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TRANSMITTAL OF REPORTS

Enclosed are copies of the below listed reports you requested from T. C. Mehas at the "External Dose Assessment Workshop" held at DOE/NV on February 22, 1980.

> "Criteria for Evaluating Gamma Radiation Exposures from Fallout Following Nuclear Detonations"
> Gordon M. Dunning
>
> WASH-290 "Discussion of Radiological Safety Criteria and Procedures for Public Protection at the Nevada Test Site"
> Gordon M. Dunning, February, 1955

Arden E. Bicker

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[Reprinted from RADIOLOGY, Vol. 66, No. 4, Pages 585-94, April, 1956.]

Criteria for Evaluating Gamma Radiation Exposures from Fallout Following Nuclear Detonations[1]

GORDON M. DUNNING[2]

THE RADIATION factor of greatest immediate concern to man in the fallout incident to nuclear detonations is the external gamma radiation emitted from material after deposition on the ground. This is the only factor that will be discussed here.

COMPARATIVE RADIATION DOSES AND BIOLOGICAL EFFECTS

In evaluating the biological effects of gamma radiation exposures from fallout, it is natural to turn to the many experiments that have been performed in the laboratory. In making a comparison, however, certain differences between the two sets of conditions necessitate consideration.

First, in the laboratory, narrow-beam exposures, unilateral or bilateral, have been the rule, while radiation from a fallout field may represent a source in radial geometry, *i.e.*, the radiations reach a given point from material which is spread over a plane. A usual laboratory method is to measure the air dose rate from a unilateral or bilateral source at the proximal surface of the subject, and to report the dose required to produce a given biological effect. For larger animals this dose may be significantly higher than one calculated by integration of the air dose all around the subject, which, in essence, is the situation when an air dose rate measurement is taken in a fallout field. Thus, biological effects comparable to unilateral and bilateral exposures may be produced by lower air doses as measured in a fallout field.

This geometry factor has been shown to have genuine significance for large animals, such as swine, where the LD 50/30 values (the instantaneous dose of radiation that will cause one-half of the animals to die within thirty days) decreased from 500 to 350 or 400 r when the method of exposure was changed from unilateral to bilateral (1). Still further reductions might be expected in changing to exposure from a source in radial geometry.

Second, an experiment with *Rhesus* monkeys (2) in which 250-kvp x-rays were used gave an LD 50/30 value of 530 r. A significant number of the monkeys died, however, after the thirtieth day. If the survival data at one hundred days (the extent of the data reported) were utilized, the figure (LD 50/100) might be close to 430 r. While it is proper to report and use LD 50/30 values for experimental purposes, such values are less relevant in the present study, since we are concerned with the general health and welfare of the public. It is as serious for a man to die on the one-hundredth day as on the thirtieth day.

That the factor of deaths after thirty days may be extrapolated from one primate to another is suggested by the Japanese data (3). In the group sampled for Hiroshima, the number of reported deaths between the twentieth and twenty-ninth day was 137; for Nagasaki the figure was 87. After the twenty-ninth day 117 deaths were reported at Hiroshima and 87 at Nagasaki. (There were, of course, many deaths in these sampled populations *before* the twentieth day.) The difficult task of accurately recording, isolating, and identifying the causes of these deaths is recognized, but an analysis of the extent of radiation injury and the time of death would strongly indicate that radiation was a major factor in a significant number of the fatalities occurring after the thirtieth day.

The final difference between laboratory exposures and doses from fallout requiring

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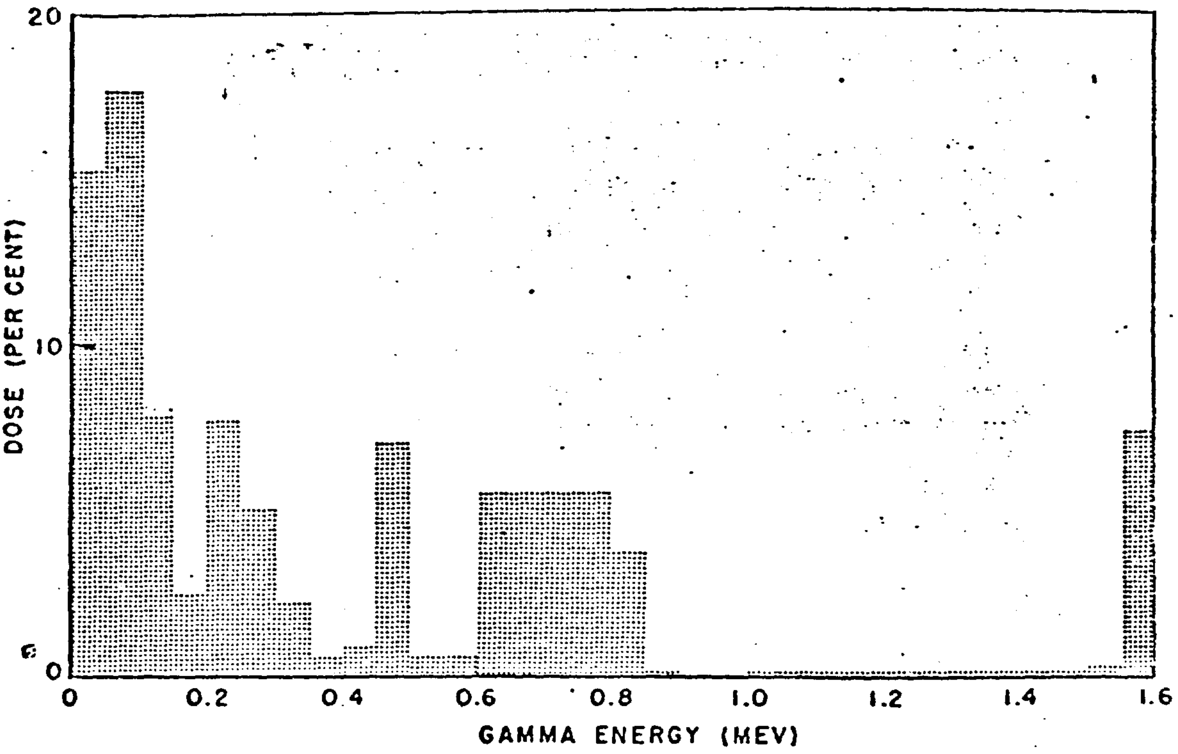
[1] Presented at the Forty-first Annual Meeting of the Radiological Society of North America, Chicago, Ill., Dec. 11-16, 1955.

[2] Health Physicist, Division of Biology and Medicine, U. S. Atomic Energy Commission, Washington, D. C.

consideration is the energy spectrum of the radiation. The gamma spectrum emanating from fallout material is complex. In Graph 1 is shown the gamma spectrum for fallout after the detonation of March 1, 1954, at the Pacific Proving Ground (4), with the estimated percentage contributions of the gamma quanta of differing energies (million electron volts). It is recognized that such spectra may vary and that any single value may conceal important features, but an estimate of 0.7 Mev mean energy has been quoted as a first approximation (5).



Graph 1. Percentage of total dose contributed by gamma quanta energies shown (million electron volts).

WEATHERING AND SHIELDING

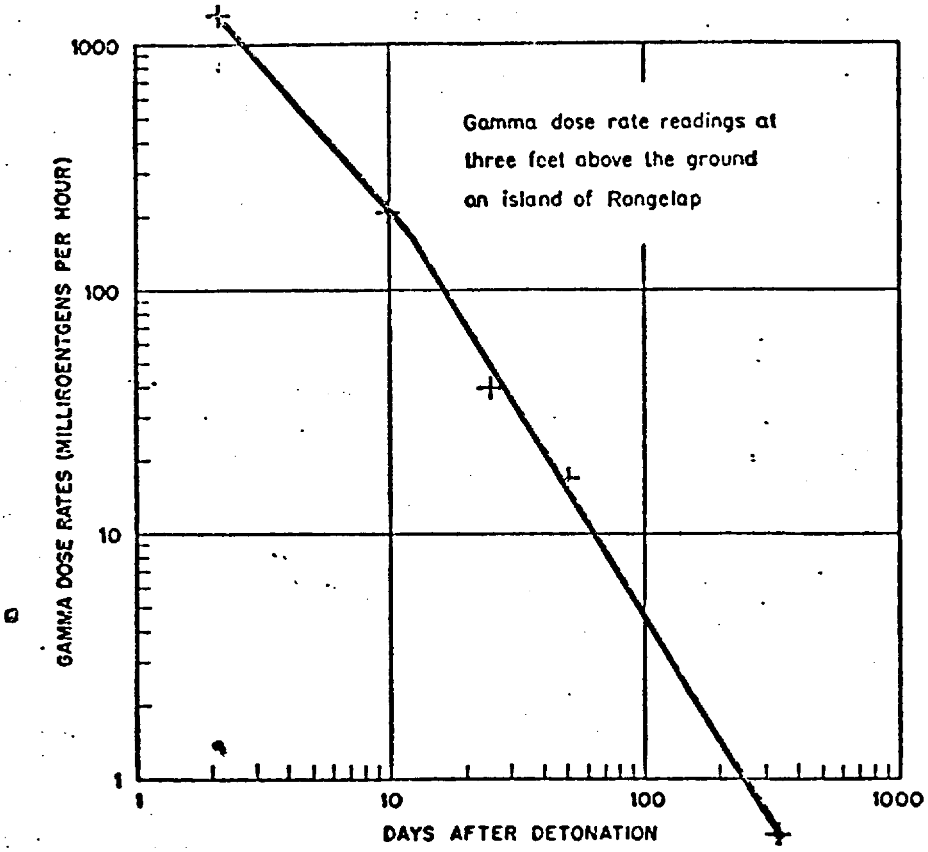
The variable nature of the two parameters of weathering and shielding makes establishment of a precise rule, covering all situations, impossible; yet these factors are operative in determining the total exposure received from fallout.

One example will be used here to give some perspective as to weathering effects. After the detonation on March 1, 1954, in the Pacific Islands, the winds were light and the first rainfall did not occur until about two weeks later. Graph 2 shows the gamma dose rates taken at 3 feet above the ground on the island of Rongelap over a period of nearly a year. In the first ten days the decrease in activity, or disintegrations per unit time, is roughly consistent with the known radiological decay rate for fallout material, *i.e.*, a slope of minus 1.2. The break between the tenth and twenty-fifth day, therefore, undoubtedly represents the effects of rain (and possibly winds), which was known to have occurred. The rest of the points fall roughly on a line of $(\text{time})^{-1.7}$, reflecting principally the effects of weathering and possibly, to a smaller degree, the fact that the number of gamma *quanta* released per disintegration decreases after the first thirty to forty days. In employing these data, however, one is faced with the problem of translating the effects from a Pacific island to larger land areas with different climatic conditions.

Neither the exact time of winds and rains nor the precise extent of dose-rate reduction can be predicted. These two parameters are obviously quanta events to which a straight line function may be ascribed only by the process of generalization, as in Graph 2. The following estimates may be proposed: For the first week following fallout, the measured gamma activity is assumed to decay according to $(t)^{-1.2}$, for the second week $(t)^{-1.3}$, and for the third week and thereafter $(t)^{-1.4}$. Justification for such values lies not in the high probability that they will occur at these times but rather in the necessity of generalizing (probably conservatively) in advance, so that some estimate of the parameter of weathering may be incorporated into evaluations of possible future contamination.

