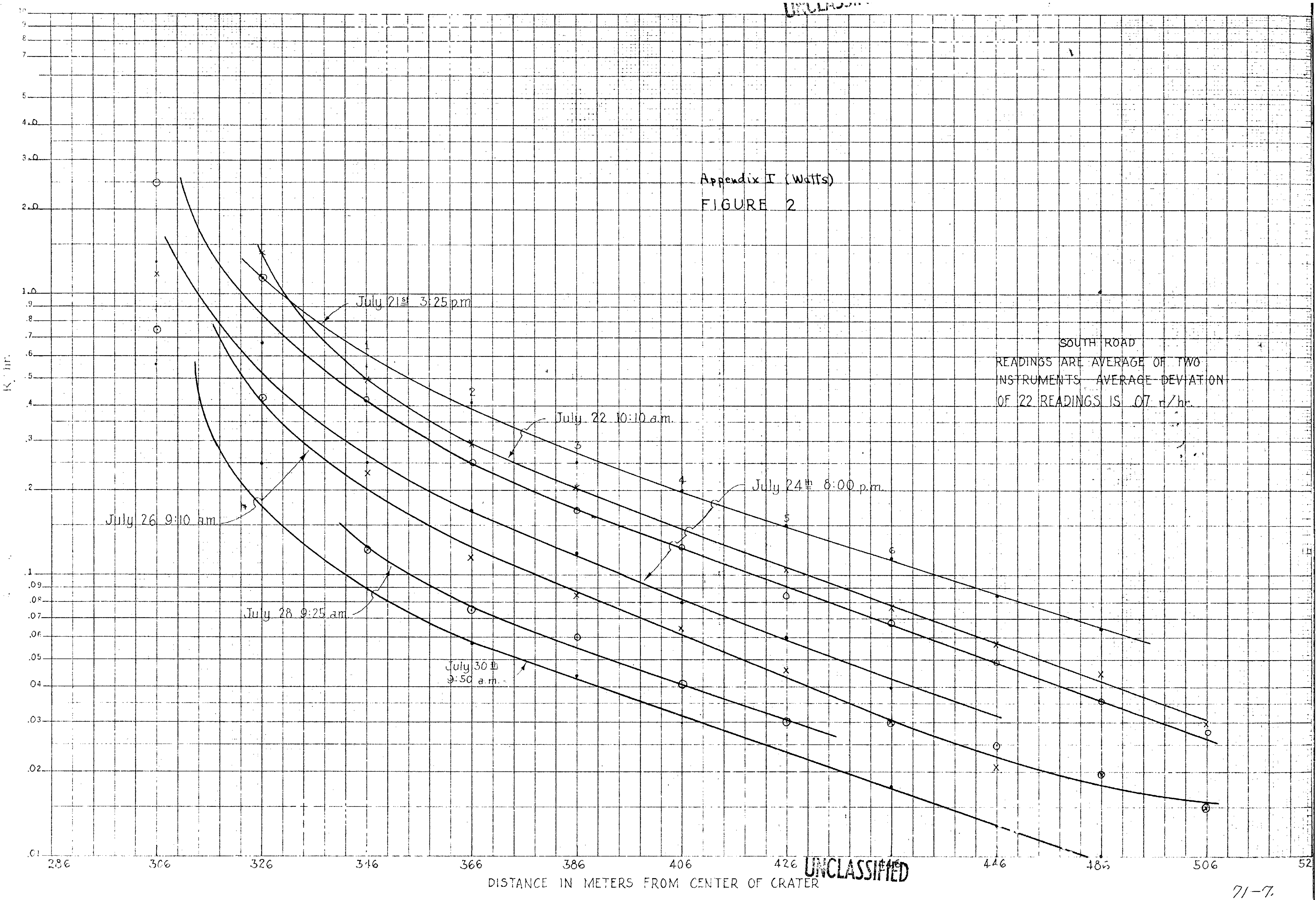
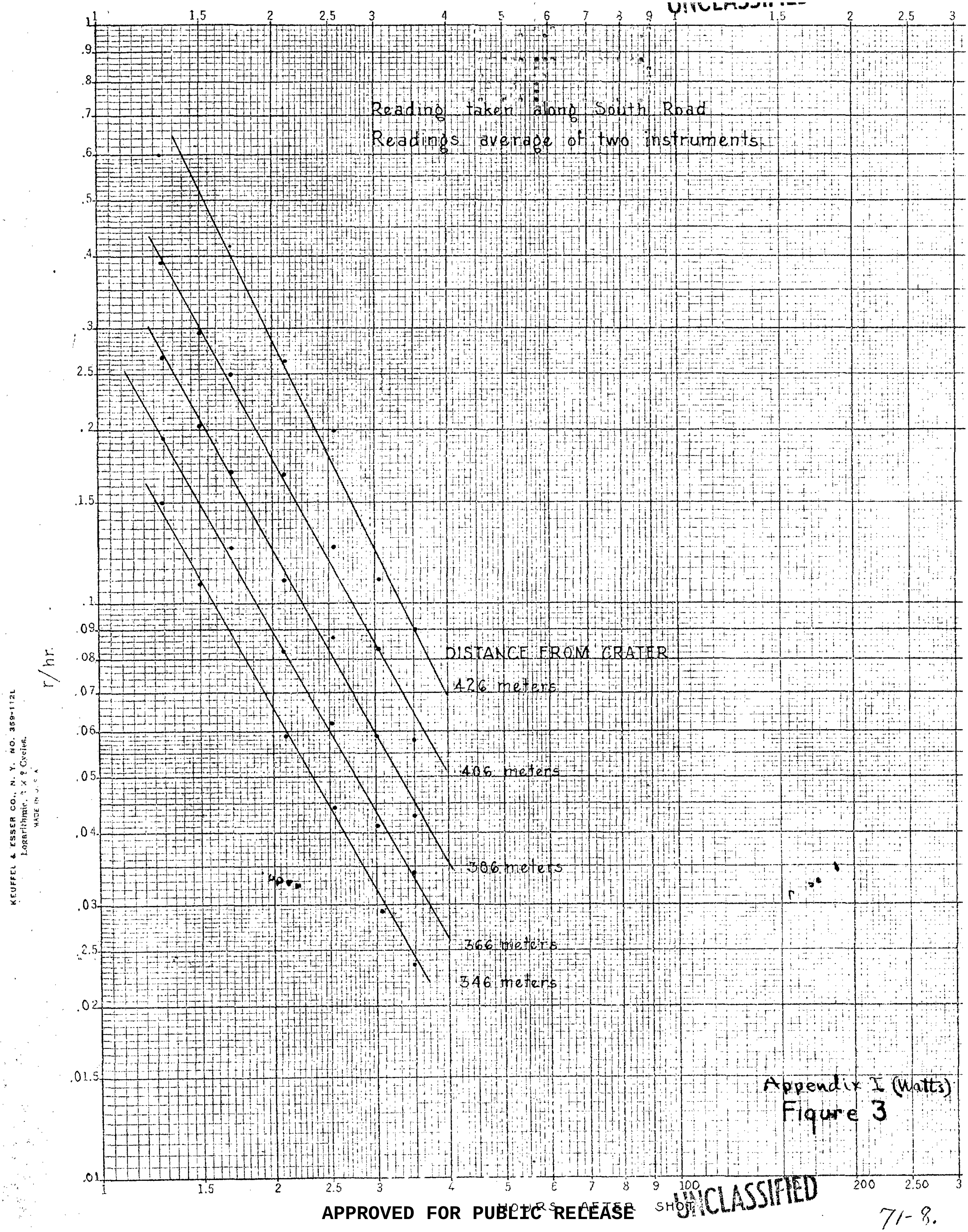