TABLE I: ESTIMATED ATTENUATION FACTORS OF GAMMA DOSE RATES FROM FALLOUT

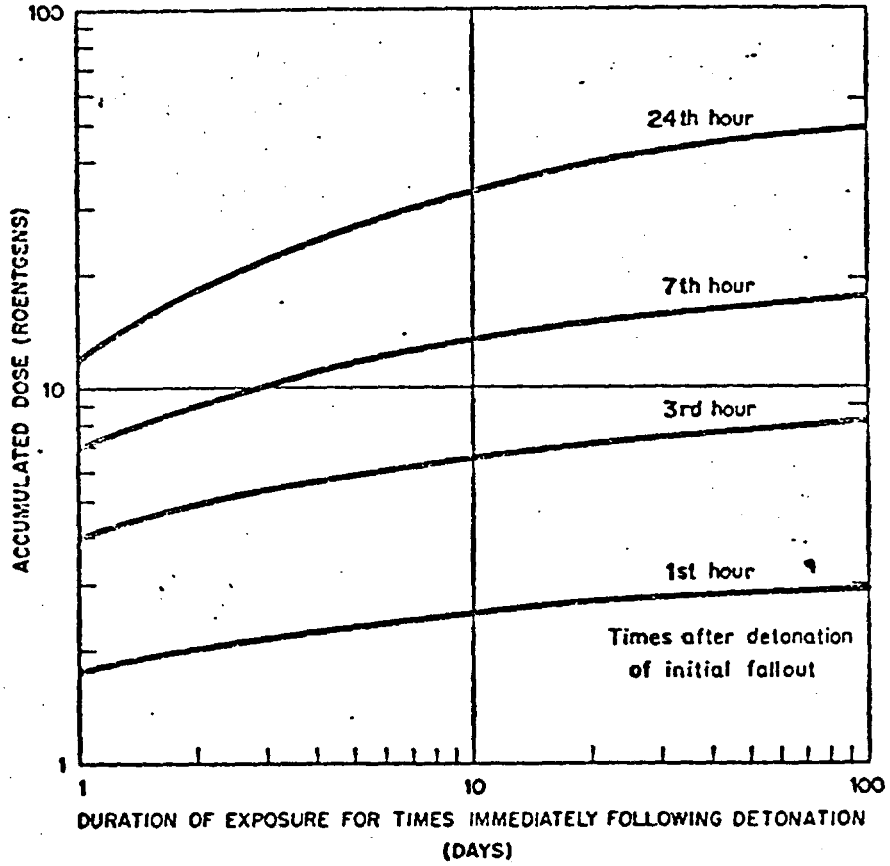
Structure	*Approximate Factor*
Frame House	
First floor	2
Basement (center)	10
Basement (side)	>10
Multistory Reinforced Concrete	
Lower floors (away from windows)	10
Basement	~1,000
Shelter (equivalent of 3 feet of earth)	~1,000



Graph 2. Gamma dose rates on the island of Rongelap following detonation of March 1, 1954.

Field measurements, as well as calculations, have indicated the attenuation of gamma dose rates to be expected from the shielding afforded by various structures. Obviously, there will be wide differences in this respect, depending upon the type and size of the structures; Table I gives some rough estimates of this factor of shielding. For the moment, let us consider a situation in which no special evasive measures are taken and people continue to live normally in the contaminated environment. Great variation in the amount of accumulated radiation dose may be observed, dependent upon the location of personnel in relation to different types of buildings or natural terrain features and on the length of stay at a particular place.

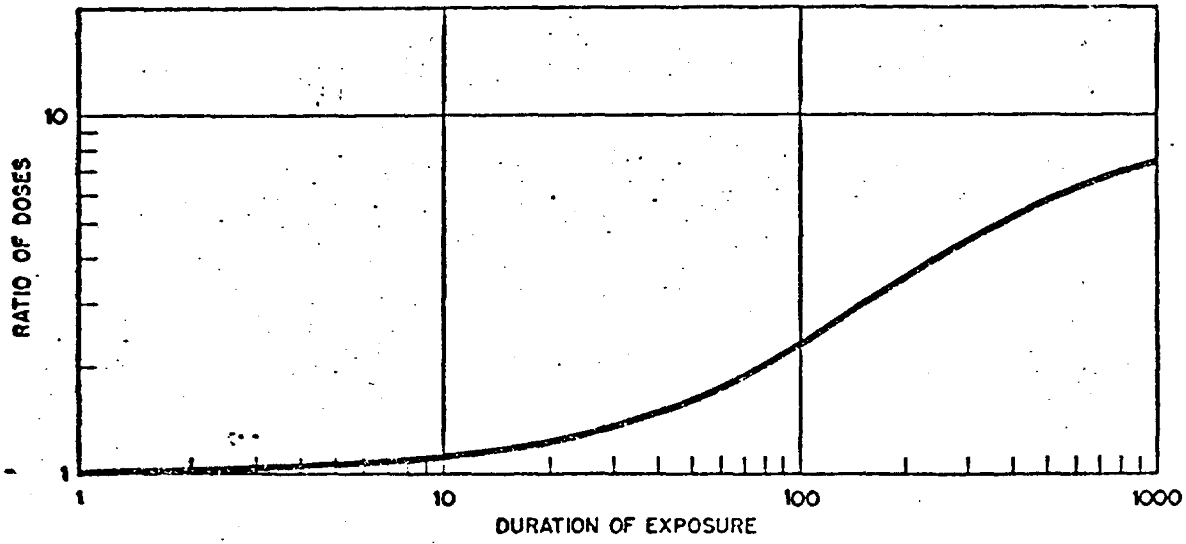
During the 1955 nuclear test series at the Nevada Test Site, a number of film badges were placed outside and inside school buildings. The ratios of out-of-door to indoor doses ranged from 1.3 to 7. As anticipated, one-room frame buildings generally provided the least protection, with multiroom single-story concrete block buildings falling within the upper range of values. Since the duration of the exposures was generally less than one week, the effect was undoubtedly due principally to shielding rather than to weathering effects. Limited data were also collected for personnel—school teachers, physicians, mechanics, and others—wearing film badges as they went about their normal activities in adjacent communities. Out-of-door radiation doses were calculated on the basis of the survey data of monitoring teams shortly after fallout (as would be done in emergency situations); these were later compared with the doses indicated on the personnel film badges. The ratio of doses measured on film badges to those calculated for out-of-doors generally fell between 0.4 and 0.5. Duration of exposure ranged from two to three weeks.



Graph 3. Estimated average accumulated gamma radiation doses for personnel continuing to live normally in a contaminated area, based on a dose rate of 1 r per hour at time of fallout. See text for assumptions.

On the basis of these data the dose with shielding during normal occupancy of an area may be conservatively estimated at 25 per cent less than that received by persons fully exposed for twenty-four hours each day.

One may combine the assumptions made for weathering and shielding and arrive at a family of curves which estimate the accumulated radiation dose for persons living normally in a contaminated area (Graph 3). Since Graph 3 is based on an assumed dose rate of 1 r per hour at the time of fallout, the accumulated doses may be linearly extrapolated to any other dose rate at fallout. For example, if fallout begins at three hours after detonation and the dose rate at that time is 10 r per hour, then about 90 r might be accumulated by personnel continuing to live normally in the contaminated area.



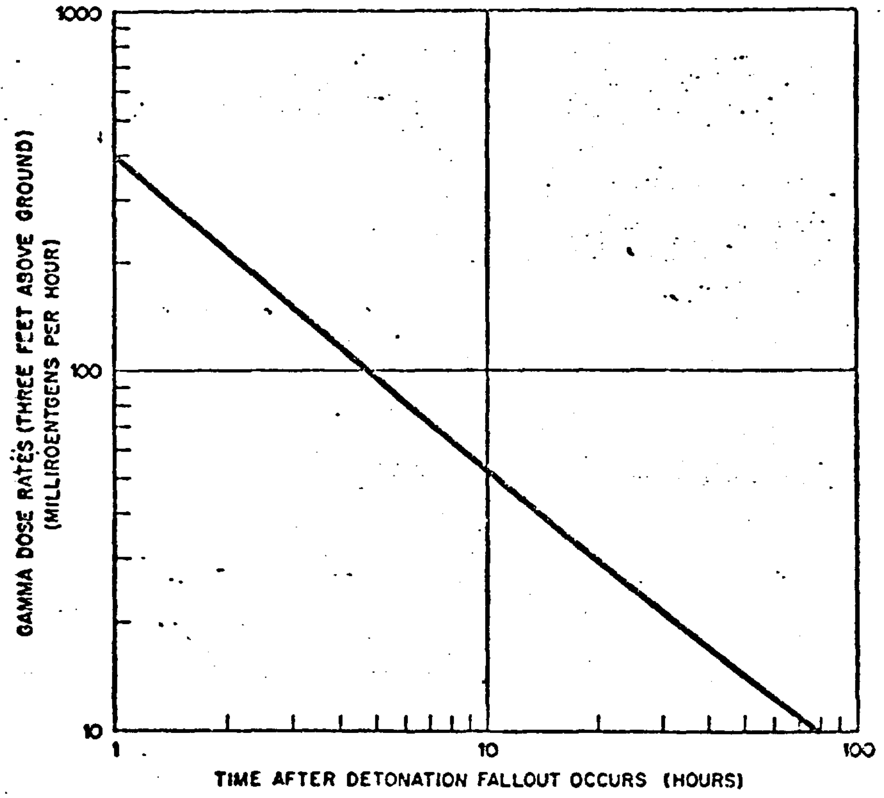
Graph 4. Ratio of total accumulated equally fractionated daily gamma whole-body doses to a one-day exposure to produce the same whole-body effects.

TIMED DOSES AND BIOLOGICAL EFFECTS

It has been recognized that, in general, the longer the period over which a given radiation dose is delivered, the less is the resultant biological effect, except for such aspects as the genetic. Since past experiments usually have been designed for other purposes, the data from these do not readily elucidate the rate of repair or the proportions of reparable and irreparable damage resulting from differently timed doses. Varying relationships have been demonstrated, depending upon the species or even the strain of animal, as well as the criteria selected for study, such as skin damage, life shortening, and LD 50 values. Our present knowledge does not permit establishment of a precise overall relationship for timed doses *versus* biological effects; yet there are sufficient convincing data to permit an attempt at estimating the effect of this phenomenon.

Blair (6, 7,) Smith (8), Davidson (9), and others have made extensive analyses of existing data on the effects of time-spaced doses for several species of animals. Generally, the recovery rate for larger mammals, such as dogs, is significantly less than for mice. One estimate places the half-time recovery for man at four weeks (9). The most conservative estimate of the effect of time-spacing of doses, for application to the problems under discussion, is that of Davidson. On the basis of his analysis, a plot has been constructed (Graph 4) of accumulated, equally fractionated daily doses *versus* an acute exposure which would result in the same whole-body effect (death or sickness). This analysis indicates, for example, that if a radiation exposure is divided into equal daily doses, the total amount accumulated over eighty days would be twice the amount required by a one-day exposure to produce death or sickness.

The calculations necessary to incorporate the factor of timed doses into those for radiological decay, weathering, and shielding are rather tedious. An approximation may be made merely by superimposing Graph 4 on Graph 3; the point where the curves become tangential is the point of maximum effect to be expected from doses accumulated from fallout. It is not intended to imply that no further radiation damage is received from exposure after that time. Rather, the analysis does indicate that if the accumulated dose from fallout up to the time of tangency is not sufficient to produce death or radiation sickness, than (*a*) the rate of repair (for the reparable portion of the dose received) will exceed the rate of exposure thereafter, and, of course, (*b*) the irreparable fraction of the total dose for the duration of the fallout will be insufficient to produce these whole-body effects. It is recognized that the rates of dose accumulation as calculated by the two methods (Graphs 3 and 4) are not identical, since a larger proportion of the total dose accrues from fallout during the first part of the exposure period. This more rapid rate of delivery might increase the percentage of irreparable damage to some extent. On the other hand, a greater proportion of the biological damage would occur early in the exposure period, allowing a longer time for the reparable factor to operate before the curves become tangential. The radiation status for the reparable fraction of the damage is thus better at the time of tangency. Until more definitive data are obtained, this analysis may serve to approximate the biological repair factor.



Graph 5. Approximate gamma dose rates at time of fallout to produce an estimated effective biological dose of 1 r for personnel continuing to live normally in a contaminated area. See text for assumptions.

Graph 5 incorporates into a single curve the major effects due to weathering, shielding, and biological repair. The radiation dose arrived at by these calculations is called the "effective biological dose." As in the previous graph, the accumulated

TABLE II: APPROXIMATE AREAS ENCOMPASSED BY THE EFFECTIVE BIOLOGICAL ISODOSE LINES SHOWN IN THE MAP (FIG. 1).

Isodose Line (r)	*Approximate Areas Encompassed (square miles)*
50	25,000
100	12,500
400	5,000

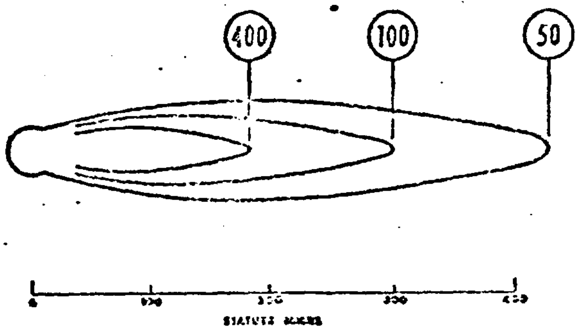


Fig. 1. Idealized fallout diagram, based on high-yield nuclear detonation of March 4, 1954. Isodose lines represent effective biological doses (roentgens).

doses may be extrapolated linearly to any other dose rate at time of fallout. For example, if fallout begins three hours after detonation and the dose rate at that time is 10 r per hour, about 67 r (effective biological dose) will be accumulated provided personnel continues to live normally in the contaminated area.

$$\frac{10}{0.15} = 67$$

It is frankly recognized that in any single curve, such as that shown in Graph 5, there are inherent a number of uncertainties that are open to discussion. Criteria based on deliberate analyses of the relevant data, however, may be more valid than those determined under the duress of an emergency situation. Such a simplified graph might provide radiological monitors with a quick, even if rough, estimate of the potential hazards and thus assist in making decisions as to possible evacuation, etc.

FALLOUT PATTERN FROM HIGH-YIELD WEAPONS

From Graph 5 and data from other sources (10, 11), an idealized diagram of effective biological doses for fallout from the March 1, 1954, surface detonation at the Pacific Proving Ground has been prepared (Fig. 1). It is to be emphasized that (*a*) *different yields of weapons, different wind structures, and different kinds of land surface, would result in different patterns*, and that (*b*) *this is the amount of fallout from a single high-yield weapon.*

The two innermost isodose lines shown were selected to suggest regions where (*a*) a significant percentage of personnel might be expected to die (400 r) and (*b*) a few per cent to become ill (100 r), assuming continued occupancy of these areas with no special protective measures. These percentages would, of course, rise within the encompassed areas. The 50-r effective biological isodose line has no unique significance but suggests the magnitude of dose which might call for emergency measures against radiation exposures even in the face of other possible hazards. Table II shows the approximate areas encompassed by the three isodose lines. For areas where the fallout occurs a few hours or more following detonation, many days or weeks will be required to accumulate the major portion of effective biological doses, so that spot decisions involving additional hazards might not be necessary.

PROTECTIVE MEASURES

The idealized fallout diagram is based on the assumption that people continue to live normally in an area and that they do nothing special to protect themselves. Actually many measures can be taken to reduce the gamma radiation dose. These may be classified under four headings: 1. Evacuation. 2. Use of shielding. 3. Decontamination of the environs. 4. Allowing for lapses of time before entry into a contaminated area. These measures will be discussed only briefly.

Where relatively small numbers of people are involved, *evacuation* could be an easy solution. For large communities, major factors of danger and/or hardship must be considered. Each situation may be unique, and independent decisions must be

TABLE III: ESTIMATED REDUCTION IN GAMMA DOSE RATES AT THREE FEET ABOVE THE GROUND TO BE EXPECTED FROM VARIOUS DECONTAMINATION PROCEDURES ON LAND SURFACES*

Procedure	*Approximate Reduction Factor*
Plowing (to depth of 8 inches)	3
Bulldozing or grading (to depth of 4 inches)	4
Fill (clean dirt to depth of 6 inches)	5
Scraping (to depth of 4 inches, with concurrent removal of exhumed dirt)	10

* Based on data in Radiological Recovery of Fixed Military Installations (12).

made accordingly; it is not possible to establish beforehand any general rule of action based on radiological considerations alone. The complex factors entering into this problem cannot be discussed here. There is available, however, a considerable amount of data on the radiological aspects of fallout to aid civil defense authorities in making the decisions which will ultimately rest with them.

The amount of protection afforded by *shielding* is suggested in Table I. The exact dose rates that might be expected from a fallout cannot be predicted, but it appears reasonably certain that a shielding factor of 1,000 would, even in the areas of heavy fallout, reduce the radiation below levels which might produce sickness. Such a reduction might be attained by about 3 feet of earth or sand or 19 inches of concrete. Even the cellar of a frame house will reduce the dose rate by a factor of about 10, which might spell the difference between relative safety and the danger incident to full exposure. In the area of maximum contamination, however, located within the 400 r ellipse of the fallout diagram, a factor of 10 might not be enough to keep the accumulated dose below a hazardous level, even for a period of half a day following fallout; in that case more protective shelters or evacuation would be required.

The third measure that might be taken to reduce the radiation dose is *decontamination* of the environment after fallout has occurred. Table III, based on field data (12), indicates the degree of reduction in gamma dose rates at three feet above the ground which might be accomplished by various operations on the soil. Table IV gives reductions of contamination of surfaces as estimated by one method of determination. (For more extensive analyses see references 12, 13, and 14.)

The final factor of major benefit in reduction of radiation dose is the *lapse of time*. On the basis of radiological decay alone, the activity (disintegrations per minute) decreases approximately according to the principle of $(\text{time})^{-1.2}$. Thus, for every sevenfold lapse of time after a nuclear explosion, there will be a tenfold reduction in dose rate. For example, if fallout occurs one hour after a detonation, the dose rate will be one-tenth of its initial value by the seventh hour; an additional tenfold reduction would require about two additional days of waiting. Similarly, the total possible out-of-doors dose accumulated from the first to sixth hour after detonation would be approximately the same as that from the sixth hour until one week later. Further, this first-week dose would be about twice as great as the entire remaining dose possible for the lifetime of the activity, even in the absence of weathering. This rapid decay suggests the benefits of protection in the early periods after fallout and, where possible, delay of entry into a contaminated area.

TABLE IV: ESTIMATED REDUCTION IN CONTAMINATION OF SURFACES USING A FIRE HOSING METHOD*

Surface	*Approximate Reduction Factor*
Concrete	10
Wood	30
Metal	30
Roofing	30

* Based on a dry contaminant. For a slurry contaminant, the reduction factors might be only one-third as great. Pre-protection of wood and concrete surfaces, *e.g.*, with sealers or paints, might increase the reduction factor by a factor of about 3. (Based on data in Radiological Recovery of Fixed Military Installations (12)).

The question is frequently asked as to the time one must spend within a shelter or remain outside of a contaminated area. The answer depends upon a number of parameters, such as the criteria established for maximum permissible dose, as well as length of stay within the area of contamination. With knowledge of the magnitude of the radiation levels present and the rate of decay, $(t)^{-1.2}$, it is possible to plan and execute a short stay even in a highly contaminated area. Planning for continuous occupancy requires more extensive analysis. The following data may aid in such evaluation.

The fallout map and Table II suggest the degree of radiation exposure received in continuous occupancy under normal living conditions beginning with the time of initial fallout. For those entering the contaminated zone four months after the first fallout, however, and then living there indefinitely, the area encompassed by the 50-r effective biological isodose line will have shrunk from about 25,000 to 2,500 square miles. At such time (four months after fallout), an area of about 1,000 square miles within the 50-r isodose line might have the highest residual contamination, amounting to about three times the dose rates at the periphery. The 0.3 r per week out-of-doors isodose-rate line might extend to about the same position as the line marked 50 on the map.

As one attempts to extrapolate such data to one year after fallout, the analysis becomes still more difficult and uncertain. The data suggest, however, that if return is postponed to one year after fallout, the 50-r effective biological isodose line will have disappeared. On the basis of these conservative estimates, the 1,000 square miles of highest contamination might have an out-of-doors dose rate of about 4 r per week after one year. Similarly, personnel might accumulate a dose of about 100 r for the first year following exposure and an additional 90 r over the next three years, independent of the biological recovery factor. It is to be expected that this factor would be relatively great for such long periods of time, thus reducing the effective biological dose below 50 r. The 0.3 r per week out-of-doors isodose-rate line might encompass an area somewhat larger than the line marked 400 on the map. (The weathering factor for the islands in the Pacific has been greater than the assumed value for large land masses, so that at one year the out-of-doors dose rate on these islands was less, by a factor of almost 2, than would be predicted by the method suggested here.)

The foregoing analyses are based on passive factors only, not taking into account the actions of persons themselves in reducing contamination. If, for example, a permanent return into an area were postponed for one year after fallout, the radiological situation would probably have been adequately appraised, and decontamination operations initiated. Moreover, with the return of a populace into a known contaminated area, more than normal precautions might be expected in regard to occupancy of the more protective types of buildings and reduction of time spent out-of-doors.

It appears not unreasonable to assume that the theoretical out-of-doors dose rates for the areas of highest residual contamination, calculated by means of the extrapolations given above, actually might be many times reduced. The data thus suggest that, with this type of detonation, continual occupancy even of the most heavily contaminated area need be prohibited for only about one year.

The task of evaluating radiation exposures from fallout is fraught with uncertainties, and one instinctively shrinks from proposing criteria based on such variables and intangibles. Yet we would be doing ourselves a disservice if we did not attempt an analysis of the relevant factors and incorporate them into some conceptual scheme as indicated here. The analytical approaches, and certainly the quantitative values suggested, are not to be considered precise but are intended, rather, to give order-of-magnitude estimates. It is believed that they are, in general, conservative, *i.e.*, they do not underestimate the potential hazards involved.

Division of Biology and Medicine
U. S. Atomic Energy Commission
Washington, D. C.

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SUMARIO

Pautas para Justipreciar las Exposiciones a las Radiaciones Gamma Procedentes del Desprendimiento Consecutivo a las Detonaciones Nucleares

Repásase aquí el problema de la radiación gamma externa emitida después de depositarse en la tierra el material lanzado.

Las exposiciones a la radiación procedente de un campo de desprendimiento discrepan de la mayor parte de los experimentos de laboratorio con respecto a la geometría y al espectro de energía, lo cual hay que tomar en cuenta al valuar los efectos biológicos. Además del factor de decadencia radiológica, los efectos se ven afectados por la exposición al aire, el resguardo (como por edificios y terreno) y el tiempo de la dosis. Utilizando estos factores, se ofrece un diagrama idealizado de desprendimiento para una explosión superficial de mucho rendimiento, indicando zonas de diversos grados de contaminación. Las medidas protectoras corresponden a cuatro tipos distintos: (a) resguardo, (b) evacuación, (c) transcurso de tiempo y (d) descontaminación.

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DISCUSSION OF
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PUBLIC PROTECTION AT THE NEVADA TEST SITE

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Gordon M. Dunning
U. S. Atomic Energy Commission
Division of Biology and Medicine
Washington, D. C.

February 1955

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DISCUSSION OF
RADIOLOGICAL SAFETY CRITERIA AND PROCEDURES FOR PUBLIC PROTECTION AT THE NEVADA TEST SITE

Gordon M. Dunning
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Washington, D. C.

February 1955

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INTRODUCTION

The criteria and procedures set forth in the following paragraphs were established after full consideration for protecting the health and welfare of the public, both in terms of radiological exposure as well as possible hazards, hardships or inconveniences resulting from disruption of normal activities. Criteria are established as guides for the Test Organization in determining whether any special actions should be taken to protect the public.

With improved methods of predicting fallout and with the use of higher towers for detonating the nuclear devices, it is expected that fallout in populated areas from future tests at the Nevada Test Site will be less than the highest amounts which have occurred in the past.

Two basic assumptions are made in this report:

a. It is the responsibility of the Division of Biology and Medicine to establish such criteria and procedures for the Atomic Energy Commission as deemed necessary to protect the health and welfare of the general populace from consequences of weapons tests conducted at the Nevada Test Site.

b. The operational procedures adopted for meeting these criteria and procedures shall be the responsibility of the Test Manager, as directed by the Division of Military Application, with the technical guidance of the Division of Biology and Medicine.

The following criteria do not apply to domestic or wild animals since levels of radiation which would be significant to them would have to be higher than those specified herein.