Appendix I (Watts)
FIGURE

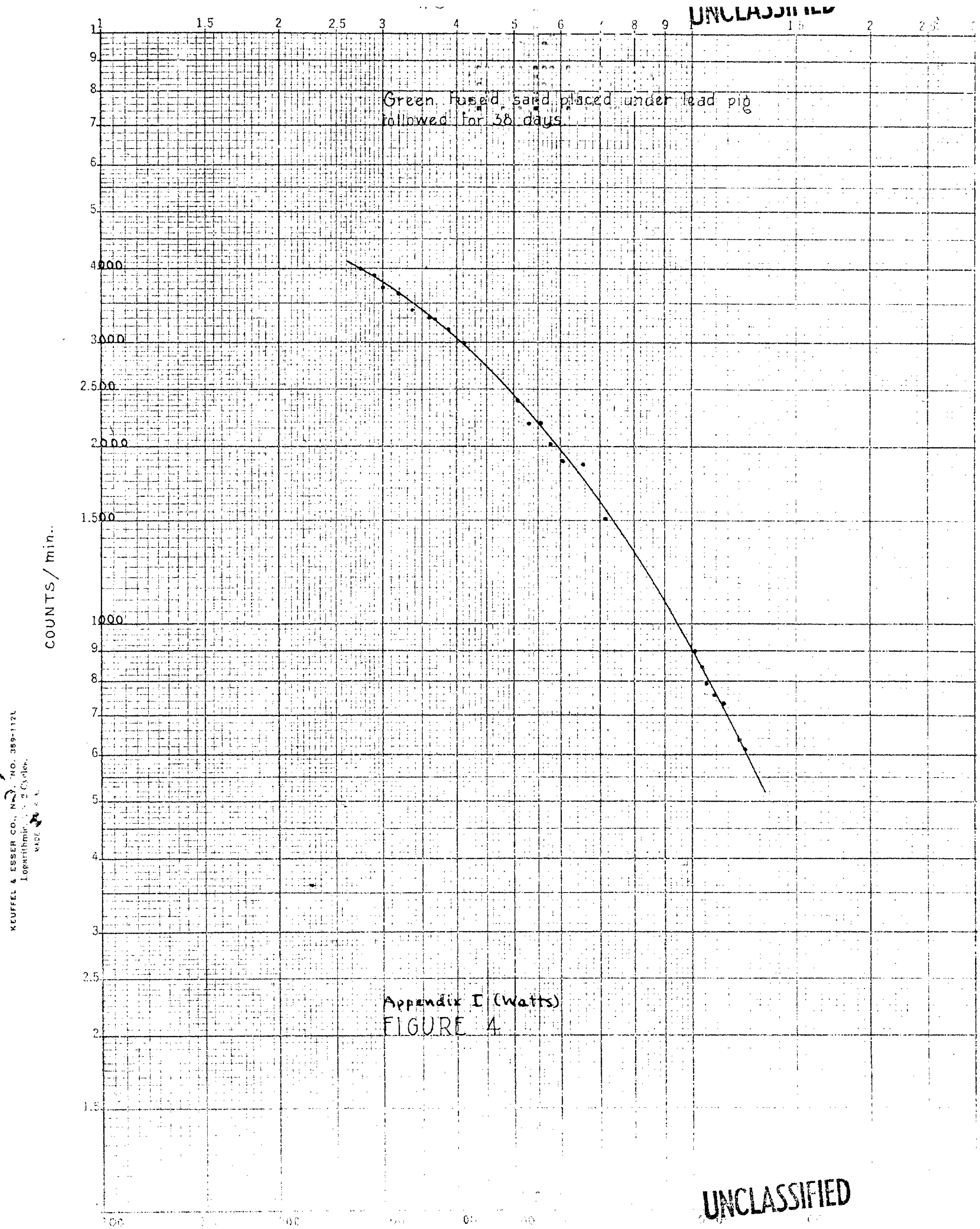
71-6


Appendix I (Watts)
FIGURE 2
SOUTH ROAD
READINGS ARE AVERAGE OF TWO INSTRUMENTS AVERAGE DEVIATION OF 22 READINGS IS .07 r/hr.
July 21st 3:25 p.m.
July 22 10:10 a.m.
July 24th 8:00 p.m.
July 26 9:10 am
July 28 9:25 am
July 30th 9:50 a.m.
R/hr.
DISTANCE IN METERS FROM CENTER OF CRATER
286
306
326
346
366
386
406
426
446
486
506
UNCLASSIFIED