CRITERIA I

Evacuation

Introduction

The decision to evacuate a community is critical for two principal reasons. One, presumably there might be a health hazard if the personnel were allowed to remain. Two, there is always an element of danger and/or hardship to personnel involved in such an emergency measure.

It is recognized that extenuating circumstances may accompany any situation where conditions indicate evacuation as a mode of action. The size of the community, areas and accommodations available for the evacuees, means of transportation and routes of evacuation, disposition of ambulatory cases, protection of the property left behind, and many other factors may enter into the decision relative to evacuation. Further, it is recognized that under certain conditions, the evacuation of a community might not only prove rather ineffectual but could result in more radiation exposure than if the population remained in place unless the situation be adequately evaluated. A blanket evaluation cannot be made in advance; each situation can be unique. The following criteria therefore are suggested as guides in assessing the possible radiological hazards; the final decision must be made on the basis of all relevant factors known at the time.

[redacted]

Criteria

Table Ia summarizes the radiological criteria to be used in evaluating the feasibility of evacuation.

TABLE Ia

RADIOLOGICAL CRITERIA FOR EVALUATING FEASIBILITY OF EVACUATION

Effective Biological Dose* Calculated To Be Delivered In A One-Year Period Following Fallout	Minimum Effective Biological Dose That Must Be Saved By Act Of Evacuation (Otherwise Evacuation Will Not Be Indicated)
Up to 30 roentgens	(No evacuation indicated)
30 to 50 roentgens	15 roentgens
50 roentgens and higher	(Evacuation indicated without regard to quantity of dose that might be saved)

*The "effective biological dose" is an estimate of a biological "damage" dose, taking into account the length of time for delivery of a given dose, and the reduction of dose due to (a) shielding afforded by buildings and (b) the process of weathering.

The rationale for table Ia is as follows: The total effective biological dose that would be received if evacuation were not ordered is obviously a determining factor. Another consideration is the fact that such an action as evacuation could be dangerous to the individuals and could also possibly be detrimental to a very necessary national effort of weapons development. One must then ask, "Just how much will be gained (radiation dose saved) by evacuation?" Estimates of these two variables are indicated in table Ia. Thus, a populace may receive up to a calculated 30 roentgen effective biological dose in one year without indicating evacuation; from 30 to 50 roentgens, evacuation would be considered

[redacted]

only if at least 15 roentgens could be saved by such action; and at 50 roentgens or higher evacuation would be indicated without regard to the possible savings in radiation dose.

In making a rough estimate of radiation doses, one may calculate a theoretical maximum infinity gamma dose and then arbitrarily divide by some number such as "2" for an estimate of dose actually received. Whereas this may be satisfactory as a first approximation, a more accurate estimate should be attempted, especially when dealing with doses that might constitute a health hazard.

Owing to the necessity of making early measurements and decisions, it is to be expected that dose-rate readings, taken with survey meters, will be the available evidence at the times of concern. Table Ib summarizes the parameters considered in estimating an effective biological dose based on dose-rate readings.

TABLE Ib

PREDICTING EFFECTIVE BIOLOGICAL DOSES FROM DOSE-RATE READINGS

	A. Theoretical Maximum Dose (Based on Best Estimated Rate of Decay)	B. Biological Factor	C. Attenuation and Weathering Factor	D. Effective Biological Dose Factor (ColumnBxC)	E. Effective Biological Dose (ColumnAxD)
From time of fallout until time of evacuation		1/1	1/2	1/2	
From time of evacuation to time of return*		3/4	3/4	1/2***	
From time of return to a time 15 days after initial fallout**		3/4	3/4	1/2***	
From 15 days until one year after initial fallout		2/3	1/2	1/3	
				TOTAL	

*This estimate is based on the concept that if evacuation were not accomplished, then a certain radiation dose would be accumulated over the period of time selected. This time period also represents the radiation dose saved if evacuation were accomplished.

**This assumes that the time of return occurs before 15 days. A period of 15 days was selected to provide a dividing point between the time of initial exposure from fallout to a time one year later. The 15 days has no unique significance other than providing a basis on which to estimate the biological factor.

***The value of 9/16 has been rounded off to 1/2.

[redacted]

At a later time after fallout, better estimates of radiation doses received may be obtained from film badge readings or dosimeters. If these film badges or dosimeters are worn on personnel and the evidence of their use supports the view that the readings are a reasonably accurate account of the radiation dose received then the values recorded on the film badge or dosimeter may be accepted with a correction factor of 3/4 to account for the difference between the dose received by the film badge or dosimeter (including backscatter) and that received at the tissue depth of five centimeters. Table Ic may be used in estimating the effective biological dose from film badge or dosimeter readings.

TABLE Ic

	A. Film Badge Reading	B. Biological Factor	C. Film Badge or Dosimeter Correction	D. Effective Biological Dose Factor (Column B X C)	E. Effective Biological Dose (Column A X D)
From time of fallout until time of evacuation		1/1	3/4	3/4	
From time of return to 15 days after initial fallout		3/4	3/4	1/2*	
From 15 days until one year after initial fallout		2/3	3/4	1/2	
				TOTAL	

*The value of 9/16 has been rounded off to 1/2.

Discussion of the Biological Factor. As longer periods of time are involved in the delivery of a given radiation dose, lesser biological effects may be expected. From the time of fallout until the time of evacuation probably will be a matter of hours, which has been considered essentially an instantaneous dose, i.e., the biological dose factor is 1/1. From the time evacuation could be accomplished to time of return probably would be a matter of several days, so the biological factor has been estimated at 3/4. From 15 days after fallout until one year later is essentially a duration of one year, so the biological factor has been estimated at 2/3. It will be noted there is no calculation after one year, because it is expected under actual conditions of radiological decay and weathering that probably no significant dose will be delivered after a year's time in populated areas around the Nevada Test Site.

It is recognized that the precise quantities suggested for the biological factor cannot be supported by conclusive evidence. It is reasonable to expect that the delivery of a given radiation dose over a period of many days will have less biological effectiveness than an instantaneous one (neglecting genetic effects) and that the extension of the period to essentially one year should yield a still lower biological factor. One piece of supportive evidence is the work of Strandgvist* where X-ray doses to the skin were fractionated into daily amounts, and the biological effects compared to a one-treatment dose. A log-log plot of total doses versus days after initial treatment yielded straight lines. For example, the curve for skin necrosis indicated a ratio of 3000/6700 roentgens for a one-treatment versus 15 daily equally frac-

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*Sievert, Rolf M. "The Tolerance Dose and the Prevention of Injuries Caused by Ionizing Radiations". British Journal of Radiology, Vol. XX, No. 236, Aug. 1947.

[redacted]

tionated doses. Of course, daily radiation doses received from fallout are not equally fractionated so that the ratio would be in the direction of unity. Day-by-day doses delivered from fallout from the 15th day to one year are more nearly equivalent than at early times (ignoring the weathering factor). Strandgvist data do not extend beyond 40 days and it is questionable to extrapolate his data in an attempt to derive a similar ratio as above based on one year, since other uncertainties are so great, i.e., effects of weathering as affecting the rate of dose delivery, etc. The ratio would presumably be farther from unity than for a 15-day period. The skin is a relatively rapidly repaired organ and thus may tend to over-emphasize the effects of fractionation when considering whole-body gamma doses*.

Cronkite reports**

> "In the dog, with cobalt gamma rays, the d[illegible] that will kill 50 percent of the dogs in a thirty-day p[illegible] when delivered in a single dose at roughly 15 r per min[illegible] s approximately 275 r. After this dose of radiation th[illegible] ls become ill within a period of 7 to 10 days and deat[illegible] ur between the eighth and twenty-fifth day. Hemorrhag[illegible] ctions, and profound anemia are prevalent. If the [illegible] decreased to 100 r per day given over a fourteen-hou[illegible] d, the lethal dose is increased to 600-800 r. Under [illegible] nditions, the animals die in approximately the same p[illegible] of time with identical manifestations. If the expos[illegible] dropped to 25 r per day given over a fourteen-hour peri[illegible] lethal dose is then increased to well over 1200 r, and [illegible] ymptoms and findings are changed."

One problem in such experiments is the evalu[illegible] n of possibility that the animals may be virtually dead while the [illegible] sures are continued. This might be illustrated in experiments [illegible] ing the burro where the daily doses of 400, 200 and 100 roent[illegible] given to three separate groups required 3600 to 4000, 2800 to 3[illegible] and 2000 to

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*See Addendum, page 28.

**Medical Aspects of Radiological Defense. Cronk[illegible], E. P. Lecture to Federal Civil Defense Administration, Region[illegible] onference of Northeastern States of Radiological and Chemica[illegible] fense, New York City, October 22, 1953.

2600 total roentgens respectively for 100 per cent lethality*.

Experimental data reported by Boche** are summarized below.

No. of Days	Dose per Day (r)	Dose per Week (r)	Survival Time (Wks)	Total Dose (r)
20	10	60	24	1440
10	6	36	83	2988

Unfortunately normal survival times were not given nor were the ages of the animals (dogs).

Blair*** has taken the two points from Boche's data, inserted these into his (Blair's) equation relating reparable and irreparable damage. The ratio of instantaneous dose to 15-day dose is 350/450 or 0.78, and for 4 months dose about 350/525 or 0.67.

Blair suggests that "The points are too few to determine the constants (of the equation) with any accuracy but should at least be in the proper range." However, the constants of his equation have checked well with more extensive data on other animals. His equations indicate that the rate of recovery of reparable injury is fastest in the mouse (of the types of mammals selected), about one-half as fast in the rat and about one-seventh as fast in the guinea pig and dog, but as Blair pointed out, the reaction of the dog is more representative of the larger, longer-lived animals.

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*UCLA-295. <u>Response of the Burro to 100 r Fractional Whole-Body Gamma Ray Radiation.</u> Haley, T. J. et al. June 10, 1954. Unclassified.

**MDDC-204. <u>Observations on Populations of Animals Exposed to Chronic Roentgen Irradiation.</u> Boche, R.D. 1947. Unclassified.

***UR-207. <u>A Formulation of the Injury, Life Span, Dose Relations For Ionizing Radiations. II. Applications to the Guinea Pig, Rat, and Dog.</u> Blair, H. A. July 3, 1952. Unclassified.

[redacted]

Discussion of the Attenuation and Weathering Factor. From the time of fallout until the time of evacuation it is expected that personnel will be kept indoors. (See Criteria II.) Major losses due to weathering can not be relied upon during this period, so that the estimated factor is 1/2. From the time evacuation could have been accomplished until the time of estimated return it is assumed that personnel will be indoors about half of each 24 hours and that major losses due to weathering can not be relied upon. The over-all factor is thus 3/4.

The same reasoning applies to the third period of time, i.e., from assumed time of return to 15 days after fallout.

From 15 days after fallout until one year later it is estimated that the attenuation due to buildings and the effects of weathering will yield an over-all factor of 1/2.

Dose rate readings have been taken with survey meters outside and inside of houses around the Nevada Test Site after fallout occurred. The ratio of readings varied with the type of construction of the house and with the location within the building. Generally, the ratio of readings outside to inside a frame house was about 2/1 with a somewhat greater difference for masonry construction. A limited number of film badges were placed outside and inside of some houses during Tumbler-Snapper and also Upshot-Knothole. In the first case, the difference in total doses was again 2 to 1 or greater but during Upshot-Knothole only about a 20% difference was noted. In fact, in one case during Upshot-Knothole the film badge inside read higher than outside. The differences between these experimental data will have to be investigated during future operations.

The very nature of the weathering factor makes this a difficult parameter to evaluate. The probability of occurrence of precipitation and/or winds and to what degree has to be estimated as well as their effects on radiation levels. Leaching effects were studied on soils about 130 miles from ground zero where fallout had occurred during Upshot-Knothole. Dose rate readings were insignificantly lower than those predicted by radiological decay according to $t^{-1.2}$ after a period of more than one year. One example of the effects of winds was observed during Upshot-Knothole. The fallout from the March 17, 1953 detonation was in a long narrow pattern to the east of ground zero. The second day after fallout a rather strong surface wind blew almost at right angles across the area, for about a period of a day. Dose rate readings were taken on the first and fourth days at the same locations and then were compared. The fourth day dose rates were less, by factors of three to six, than those to be expected from the first days readings, based on rate of decay of $t^{-1.2}$. (Other fallout measurements indicated that the rate of decay of this fallout material was not significantly different from $t^{-1.2}$.) Because of the physical conditions described above, these reductions in contamination probably are near the upper limit to be expected from wind.

Operational Feasibility of Criteria

It is not the intent here to discuss operational procedures, but it should be indicated that the computing of radiation doses as recommended in Criteria I is a not too difficult task. If one assumes a $t^{-1.2}$ rate of decay as a first approximation, then a single graph of dose rates versus times after detonation can be constructed that will represent a 30 roentgen effective biological dose for one year. An additional family of curves can be made that will provide the answers to the parameters of how much time would be available before evacuation and of how long a time personnel would have to remain out of the radiation area in order to provide for a savings of at least 15 roentgens.

The highest whole-body gamma dose recorded for any locality where personnel were present outside the Nevada Test Site was at Riverside Cabins, Nevada (about 15 people) following shot number seven of ~~Tumbler-Snapper~~ Upshot-Knothole. The maximum theoretical infinity gamma dose was estimated to be 12-15 roentgens.

CRITERIA II

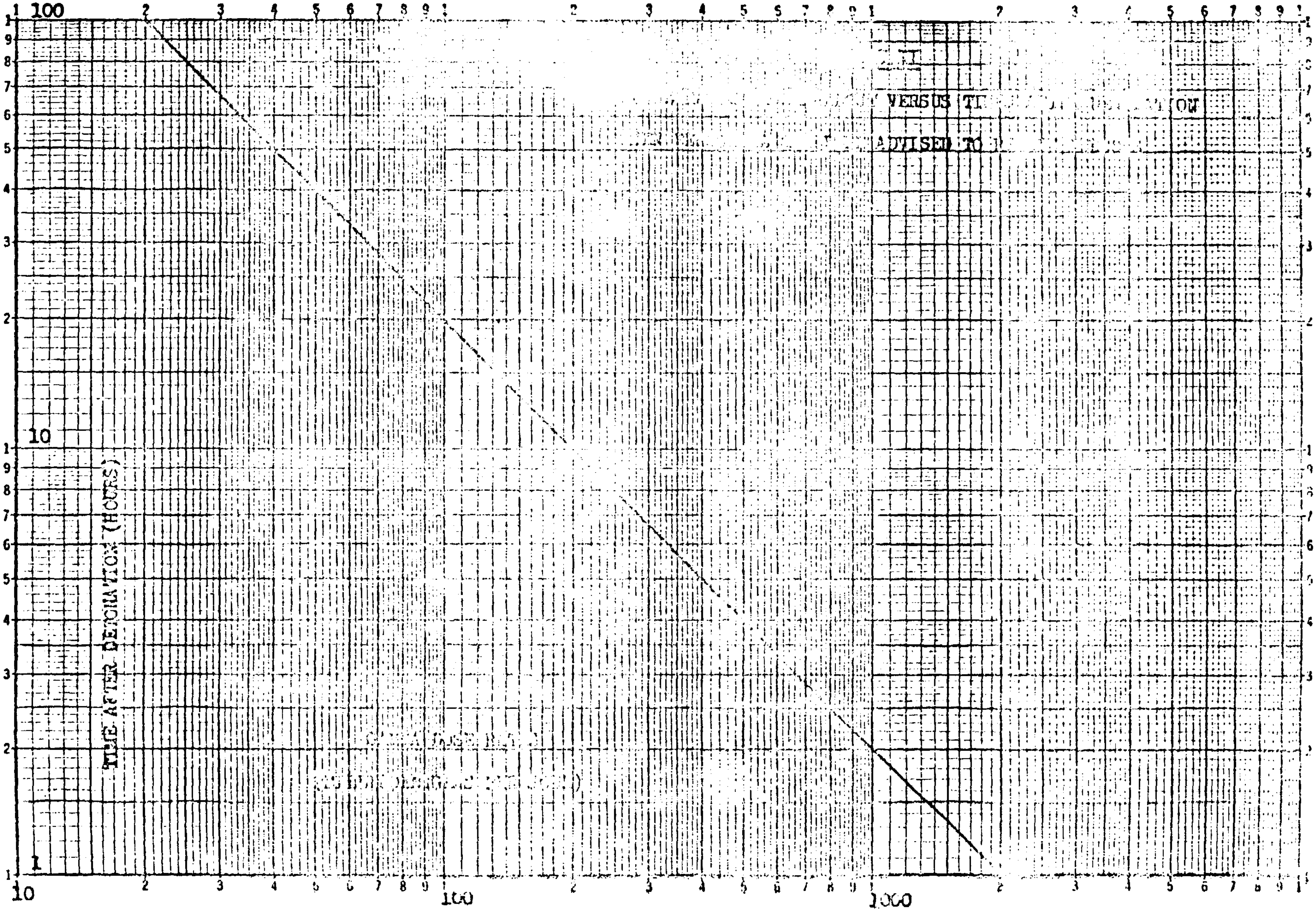
Personnel Remaining Indoors

When the gamma dose rate reading as measured by a survey meter held three feet above the ground reaches the values given in Graph II at the times indicated, it is recommended that personnel shall be requested to remain indoors with windows and doors closed. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

In the event that there be convincing evidence that the radiation levels given in the graph will be reached, it is recommended that personnel be requested to remain indoors BEFORE fallout occurs or before the radiation levels equal those in Graph II. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

It is recommended that people who had been out-of-doors during fallout of the above magnitude or greater be advised to change clothing and to bathe. The clothing may be cleaned by normal means. While bathing, special attention should be paid to the hair and any exposed parts of the body.

In the event that the monitoring takes place AFTER the fallout has occurred, and extrapolation of the dose rate readings equals or exceeds those in Graph II at the estimated time of fallout, then it is recommended that the same advice be given as in the preceding paragraph.


VERSUS TI
ON
ADVISED TO
TIME AFTER DETONATION (HOURS)
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100
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1
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4
5
6
7
8
9

CRITERIA II

Personnel Remaining Indoors

DISCUSSION

The action of requesting personnel to remain indoors is predicated on the principle that the radiation levels are below those established for evacuation and that this action could reduce the amount of contamination of personnel and reduce somewhat the whole-body gamma dose. (See Appendix A for estimates of reduction in whole-body gamma dose.) The actual "savings" healthwise have to be balanced against possible adverse public reaction.

The principal gain in requesting personnel to remain indoors is to prevent or reduce the amount of atomic debris that may actually fall on the body or clothing. Since the peak of fallout usually occurs shortly after the start of fallout, it is important that prompt decisions and actions be taken. Thus, by necessity, the most practical criteria upon which to base a decision are gamma dose rate readings, which are in turn related to the amount of fallout.

Beta Dose To Skin

The most immediate solution might be to establish lower permitted dose rate levels at later times after detonation. However, if a series of dose rates are established for increasing times after detonation so that their relationship follows $t^{-1.2}$, then the doses delivered in X hours (before the material is washed off) will be greater for earlier times after detonation. If one were sure of the time that the fallout material was to remain in place, then a scale of dose rates versus time after detonation could be made to yield the same total dose over the X hours. Since there is obviously no set time period for duration of contact that would be valid for all cases, one might assume the worst case where the material remains in place until its activity has decayed to an insignificant level. Dose rates could then be approximated, to yield a given infinity dose, by:

$D = 5At$ where: D = infinity dose
A = dose rate at time "t".

If the above discussion is accepted, then the remaining question is to set the infinity dose. Here, we must be clear that whereas the measurements taken by the monitors, and the data upon which action will be decided will be gamma dose rate readings, the point of principal concern is the beta dose delivered to the basal layer of the epidermis (assumed as 7 milligrams per square centimeter). The ratio of emission of beta to gamma is a function of time after detonation and follows no simple relationship. Further, this ratio at any given time after detonation has not been firmly established. One report* suggests the following data:

Time After Detonation	Beta/Gamma
72 hours	157/1
168 hours	156/1

These data were obtained from a cloud sample, rather than actual fallout material, and were a measure of surface dose on a plaque using a "dosimeter type beta-ray surface ionization chamber."

The method of collection suggests the possibility that the thickness of material on the plaques may be less than that to be expected from the amount of fallout that would be of concern when estimating probabilities of beta burns. This would result in a different angular distribution of the betas influencing the beta dose rate in the direction of a higher value for the plaques.

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*WT-26. Scientific Director's Report, Annex 6.5. "Interpretation of Survey-meter Data". SECRET.

[redacted]

Another report* indicates a beta to gamma ratio of 130 to 1 based on theoretical computations. A third report** suggests a radically lower ratio; however, there may be some doubt as to its conclusions since the ionization chamber used to measure gammas only, had a wall thickness of 1 mm of bakelite which "...excluded a small part of the total gamma dose present, as well as a large, but unknown, fraction of the beta." (The range of 0.35 Mev betas is about 100 mg/cm^2 or approximately 1 mm of bakelite.) For our discussion here, we will assume a surface beta to gamma ratio of 150 to 1.

In estimating the beta dose to the basal layer of the epidermis, one may refer to the work of Henriques***. He exposed the skin of Chester White pigs to plaques containing different radioisotopes. Pertinent data are abstracted as follows:

Isotope	Energy	Surface Dose Required To Produce Recognizable Transepidermal Injury (Roentgen-equivalent-beta)	Estimated Amount of Radiation That Penetrated Skin To A Depth of 0.09 mm. (reb)
Yttrium^{91}	1.53	1,500	1,200
Strontium^{90} Yttrium^{90}	0.61 2.20	1,500	1,400

The average maximum energy of the beta particles from fallout material varies with time but will be assumed to be roughly comparable, in respect to depth dose, to Yttrium^{91} or Sr^{90}-Y^{90}. Since the gamma dose at a depth of 7 mg/cm^2 would not be significantly different from the surface gamma dose, the ratio of 130 to 1 for beta-gamma will be assumed at the basal layer of the epidermis.

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*"An Estimate of the Relative Hazard of Beta and Gamma Radiation from Fission Products". Sullivan, William H., NRDL. April 1949. CONFIDENTIAL.

**UKP-37. Project 4.7. "Gamma-beta Ratio in the Post-shot Contaminated Area". June 1953. CONFIDENTIAL-RESTRICTED DATA.

***"Effect of Beta Rays on the Skin As A Function of the Energy, Intensity, and Duration of Radiation". Henriques, F.W. Laboratory Investigation.

[One experiment with sheep, using Sr^{90}-Y^{90} plaques, showed that 2500 reps at the plaques' surface produced ulceration in one but not another of two sheep.* On the other hand, 1000 rads delivered to tissue depth of 7 mg/cm^2 from a P^{32} one inch diameter disk (type of animal not stated) produced tanning, prolonged erythema and desquamation.**]

It is to be remembered that the above discussion was first based on <u>surface</u> gamma dose rates whereas the monitors will be making their gamma measurements at a height of three feet. Past field experience has indicated that the gamma reading from ionization-type survey meters at ground level is about 50% higher than at three feet. Therefore if it be assumed that a ground level gamma reading of a survey meter is equivalent to a surface dose rate, the ratio of beta dose rate at 7 mg/cm^2 to gamma dose rate at <u>three feet</u> is about 200 to 1.

Another approach to estimating the ratio of beta dose rate at 7 mg/cm^2 to gamma dose rate at three feet is as follows. Assuming a uniform distribution of 1.0 megacurie per square mile of gamma activity, the dose rate reading from an infinite field is about 4.1 roentgens/hr.*** Calculations given in appendix B indicate that a like concentration of fallout material will produce about 430 reps/hour at 7 mg/cm^2. This suggests a beta to gamma ratio of about 100 to 1 which is about a factor of two lower than the first approach. Added support to this latter method of estimating beta doses is found in appendix C.