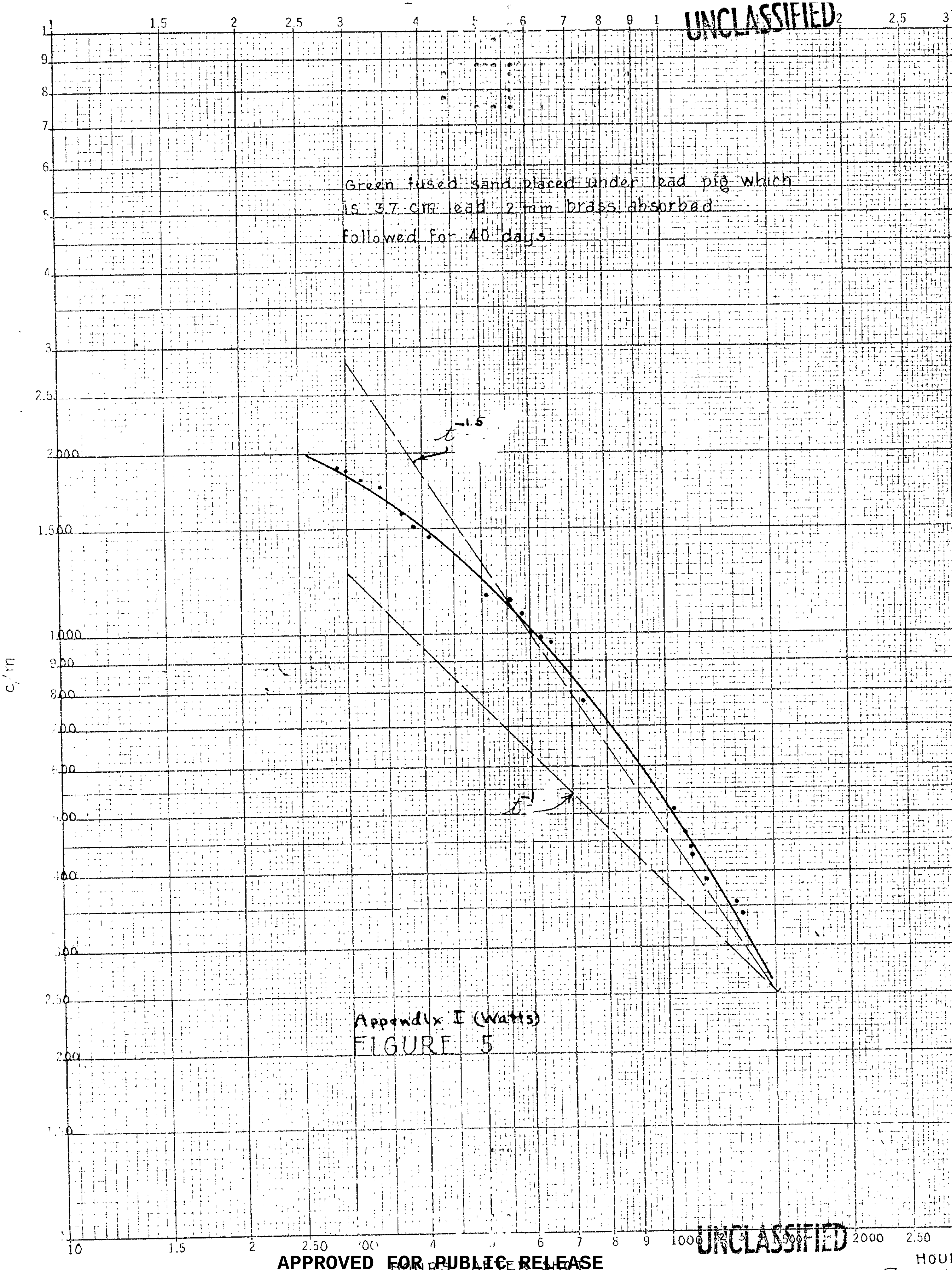
71-7



Appendix I (Watts)
Figure 3



Appendix I (Watts)
FIGURE 4



Appendix I (Watts)
FIGURE 5

UNCLASSIFIED

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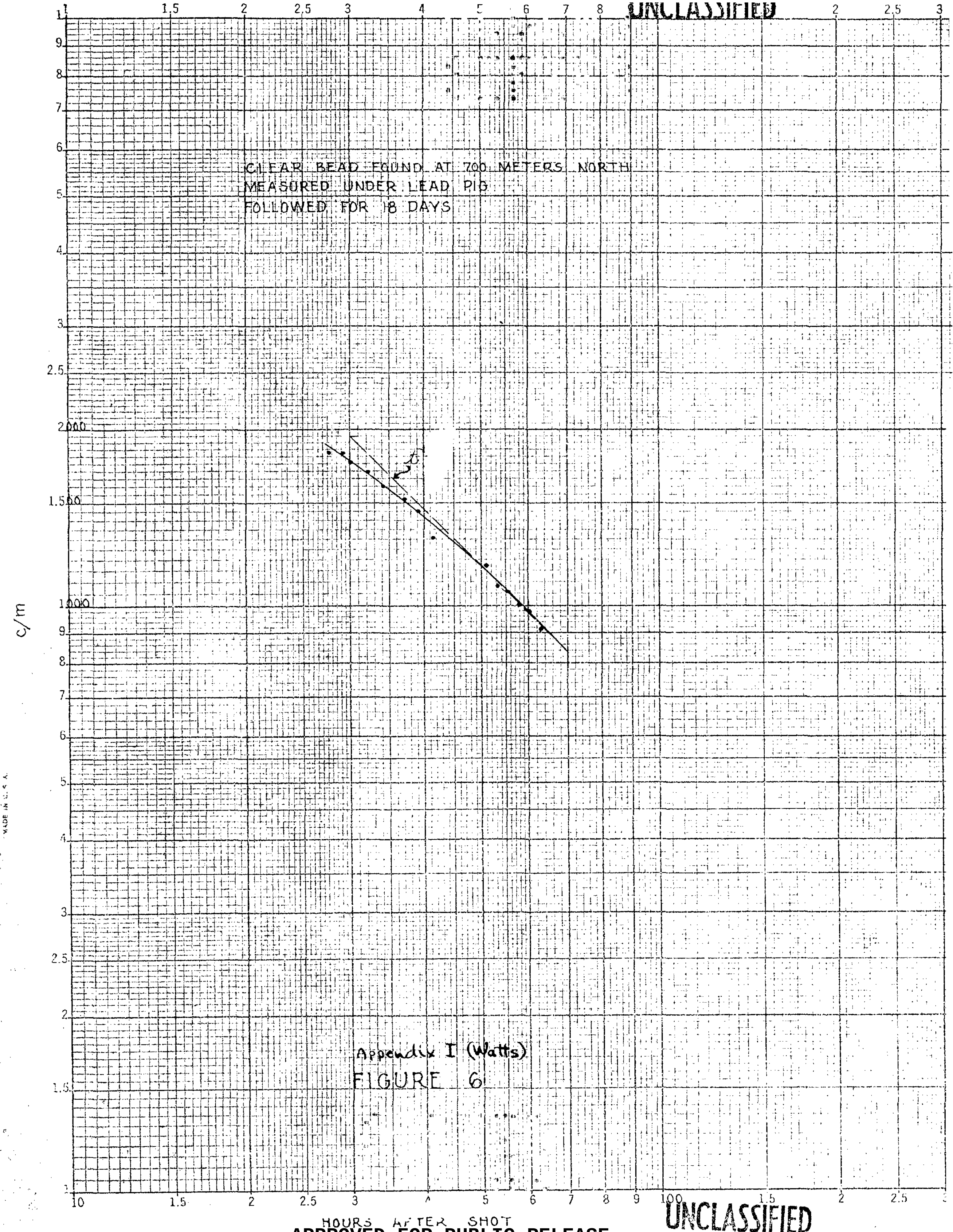
71-10



Appendix I (Watts)

FIGURE 6

5.0 Calibration of the Instruments.

All the Gamma instruments were calibrated by means of a standard source and the inverse square law. The alpha instruments were calibrated with a standard source made from the product. In order to be sure that all the instruments were working properly after they were set up the gamma instruments were tested with a piece of uranium glass and the alpha instruments were tested with a piece of filter paper that had a small amount of plutonium deposited upon it. By this means the operator could test his instrument at any time to see if it was working properly.

6.0 Results of the Shot.

Although no instantaneous activity was to be expected at the shelters from the shot, it was an easy matter to check this point. Consequently, the neutron counting rate meter illustrated in Photograph 4 was set up. This meter has a normal boron coated counter. It is operated in the proportional range such that the circuit is only responsive to pulses above a certain height. Thus gamma-ray pulses are eliminated.

This meter together with the Dural Beta-Gamma G-M Meter was set up outside the South Shelter. The position was chosen so that there were no obstructions between these tubes and the Shot. The observer protected himself by being behind the earthwork flung up to protect the shelter. The dials were then observed with the aid of a flashlight. No appreciable change in the background was observed during the shot or afterward. Immediately after the shot a proportional counter was set up outside the South Shelter with the window facing the sky. In this way it was hoped that any alpha activity that would settle from the air would be observed. No activity was found. The observation was discontinued after four hours after the shot. No alpha activity was observed at the West Shelter. No readings were taken at the North Shelter for the personnel at this shelter vacated immediately after the shot as it appeared that the radioactive cloud would go over it.

The recording Gamma-Beta meters at Hot Springs, San Antonio, and Tularosa showed no activity. The meter at Carrizozo went off scale and remained off scale until it was returned 12 hours later. Full scale on this machine was 10,000 counts per minute. The survey meters however which were less sensitive showed that this activity was not high enough to be dangerous to personnel. This rise in activity is shown on Photograph 5.