Such considerations may be fraught with pitfalls. For example, the above discussion implies a uniform distribution of fallout

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*"Comparative Study of Experimentally Produced Beta Lesions and Skin Lesions in Utah Range Sheep". Lushbaugh, C. E., Spalding, J. F., and Hale, D. B. LASL, November 30, 1953. (UNCLASSIFIED)

**HW-33068. A status report. September 15, 1954. (CONFIDENTIAL)

***<u>Effects of Atomic Weapons</u>. 1950 material. Obviously, this is not correct but how far this deviates from the facts and to what extent this influences the results is difficult to assess. Calculations indicate that the production of recognizable beta burns from a single particle requires a high specific activity. (See Criteria III for discussion.) It may well be, however, that the particles of fallout are close enough to have overlapping of radiation fields and thus require significantly lower specific activity of the particles to produce beta burns. This hypothesis has support in that even the most superficial beta burns of the natives exposed to fallout following the March 1, 1954 detonation showed a general area affected rather than small individual spots. On the other hand, the cattle and horses exposed near the Nevada Test Site showed burns over areas only about the size of a quarter. Even though these may not have been produced by single particles, they do represent less of an area effect than suggested for the natives. Also, radioautographs of the fallout in areas outside the Nevada Test Site suggest the occurrence of individual particles with non-overlapping of radiation fields. However, in nearby areas where the fallout was relatively heavy, there was a definite overlapping of the fields.

WITH OUR PRESENT KNOWLEDGE IT SHOULD BE STATED THAT DUE TO THE PARTICULATE NATURE OF FALLOUT IT WOULD NOT BE POSSIBLE TO ESTABLISH REASONABLE AND OPERATIONALLY WORKABLE CRITERIA THAT AT THE SAME TIME WOULD GUARANTEE THAT THERE <u>NEVER</u> WOULD BE AN OCCURRENCE OF A BETA BURN.

If one were to accept the assumed beta to gamma dose rates of about 100-200 to 1 (measured under the conditions given above), this might mean an infinity beta dose of 1000-2000 reps to the basal layer of the epidermis when the whole body infinity gamma dose was 10 roentgens.

Of course, the fallout material may be removed before the infinity dose is delivered; yet, on the other hand, it is not improbable that it could remain in the hair for essentially this length of time. In the case of a one-hour fallout, almost one half of the dose would be delivered in the next 24 hours.

The efficiency of a surface for collecting and holding the fallout material is important. It is not surprising that the highest dose rate readings as well as biological effects were noted on the hair of the natives and also on parts of the exposed body where perspiration was present. Further, it was observed that even one layer of light cotton material was sufficient to protect against beta skin damage in most cases*. This was due probably not to the relatively small attenuation of the betas by the clothing but rather to the physical situation of holding the radioactive material at some distance from the skin, which effect would be relatively large.

An added consideration is the possibility of high beta doses delivered to personnel from the fallout material lying on the ground and other surfaces. If the highest degree of contamination considered under this policy is safe when in direct contact with the skin, then the beta dose from an equally contaminated ground will not be hazardous. (See Criteria III for discussion on unequal contamination on personnel.) However, it is true that the contamination may exceed the amount to deliver dose rates given in graph II and yet not be great enough to consider evacuation. Some personnel may not go indoors and those who did will eventually be released from this restrictive action and then may walk around in a relatively highly contaminated area. Because of the more limited range of the beta, the location of greatest concern

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*ITR-923. Study of Response of Human Beings Accidentally Exposed to Significant Fallout Radiation, Cronkite, E. P., et al. May 1954.

is the lower legs.

One report estimates a beta to gamma dose rate ratio of about 75 to 1 at 10 centimeters above the ground.* Under Criteria I it was recommended that consideration be given to evacuation when the gamma dose rate reading at three feet was, for example, about 6.2 r/hr at H+3 hours. Roughly, this would correspond to about 575 reps/hr of beta at 10 centimeters. Of course, this activity decays and also it is presumed that personnel would be sent indoors, at least for a few hours. On the other hand, it strongly suggests that biologically significant doses may be delivered to the feet if not protected. Skin lesions were frequent on the bare feet of the natives evacuated during CASTLE. This probably was a combination of beta dose from material on the ground and from that scuffed up over the bare feet and then clinging to the skin. (No lesions were observed on the bottom of the feet, undoubtedly due to the thick epidermis.) It would be expected that normal closed-type footwear (as compared to open sandals) would afford adequate protection to the feet from such high beta doses as discussed here. There is still no guarantee that beta radiation from material on the ground will not deliver significant biological doses to the ankles and perhaps lower legs, after personnel are released from staying indoors. For example, if the beta dose at 10 centimeters above the ground is 575 reps/hr at H+3 hours, it would be about 250 reps/hr three hours later and 160 reps/hr six hours later.

One further possibility is the accumulation of radioactive material around the ankles and lower legs resulting from normal walking about the area. This is discussed under Criteria III.

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*AD-95(H). <u>An Estimate of the Relative Hazard of Beta and Gamma Radiation from Fission Products.</u> Condit, R. I., Dyson, J. P., and Lumb, W. A. S. NRDL 1949 (UNCLASSIFIED)

Data On Human Exposures

The work of Henriques* suggests that at the depth of 0.09 mm in living porcine skin (maximum thickness of epidermis) that "1400 ± 300 roentgen-equivalent-beta" (delivered over short periods of time so that they may be assumed to be instantaneous) is required to produce recognizable transepidermal injury. The curve of biological damage rises rather sharply so that at a dose of just under 2000 rep (at 0.09 mm), the epidermis may be expected to exfoliate and in the majority of cases go on to develop chronic radiation dermatitis persisting for months.

The preceding discussion suggests that, using the gamma dose rates listed in these criteria, which are based on an estimated 10 roentgen infinity gamma dose, as high as 2,000 reps might be delivered to the basal layer of the epidermis over a period of time covered by the lifetime of the radioactive material.

There have been instances where the calculated infinity gamma dose in areas where personnel were present around the Nevada Test Site have reached 12-15 roentgens but there have been no known cases of beta burns in these areas. The number of persons involved in these areas of highest contamination was relatively small, perhaps a few dozen, and with an observed duration of fallout of about one hour it is possible that they were not in a position to receive the full fallout. Likewise, minute areas of the skin may have been so affected yet not detected or reported. In other areas encompassing some 2,000 people the infinity gamma dose was about eight roentgens and no instances of beta injury appeared.

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*Op. cit.

The estimated whole-body gamma dose to natives evacuated from the island of Utirik following the March 1, 1954 detonation at the Pacific Proving Ground was about 15 roentgens for a period of about three days, but no beta burns appeared. It is fair to assume here that direct contamination took place due to their mode of living including housing that was quite open to air currents. Gamma dose rate readings were taken over the bodies of the natives at about H + 78 hours both on the beach and after boarding the ship. On the beach the personnel readings averaged about 20 mr/hr gamma (but this probably included some contribution from the ground contamination), and after wading through the surf and boarding the ship the levels averaged 7 mr/hr gamma.

The 18 natives on Sifo Island, Ailinginae Atoll, received an estimated whole-body gamma dose of 75 roentgens in about two and a quarter days. Of these, 14 later experienced slight beta burns, 2, moderate burns, and none showed epilation.

In the case of the Rongelap natives, the estimated whole-body dose was about 170 roentgens in about two days. All 64 natives later experienced beta burns to some degree from slight to severe and over half of the natives showed epilation from slight to severe.

The 16 natives from Rongelap evacuated directly by air to Kwajalein had personnel gamma dose-rate levels generally 80 to 100 mr/hr although one was as high as 240 mr/hr and one as low as 10 mr/hr (at H + about 55 hours). The remaining 48 natives evacuated by ship were reported to have personnel readings that "averaged" 60 mr/hr before decontamination. The picture is further confused because some of the natives had bathed and some had not before the arrival of the evacuation team.

Most of the 28 U. S. Service personnel stationed on Eniwetak Island, Rongerik Atoll, received about 40-50 roentgens, based on film badge readings. Three members of the group who were located for part of the time in another section of the island were estimated to have received somewhat higher doses. Seventeen of the 28 personnel showed only slight superficial lesions with one questionable case of epilation. It should be pointed out that the personnel were in metal buildings during some of the fallout time and for most of the time thereafter until evacuation. This reduced the direct contamination as well as the whole-body gamma dose. A film badge hanging on the center pole of a tent at one end of the island read 98 roentgens. Calculations based on dose rate readings at another part of the island indicated somewhat lower doses, if personnel had remained in the open for the period of time from fallout (about H + 7.5 hours) to evacuation (at about H + 34 hours). Upon arrival at Kwajalein one personnel gamma dose rate reading was as high as 250 mr/hr at about H + 35 hours.

The above data do suggest that there may be possible a rough bracketing of gamma-beta doses versus beta burns. On the one hand, the natives from Utirik received an estimated whole-body gamma dose of 15 roentgens and showed no evidence of beta burns. On the other hand, the natives on Sifo Island, Ailinginae Atoll, received about an estimated whole-body gamma dose of 75 roentgens with 14 personnel showing slight burns, 2, moderate burns, 2, no burns, 3 with moderate epilation, and 15 with no epilation. In addition, Roneglap natives received 170 roentgens whole-body gamma dose, and about 90% showed some degree of lesions and 56%, some degree of epilation.

It is to be recalled that: (a) the natives probably were out-of-doors and received the full fallout, (b) the oily hair, semi-naked perspiring bodies including bare feet, and lack of bathing for most would tend to collect and hold the fallout material, (c) the time of delivery of essentially all of the doses was two to three days. Further, it may be speculated that the fallout on the more distant island of Utirik (about 300 statute miles) would consist of smaller particles and also perhaps lesser possibility of overlapping of radiation fields from these particles.

Some of the relevant data are summarized in table II. Due to the uncertainty of the degree of exposure of personnel on Rongerik to the direct fallout, this group is not included. It is to be immediately emphasized that any comparisons made or implied in the table are at the most only semi-quantitative. Table II will be referred to in Criteria III and IV but is included here as a summary of the data discussed above.

TABLE II

I	II	III	IV	V	VI			
					Best Estimate of Average Dose Rates (mr/hr) of the Islands (Taken at Three Feet above the Ground) and of Natives (Personnel Readings) after Removal from Radiation Field. Both at Approximately Same Time.			
Location	Estimated Time of Fallout	Best Estimate of Whole-body Gamma Dose (Roentgens)	Skin Effects	Personnel Reading	Island	Personnel	Ratio	Approx. Time
Rongelap	5½ hrs	170	Lesions: 6 None 19 Slight 22 Moderate 17 Severe Epilation: 28 None 11 Slight 11 Moderate 14 Severe	a. Majority: 80-100mr/hr at H+54 hrs[1] b. Average: 60 mr/hr at H+50 hrs Corrected Average: 80 mr/hr[2]	1300	80	16/1	H + 50 hrs
Ailinginae	5½ hrs	75	Lesions: 2 None 14 Slight (very superficial) Epilation: 15 None 3 Moderate	Average: 40 mr/hr at H+52 hrs Corrected Average: 53 mr/hr[3]	410	53	8/1	H + 52 hrs
Utirik	16-18 hrs	15	Lesions: None Epilation: None	Average: 20 mr/hr Assumed: 15 mr/hr at H+78[4]	110	15	7/1	H + 78 hrs

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[1] 16 natives evacuated by air to Kwajalein and monitored upon arrival.

[2] 48 " " " USS Philip and monitored aboard the ship. Data suggest meter readings low by about 50% since natives from same island read 80-100 mr/hr at Kwajalein some four hours later with calibrated meters.

[3] 40 mr/hr corrected to 60 mr/hr according to information in footnote 2. Report did not indicate range of values among individuals nor at different parts of body.

[4] Readings taken by monitors from the RENSHAW on the Utirik beach where there may have been some contribution to dose rates from land. After wading to ship, average personnel readings were 7 mr/hr.

Data on Animal Exposures

The data on animal exposures are less firm than those for humans. Unmistakable beta burns occurred on cattle at Alamogordo in July 1945, on cattle at the Nevada Proving Grounds in spring 1952, and on horses in spring 1953. (The skin damage observed on sheep in the spring 1953 was not established to be beta burns.) However, the exact positions of the animals in relation to known amounts of fallout are not clear.

Following the last detonation of the spring 1952 series at the Nevada Proving Grounds, about one half of a herd of 150 head of cattle were found to have evidence of beta burns. They were thought to have been 15-20 miles from ground zero in Kawich Valley to the northeast and to have been exposed to fallout from the last detonation. Highest dose rate readings taken along a dirt road running lengthwise through this valley integrated to 75-100 infinity gamma doses.