Filter Queen samples were takn at Tularosa, Hot Springs, San Antonio, Carrizozo, and Elephant Butte. Samples taken from these filter papers revealed no activity. The filters were run for varying periods of time, none of which were less than three hours.

One week after the shot, twenty-four dirt samples had been collected from the surrounding territory. These samples corroborated the activities claimed by the observer. No significant activity could be found in these samples.

To measure these dirt samples there was transported to Trinity the standard dural Geiger tube with a lead pig shielding and a scale of 16 circuit. Because the A. C. supply at Trinity was not too stable, it occasionally caused the scaler to become inoperative when the voltage fell too low. However, we found that the dirt samples which were active could not be measured in this way for their activities were well above the Geiger counter range.

7.0 Gross Activity Decay.

Although it did not appear to be too significant, it was thought that the rate at which the activity around the site decayed might be measured. This knowledge might then be useful from the standpoint of another test, and it also afforded an excellent test for the meters under field conditions.

Consequently, stakes were set up 20 meters apart along the north and south sides. Readings were taken with two instruments of the type illustrated in Photograph 3. These instruments were held at waist height with the chamber facing the crater. The readings of the two instruments were then averaged.

Figure 1 is a plot of these readings against distance on the north set of stakes for the dates given. It illustrates very well the bump in activity at 800 meters north which was noticed by several observers. Inasmuch as many round clear glass beads about 1/8" in diameter was found at this point, it was thought that this bump in activity might be due to radioactive material falling from the cloud.

Figure 2 is a similar plot of intensity vs. distance along the south road for the dates given. Other commitments did not give us time to examine the north side as thoroughly as this south set of stakes was investigated. The inconsistencies in the upper end of these curves might be attributed to two reasons; (1) The wind blowing the radioactive sand around causing different intensities from day to day or (2) Recombination of ions or lack of saturation in the chambers at high intensities.

During the time this data was being taken there were several rainstorms.

In twenty-two readings the average deviation between readings was .07R/hr. This deviation between instruments is attributable in part to two things; (1) the skill of the operator in setting the zero of the instrument each time (2) the hot sun on the instrument had a marked effect on the battery potentials. This effect was rather difficult to avoid.

Figure 3 is a plot of intensity vs. time for the hours given. This data was taken from Figure 2. These curves have been discussed by J. G. Hoffman in the bain body of the report, Chapt. II.

Figures 4 and 5 are measurements of the gamma activity of the green fused sand. This sand was too active to put in the counter. The samples were therefore placed outside the lead shield which surrounds the G-M tube.

Figure 6 is a similar measurement of a clear bead which was found at 700 meters north. An attempt was made to follow the decay of the green fused sand with a thin wall dural G-M tube. At first the attempt was abandoned because of the intense activity. The following table will give an idea of the rate at which it is now decaying.

Sample No.	Date	Counts per minute
1-A	12/12/45	4924
	3/21/46	3206
1-B	12/12/45	7316
	3/21/46	5176
1-D	12/12/45	10106
	3/21/46	6918

The total number of counts taken for each reading was over 20,000. The G-M tube was checked for stability of operation over this length of time by means of a uranium glass standard.

8.0 Conclusions.

Although none of the instruments used at Trinity may be considered perfect the results may be considered adequate. Insufficient time prevented a thorough test of all the equipment. For guidance in the future it should be pointed out that all instruments should be dust tight and waterproof. The electronic circuits should incorporate devices such as feedback to make them more independent of battery fluctuations. The G-M tube fillings should be such that they are as temperature independent as possible and the G-M tube circuits should incorporate a univibrator or some device that renders the counting rate meter independent of pulse height.

Smaller instruments would be desirable. All instruments should be tested on a shake table. Because of the rough treatment these instruments received in the field at least 10% of them failed. The chief offender was the Hallicrafter G-M meter. Inexperienced personnel had difficulty with the Victoreen triple range survey meter. These meters have rubber washers under the knobs. When the knobs are turned to set the zero enough tension remains on the washer to pull the knob back. This makes it appear that the zero is unstable.

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APPENDIX II

17 August 1945

ITINERARY OF TRIP

MADE by Colonel Warren, Captain Whipple and L. H. Hempelmann on 12 August 1945

Left site at 5:00 AM, had lunch at Trinity. Colonel Warren had to return immediately to site but Captain Whipple and Hempolmann went to Bingham, White Store and the Hot Canyon to make further measurements and to interview persons. Victoreen Meter #46,174 calibrated on evening of 11 August 1945 by Whipple and Hempelmann. Another single range Victoreen Meter was calibrated but failed to work properly on 12 August 1945.

Bingham 3:30 PM - R. H. Dean, wife, daughter and son live here. They were awakened by the shot on 16 July 1945, entire house rattled and three windows broke. They went to the window to see what had happened, saw the huge cloud of smoke, reasoned that there was an explosion of some sort and went back to bed for about 30 minutes. The entire family has been quite well and healthy.

Meter reading #46174

Victoreen single range - ground = 0.003 r/hr.

Inside store (waist level) 0.0001 r/hr.

Speedometer reading at Bingham was 776.0 miles. From here we drove eastward on the road to Claunch and then continued east where this highway turns north onto the road to the "Hot Canyon". The following are the readings and observations as made by us:

Mileage	Observations	Readings
776.0	see above	0.003 r/hr
780.0	Cows appear healthy, no apparent anemia or diarrhea, noses pink, grass sample taken	
781.2	At junction with road which leads to Hot Canyon. Grass sample taken.	0.02 r/hr (ground) 0.013 r/hr (waist)
781.45	on road to Hot Canyon	0.022 (ground) 0.018 (waist)

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Mileage	Observation	Readings
781.7	On road to Hot Canyon	0.022 r/hr (ground) 0.020 r/hr (waist)
781.8	On road to Hot Canyon	0.030 (ground) 0.025 (waist)
781.95	On road to Hot Canyon	0.027 (ground) 0.020 (waist)
782.2	Measurements at roadside	0.027 (ground) 0.025 (waist)
782.2	Measurements 20' off road	0.029 (ground) 0.026 (waist)
782.45	Point corresponding to previous highest reading in Hot Canyon. Same place but off road (20')	0.024 (ground) 0.023 (waist) 0.032 (ground) 0.029 (waist)
782.50	At roadside	0.027 (ground) 0.025 (waist)
	Off road (20')	0.029 (ground) 0.027 (waist)
782.7		0.030 (ground) 0.027 (waist)
782.7	On and Off Road	0.032 (ground) 0.030 (waist)
782.9		0.028 (ground) 0.025 (waist)

No more readings taken while going in towards the house in the Hot Canyon, however, the following readings were taken on the way out:

1/2 mi. from house	0.033 (ground) 0.028 (waist)
1/4 mi. from house	0.026 (ground) 0.025 (waist)
just below house - this reading was checked.	0.0013 (ground) 0.0018 (waist)

Raitliff House in Hot Canyon(Chupadera Mesa) Mr. and Mrs. Raitliff (both over 50 years) and their 10 year old grandson live here. They were asleep on the morning of the shot; they heard, felt and saw absolutely nothing. They were aware of nothing unusual until the grandson returned home from Bingham late in

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the afternoon. He had left early in the morning (presumably by horseback) had reached Bingham at 9:00 AM and learned of the explosion here. By being at Bingham during the day and indoors at night, he missed most of the heavy exposure of the first day in the "Hot Canyon". During this day, Mr. Raitliff had spent most of the day outdoors but Mrs. Raitliff was indoors a large portion of the time. During the following two weeks there was no change in their usual habits of going indoors about 7:00 - 8:00 o'clock to dinner, retiring after hearing the evening news broadcast and arising at about 6:00 AM. Their house is a well built two room adobe structure with thick walls about 15" thick and a tin roof supported on wooden rafters. The house measures about 25 x 15' feet, is about 12 feet high and affords great protection (see below). The tin rooof is used to collect water for the cistern the exact size of which was not learned but is presumably 50-250 barrel capacity since others in the neighborhood are of this size. There was rain in the area on the night after the shot; this means that some of the activity was carried into their drinking water and may have been drunk on the following day and thereafter.

The health of the inhabitants of this house has been good except that Mr. Raitliff complains of nervousness, tightness in the chest and poor teeth. These are not new symptoms. The animals - goats, turkeys, donkey's - appear to be in excellent health. Samples of drinking water and soil from the yard were taken. The following measurements were made in various locations in the yard, the nearby countryside and in the house:

Yard	Position I	0.027 r/hr (ground) 0.023 (waist)
	Position II	0.025 (ground) 0.022 (waist)
	Position III	0.023 (ground) 0.023 (waist)
	Position IV	0.028 (ground) 0.025 (waist)
	Position V	0.027 (ground) 0.021 (waist)

Position VI	0.023 r/hr (ground) 0.022 (waist)
Position VII (doorstep)	0.017 (Ground) 0.013 (waist)
Position VIII (behind house)	0.028 (ground) 0.022 (waist)
Position IX (inside house)	0.003 r/hr 0.004

White Store: Mr. McSmith and family (wife, two small daughters, daughter-in-law) live here in a new adobe house with a double roof. They were awakened by a plane circling overhead the morning of the test. The plane sounded to them as if it were in distress. Shortly thereafter, their bedroom lit up as if by a light source in the room and during the blast that followed, the entire house shook. The family saw the pink cloud from the bedroom window and watched it float very high overhead. They dressed and were outside within 30 minutes. The house was not damaged and their concrete cisterns were unharmed. The following measurements were made:

on ground in front of store	0.008 r/hr
in air	0.005 "
inside store	0.0005 "

17 August is 744 hours after TR shot of 16 July. See LA notebook 311A on page 25 et seq for data.

L. H. Hempelmann, M. D.

8/17/45 Calibration of Victoreen Survey Meter #46174 - checked - still unchanged and okay.

L. H. Hempelmann, M. D.

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APPENDIX III

Monitoring Trip Northeast of Trinity, 11 December 1945

by Carl Buckland and A. Reinert.

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INTER-OFFICE MEMORANDUM

DATE December 27, 1945

TO: J. G. Hoffman

FROM: Carl Buckland & A. Reinert

SUBJECT: Monitoring Trip Northeast of Trinity 11 December 1945

Mileage	MR/hr on grd. β + γ	γ	11 December 1945
13166.4	.053	.027	Heading west toward White store on US Highway 380
168.4	.032	.022	
170.4	.265	.13	
172.4	19.0	.72	
173.4	8.6	.39	West of White Store.
176.2	3.75	1.14	Came back just east of Wh Store; started south on dirt road
177.4	1.66	.75	
178.4	2.1	.55	Trail ended at 178.9 mileage
		.39	Background in car
181.2	2.1	.64	Came back to house and started west
181.9	1.8	.62	Think it was Rock Tank
183.3	3.4	.84	Now going east (2 cisterns or cement tanks)-sample taken

Came out to highway 380 on dirt road running directly into Wh. Store.