During Upshot-Knothole, 16 horses showed skin lesions over the back and eye damage was noted in a few. The best evidence indicated that the horses were some 10-12 miles to the east of ground zero on 17 March 1954, where the fallout occurred from the first detonation (about 15 KT on a 300 foot tower). Radiation levels in this area are not known with certainty but the fallout occurred in a narrow band and was carried by relatively high velocity winds so that it probably fell on the horses at a time less than one hour. If so, probably more than one-half of the infinity dose was delivered during the next day.

[redacted]

ADDENDUM

Since the original discussion above was written, further consideration has been given to the work of Strandgvist and others* on the effect of fractionation of doses delivered to the skin and the onset of the observed results. It will be recalled (page 10) that X-ray doses to the skin were fractionated in equal daily amounts, and the biological effects compared to a one-treatment dose. A log-log plot of total doses versus days after initial treatment yields straight lines.

Basically, this means that as doses are being delivered to the skin a certain rate of repair is taking place. The over-all effect might be that higher initial doses from fallout material might be allowed than if one were to integrate the dose over a period of time without consideration for the repair. Because of the difference in shapes of the total beta dose curves for varying times of initial fallout versus Strandgvist X-ray curves the difference between the two curves cannot be expressed as a simple relationship.

Strandgvist quotes a 1000 roentgen dose in one treatment to produce erythema using X rays (a somewhat smaller number than other data quoted above), 1250 roentgens if divided into two equal daily doses, 1450 roentgens if divided into three equal daily doses, etc. Of course, there are differences between these X-ray doses and beta doses from fallout material such as differences in doses at increasing depth of tissue and the fact that the X rays were delivered essentially as an instantaneous dose at intervals of a day while the beta dose rates are assumed to follow the $t^{-1.2}$. However, accepting the assumptions of biological equivalence of these roentgen and beta doses and $t^{-1.2}$,

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*Sievert, Rolf M. "The Tolerance Dose and the Prevention of Injuries Caused By Ionizing Radiations". British Journal of Radiology. V.XX, No. 236, August 1947.

[redacted]

one may then ask the question, "What will be the beta dose rates at varying times after detonation that the contamination occurs such that the integrated doses to the skin will at no time equal Strandgvist curve for erythema?"

For early fallout times the limiting factor will be to keep the first day's beta dose below 1250 reps; for later times of initial fallout the first day dose may be less than 1250 reps but subsequent accumulative doses may be greater than Strandgvist curve. A family of curves was prepared of beta dose rates versus time after contamination such that each would meet but not exceed Strandgvist curve for erythema for times out to 40 days then, based on the discussion contained under Criteria I, a conversion factor of 125 was selected to convert beta dose rates at a depth of 7 mg/cm^2 of tissue to gamma dose rates at three feet above an infinite plane. These gamma dose rates are plotted in appendix C(a).

If one accepts all the assumptions that go into preparing this curve, then one does not have to estimate the variable of how long the fallout material was in contact with the skin, for the curve suggests that as long as the initial indicated gamma dose rates are not reached then erythema might not be expected to appear. (However, this approach still does not give assurance that <u>single</u> hot particles will not produce erythema.)

Generally, the gamma dose rate readings in the curve /appendix C(a)7 suggest theoretical maximum infinite gamma doses of about 20 roentgens for a one-hour fallout, to about 55 roentgens for a two-day fallout. For those early times after detonation when relatively heavier fallout might be anticipated, this infinity gamma dose is two to three times greater than the 10 roentgens which was used as a basis of developing criteria II. However, there are two further considerations. One, the interpretation of the data and certainly the assumptions made in developing the curve in appendix C(a) are open to discussion. Two, if one accepts the interpretations and assumptions it means a safety factor of two to three - not an unreasonable quantity.

Operational Feasibility

Under the criteria recommended in Criteria II, there would have been two occasions in the past where personnel would have been requested to remain indoors. Once was at Lincoln Mine following the second detonation of Upshot-Knothole where they were so requested to remain indoors for two hours and the other occasion would have been at Riverside Cabins (population about 15) following the ninth detonation of the same series. The dose rate reading at Lincoln Mine was 580 mr/hr at H + 2. In the case of Riverside Cabins, however, the radiological conditions were not ascertained until after the fallout had occurred. The maximum infinity gamma dose in the latter case was 12-15 roentgens.

Personnel were requested to remain indoors (for about two hours) following the ninth detonation of Upshot-Knothole. The highest dose rate reading was 320 mr/hr at H + 4.5 hours. This is less than the current recommendations.

CRITERIA III

Decontamination of Personnel

Where it is not possible to monitor personnel outside of a general radiation field, it is recommended that an estimate be made of the degree of personnel contamination by determining the location of the individual at the time of fallout. In the event there is uncertainty as to the validity of such an estimate, the assumption will be made that the individual was out-of-doors. In those areas where the infinity gamma dose equals or exceeds 10 roentgens, it is recommended that the individual be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field where personnel contamination exists over relatively large areas of the exposed body (one-half square foot or more):

> When the reading of a survey instrument held with the center of the probe or center of the ionization chamber four inches from the center of the contaminated area, equals or exceeds the values given in Graph III it is recommended that personnel SHALL be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field, where personnel contamination exists over relatively small areas of the EXPOSED body (less than one-half a square foot):

> The recommended maximum values shall be one-half those given in Graph III. Monitoring of the head, arms, hands, lower legs, and feet will be considered as coming under this category. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceed those stated below concerning monitoring of exterior surfaces of clothing.

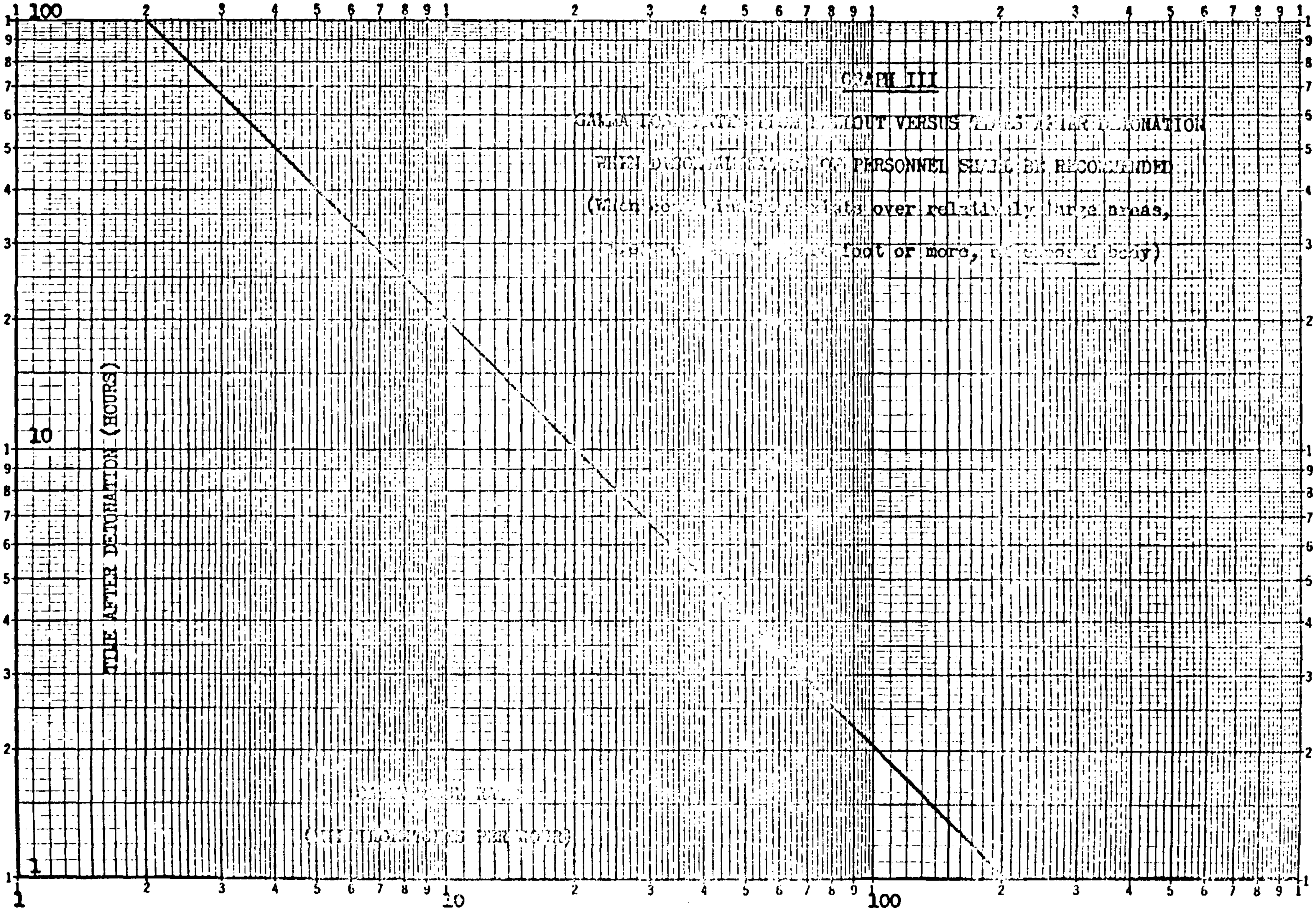
For personnel being monitored outside the general radiation field, and the contamination exists over only spots of EXPOSED body (about the size of a half-dollar or less):

> The recommended maximum values shall be one-fifth those given in Graph III. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceed those stated below concerning monitoring of exterior surfaces of clothing.

For personnel being monitored outside the general radiation field and the contamination exists over any size area on the exterior surface only of the clothing:

> The recommended values under these conditions will be twice those given in Graph III. The first recommended action shall be to resort to such simple acts as brushing off the clothing. If this action does not reduce the radiation levels to twice those given in Graph III or less, then personnel shall be advised to change clothing and to bathe.

When the general contamination of a community is of the degree to produce an estimated maximum theoretical infinity gamma dose of 20 roentgens or greater, personnel who have been out-of-doors at any time during the first two days and generally moving around in the area (as opposed to such an act as walking only between a building and a vehicle) shall be advised to brush off the footwear (outdoors), to bathe and to change clothing as soon as possible after the final return indoors each day. In addition, personnel who go out-of-doors for any length of time during the first two days after such a fallout shall be advised to wash their hands at least after the final return indoors each day, and more frequently, if possible.


GRAPH III
GAMMA DOSE RATE FROM FALLOUT VERSUS TIME AFTER DETONATION
WHEN [illegible] OF PERSONNEL SHALL BE RECOMMENDED
(When contamination exists over relatively large areas,
[illegible] foot or more, [illegible] body)
TIME AFTER DETONATION (HOURS)
[illegible] RATE
(MILLIROENTGENS PER HOUR)
100
10
1
1
10
100
2
3
4
5
6
7
8
9

[redacted]

CRITERIA III

Decontamination of Personnel

DISCUSSION

Data on Humans

In table II it was suggested that the relative average gamma dose rates from an infinity contaminated field at three feet above the ground compared to that on the natives measured by a survey meter held close to the body was:

$$\frac{110 \text{ mr/hr}}{15 \text{ mr/hr}} \cong 7/1 \text{ (Utirik Atoll)}$$

$$\frac{410 \text{ mr/hr}}{53 \text{ mr/hr}} \cong 8/1 \text{ (Ailinginae Atoll)}$$

$$\frac{1300 \text{ mr/hr}}{80 \text{ mr/hr}} \cong 16/1 \text{ (Rongelap Atoll)}$$

It is recognized that there are many uncertainties in estimating such a relationship by this means. Even if one assumes the dose rate readings were taken accurately the factors involved, especially in relation to the amount of material collected and retained on the body, certainly are not constant. The higher ratio at Rongelap Atoll might have been due to a physical phenomenon where the quantity of material falling per unit area was so great that it was not retained so completely on the body. Even if this explanation is accepted, there still remain many questions.