	1.5	.285	Bingham

Took road 161 east from Bingham and turned off at Nalda Hdqts. RCS Co.

	16.2	1.22	Nalda Hdqts.

Back to 161, continued east to intersection 161-146, on east from intersection toward M.C. Ratliff place (Hot Canyon)

13201.3	19+	1.66	Intersection 161-146
202.3	19+	1.66	
		.84	Background in car
203.3	19+	1.95	Near Ratliff house-old spot where sample was taken last trip (took another)
204.2	5.7	1.1	
205.3	19+	.55	
207.0	.595	.18	
209.1	.039	.022	
211.1	.033	.027	
214.0	.033	.027	Hobbs Tank
215.7	.033	.027	Broken Back Crater

12 December 1945

13249.0 Turned off highway 54 north of Carrizozo, went west on dirt road toward Black Crater.

258.4 In bottom left square of section R.10 E.-T5S on map No 45

259.9			Gallagher Hdqts.
264.9	.04	.023	Going NW toward Harvey or French Ranch
267.0	.03	.026	
269.0	.034	.029	
270.1	.047	.03	At Harvey or French Ranch
270.4			intersection
272.4	.47	.22	[illegible]
273.4	.46	.17	

Form 25

INTER-OFFICE MEMORANDUM

DATE December 27, 1945

TO: J. G. Hoffman

FROM: Carl Buckland and A. Reinert

SUBJECT: Monitoring Trip Northeast of Trinity 11 December 1945 (con't)

Mileage	MR/hr on grd. β+γ	γ	12 December 1945 (con't)
274.4	.53	.202	Fence beyond hole
275.4	.39	.154	
276.4	.5	.205	
277.4	.41	.16	Intersection with main road between Morgan Well & Dulce Well - near Morgan well - turned S.E.
278.4	.26	.075	
280.4	.045	.026	
283.4	.029	.026	
284.5			Dulce Well
290.6			-Now back at last intersection we came from & went NW toward Morgan Well
291.5	.76	.28	Morgan Well
292.5	1.32	.46	Still going NW
		.25	Background in car
294.0	2.6	.52	House
295.0	3.55	.5	
296.0	2.4	.5	
296.2			- Met road going N & S along fence
297.3			Maxwell Ranch
297.5	3.15	.61	Intersection, took road S.E.
298.5	1.04	.37	
299.2	1.9	.46	Came to road running N & S along Cibola Natl. Forest- also a water tank and well-went south on highway 41
301.4	4.4	.82	
		.36	Bkgrd in car
301.7			(- turned left on dirt road but too bad so turned back to hwy 41) same point
304.9			(- changed mileage) same point
309.6	4.8	.93	Came to intersection leading to Harvey boundry-turned left -(place of sign posts on last trip Nov.8)
310.6	4.0	1.38	
311.3	10.4	2.08	At boundry fence of Harvey Ranch
312.3	11.0	1.95	
		.78	Reading in car
313.3	14.0	3.15	
314.3	4.4	1.64	Coopers Well (Smith Family)
315.3	5.2	1.52	
		.41	Reading in car
316.3	1.5	.46	
317.3	.61	.29	
318.3	.25	.17	
318.9			- Came to crossing of road we took day before, back past Broken Back Crater

13 December 1945 - Snow on ground throughout day but readings taken on bare spots

		.021	Bkgrd in car

Form 25

INTER-OFFICE MEMORANDUM

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DATE December 27, 1945

TO: J.G. Hoffman

FROM: Carl Buckland & A. Reinert

SUBJECT: Monitoring Trip Northeast of Trinity 11 December 1945 (con't)

Mileage	MR/hr on grd. β+γ	γ	13 December 1945
13383.5	- Mileage at White Store - going east on highway 380		
386.0	.23	.18	Turned south off main road (Sign on fence-US Bombing Range)
388.0	.0215	.016	
390.2	.026	.019	
390.9	.035	.0215	Either Bace or Brush Tank
392.2	.027	.024	Going N on other road from tank
		Changed mileage scale at next intersection and reading	
		.25	Reading in car
399.5	.27	.21	
400.7	1.82	.87	
401.1	1.04	.41	By house-Ozone well and windmill short distance up road
402.1	1.22	.87	On way to what we think is Chicken Springs
402.6	1.5	.61	As far as we went on road to Chicken Springs
403.4	- back at house; turned left on other road going NW		
404.4	1.75	.76	
		.41	Reading in car
404.7			Bruton (dirt) Tank
405.4	1.4	.61	
406.3	1.7	.66	Another dirt water hole
	Turned back to last intersection (at house)		
407.3	1.5	.93	
			December 14, 1945
		.15	Reading in car
13526.0	- Mileage at Bingham, started NW on highway 380		
527.0	.59	.18	Turned south on dirt road
528.0	.32	.15	
529.0	.27	.12	
530.0	.44	.20	Intersection with road to Julian tank
531.0	.81	.29	
531.9	.32	.145	Julian tank
	- Took road heading east from Julian tank		
532.9	.59	.235	
533.8	.48	.215	End of road - believe this road did go to Bruton tank and Chicken Springs at one time
535.4	.Back at Julian tank now going S to SE		
536.4	.46	.205	
537.4	.41	.215	
538.4	.54	.245	
539.4	1.23	.275	
540.4	.62	.265	

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Form 25

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INTER-OFFICE MEMORANDUM UNCLASSIFIED

DATE December 27, 1945

TO: J. G. Hoffman

FROM: Carl Buckland & A. Reinert

SUBJECT: Monitoring Trip Northeast of Trinity 11 December 1945 (con't)

Mileage	MR/hr on grd.		14 December 1945 (con't)
	β+γ	γ	
13541.4	1.27	.67	Smith Tank
		.6	Bkgrd in car
542.4	2.25	1.1	
543.2	- New steel tower on right with shack (new road running west from it) Probably N tower of Trinity		
543.4	4.1	1.2	
	1.07	.35	East of shot at base of Oscura Mts near Canyon de las Venedos.

Carl Buckland
Carl Buckland

August Reinert
A. Reinert

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Form 25

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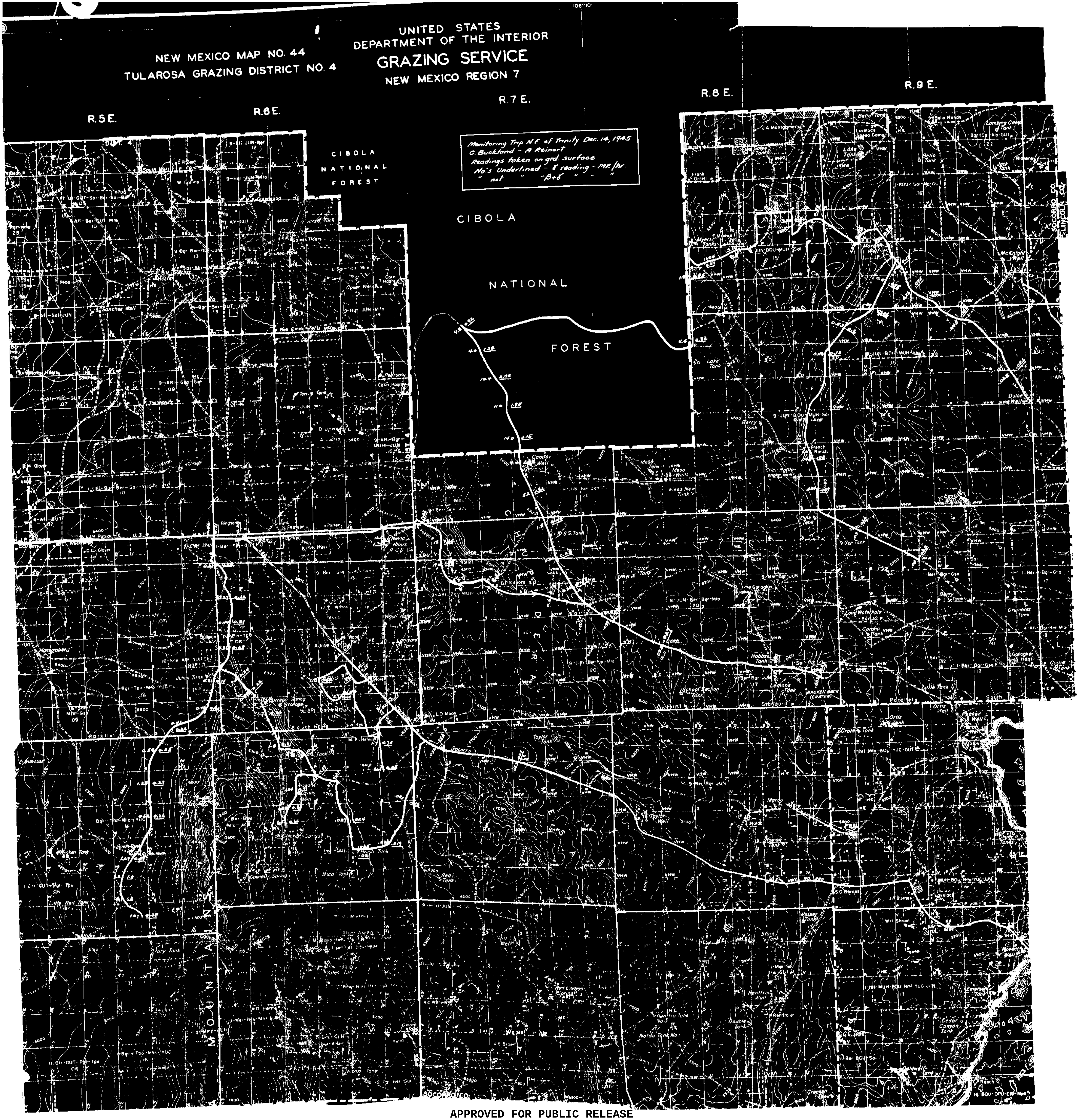

NEW MEXICO MAP NO. 44
TULAROSA GRAZING DISTRICT NO. 4
UNITED STATES
DEPARTMENT OF THE INTERIOR
GRAZING SERVICE
NEW MEXICO REGION 7
R.5 E.
R.6 E.
R.7 E.
R.8 E.
R.9 E.
Monitoring Trip N.E. of Trinity Dec. 14, 1945
C. Buckland - A. Reinert
Readings taken on grd. surface
No's Underlined - γ reading - MR/hr.
" not " - β+γ " - "
CIBOLA NATIONAL FOREST
CIBOLA
NATIONAL
FOREST
SOCORRO CO.
LINCOLN CO.