Theoretical considerations indicate a gamma dose rate ratio at three feet above an infinitely contaminated field to that at four inches from an equally contaminated field of six inch radius to be about 7/1. (See appendix D.)

The sizes of areas and distances from the surfaces were selected independently of any of the information on the fallout on the natives uncertainty of these data was discussed under Criteria II. They do suggest, however, that if the contamination of a relatively large area of the exposed body produces less than one roentgen infinite gamma dose as measured by a survey meter held four inches from the surface there is a large probability that beta burns will not result. (See also discussion under Criteria II.)

Doses From Small Sources

When the same dose rate reading is produced at a given height above a surface from a smaller area, the amount of contamination per unit area is greater (other factors being equal). Therefore, it would seem desirable to reduce the recommended dose rate levels when relatively small areas are involved. It is recognized that radiation from another nearby spot may contribute to the survey meter reading when monitoring a small area on personnel, but this has not been taken into account, first because of the difficulty of establishing a prior appraisal of this variable factor and, second, whatever this contribution may be it will now become an added safety factor.

Of course, the problem is still complex because when considering smaller and smaller areas the eventual end point is a single particle. An estimate of beta doses at the surface of an imaginary sphere surrounding a fallout particle is given in appendix E and an estimate of beta doses from a single particle required to produce recognizable erythema is presented in appendix F. Calculations indicate that the specific activity of some individual particles found in fallout would be great enough to produce recognizable erythema if held in contact with the skin for less than one day, yet the gamma dose rate reading at 4 inches may be relatively small (See appendix G.).

Additional information on doses from individual particles has recently been reported.* The particles found in and around Hanford consisted princi-

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*HW-33068. A status report. Sept. 15, 1954.

pally of three radioisotopes, Ru^{103}, Ru^{106} and its daughter Rh^{106}. The data and calculations in appendix H also strongly indicate that a single fallout particle could produce a recognizable erythema.

Contamination of Clothing

In the case of contamination of clothing, higher dose rates might be tolerated than those for exposed parts of the body. This was exemplified in the natives where no beta burns were observed under clothing of the most highly contaminated personnel. (This does not include such areas as under the waist line where material apparently collected and was held in place.) On the other hand, very large increases in contamination should not be tolerated since it is possible for the clothing to be rearranged so as to bring the contaminated surface in contact with the skin. Further, it is not unlikely that one may rub his hands over his clothing and then through the hair where the material could be held in place for relatively long periods of time.

Beta Exposure to the Hands

A further consideration is the beta dose to the hands resulting from handling objects contaminated with fallout material. Although some data are available on beta burns from handling radioactive objects, the conditions are so different from those associated with fallout that comparisons probably would not be valid.*

If the above assumptions and calculations are correct concerning contamination of a general area from fallout, then the transfer of all the radioactive material to the hands from an object of equal area would not constitute a hazard. Thus, one might consider using as criteria for monitoring objects, the dose readings given above for monitoring personnel

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*"Beta Ray Burns of Human Skin". Knowlton, et al. The Journal of the American Medical Association. V. 141, No. 4. Sept. 24, 1949.

[redacted]

outside the general radiation field. However, the problem is more complex since the hands may come into contact with contaminated surfaces many times larger in area than the hands, with an undetermined percentage of activity being transferred to the hands. Of course, an added uncertainty is the frequency of washing of the hands and/or the rubbing off of the material from the hands.

Further, one might speculate that a given surface could have significantly higher contamination than the general area and that the handling of such a surface could constitute a greater risk. This might be true because of the greater amount of activity transferred to the hands or because of the doses delivered during the time of actually handling the object. The uncertainty of the percentage of transfer of material has been mentioned. One uncertainty in the second case is the length of time the object would be handled.

Based on calculations in appendices B and D, when an object is held in a hand, a rough estimate of the ratio of dose rates of beta to the basal layer of the epidermis to that of the gamma reading on a survey meter held four inches away from an object two inches in radius (outside a general radiation field) might be 5,000 to 1 (appendix I.). Thus, if this object were contaminated with the same activity per unit area that would produce an infinity 10-roentgen whole-body gamma dose from general contamination of the area, it would produce about 50 mr/hr gamma at four inches away at H ≠ 1 hours, and about 250 reps/hour at a depth of 7 mg/cm^2.* Since the palms of the hands have an approximate epidermal layer of about 40 mg/cm^2 the beta dose to the basal layer would be about 170 reps/hour. (The time of H ≠ 1 was selected to show about the

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*These numbers agree fairly well with the computations in "Beta-contact Hazards Associated with Gamma-radiation Measurements of Mixed Fission Products". Teresi, J. D., USNRDL-383 (CONFIDENTIAL).

[redacted]

highest magnitude of dose rates.) If one assumes that the decay is according to $t^{-1.2}$, then the total beta dose to the basal layer of the epidermis of the hand in the next 10 hours would be about 320 reps.

Whereas the above estimates do not indicate an alarming situation, a more serious problem may come when the contamination is just less than that where evacuation is indicated. For example, the contamination of the general area may be five or six times that used as an illustration in the preceding paragraph, without evacuation being recommended. Thus, beta dose rates from handling objects, especially in times soon after fallout, may be high enough to be a problem. A simple and expedient procedure to reduce this factor is frequent washing of the hands after handling objects that were in the fallout.

Beta Exposure to the Feet and Lower Legs

It was suggested in Criteria II that normal closed-type footwear (as compared to such as open sandals) would probably afford adequate protection against significant beta doses to the feet from fallout material on the ground. There is still the added problem if the material be scuffed up and cling to the ankles and lower legs. If there were no intervening clothing, or perhaps even with thin stockings or socks, this might result in significant biological beta doses being delivered to these parts. For example, if the gamma dose rate reading at H + 3 hours were something less than five roentgens per hour, evacuation would not be indicated. However, for fallout material of the same concentration in contact with the skin the beta dose rate at 7 mg/cm^2 would be about 600 reps/hour (See appendix B.). Presumably, personnel would be kept indoors for a few hours but upon release the approximate beta dose rates at 7 mg/cm^2 would be 260 rep/hr three hours later or 210 rep/hr six hours later. In addition, there is the variable factor of what concentration of fallout material may accumulate in the ankle region by walking around an area.

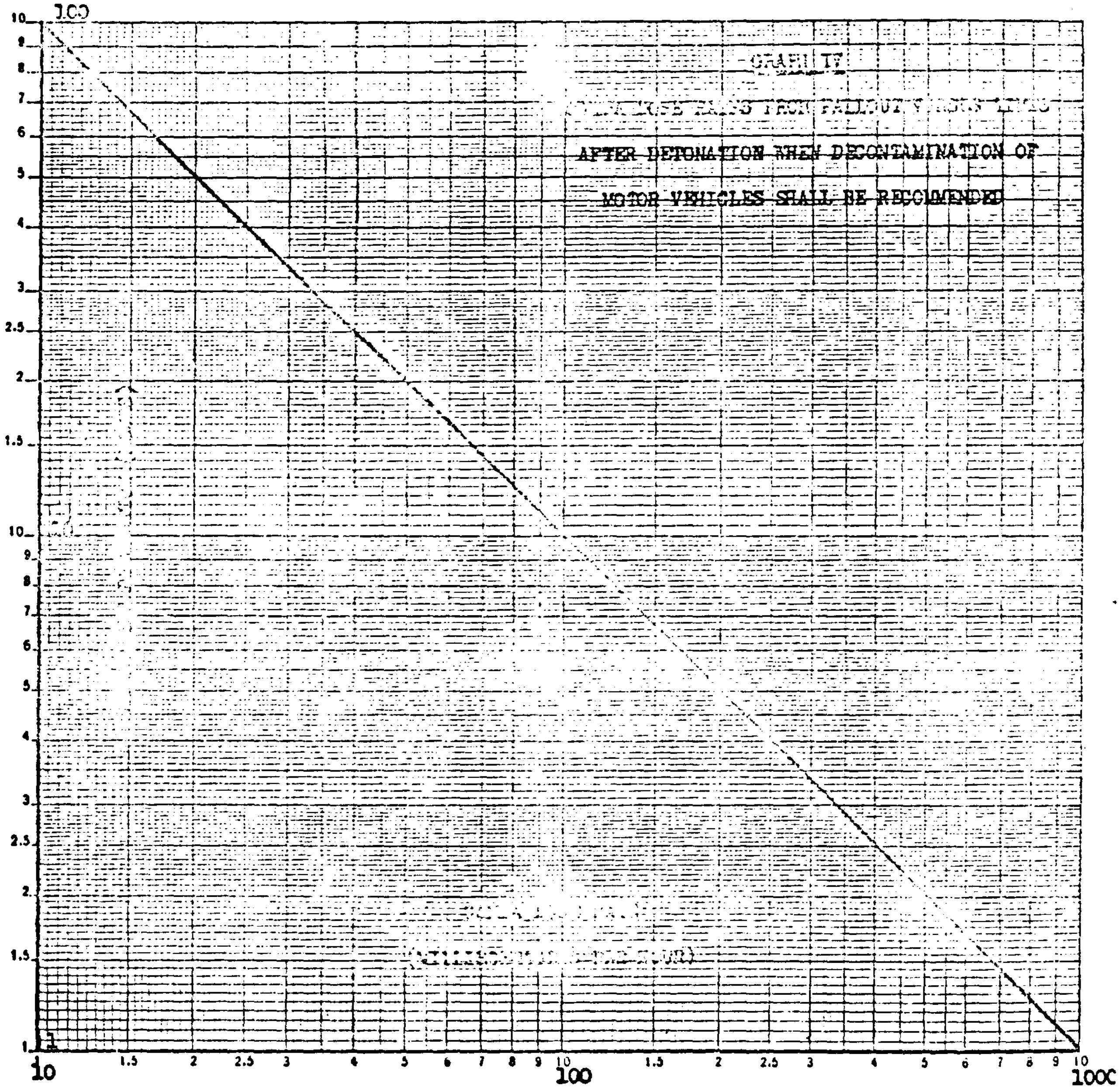
A concentration of fallout material on the ground that would result in about 20 roentgens maximum theoretical infinity gamma dose, if in contact with the skin would result in a beta dose rate to the basal layer of the skin of about 1/4 those indicated in the previous paragraph.

CRITERIA IV

Monitoring and Decontamination of Motor Vehicles

It is recommended that when the predicted fallout across a main highway will be equivalent to a 10-roentgen infinity gamma dose or higher, vehicles be held until after the actual fallout has essentially ceased. They should be then warned to proceed with windows and air vents closed and the cars should be monitored after passing through the contaminated area. When 5 to 10 roentgens are predicted across a main highway, vehicles should be warned to proceed with windows and air vents closed and should be monitored after passing through the contaminated area. Monitoring and warnings should be continued until there is reasonable belief that no or very few additional vehicles will exceed the values given in graph IV.

When the dose rate reading taken inside a vehicle, or taken over any exterior area that is readily accessible, equals or exceeds the values given in graph IV, the vehicle shall be cleaned inside and outside. Exterior areas to be monitored should include the wheels and under parts of the fenders but not the under carriage. The survey meter should be held approximately four inches from any surface.

GRAPH 17
[illegible] DOSE RATES FROM FALLOUT [illegible] HOURS [illegible]
AFTER DETONATION WHEN DECONTAMINATION OF
MOTOR VEHICLES SHALL BE RECOMMENDED
100
10
1
10
9
8
7
6
5
4
3
2.5
2
1.5
10
1.5
2
2.5
3
4
5
6
7
8
9
10
100
1000

CRITERIA IV

Monitoring and Decontamination of Motor Vehicles

DISCUSSION

In the past, fallout has occurred across highways in significant quantities. Table IV.b. below indicates some pertinent data during Upshot-Knothole.

TABLE IV.b.

Shot Number (Chronological)	Approximate Yield (KT)	Tower	Time of Fallout (Hrs)	Estimated Dose Rate Reading of Highway at Time of Fallout (mr/hr)	Location	Approximate Distance From Ground Zero (Miles)
1		300'	1¼	920	30 miles south of Alamo on Hyw. #93	60
1		"	2 3/4	260	1 mile north of St. George, Utah	130
6		"	5	325	Junction of U.S. Hyw. #91 and Nevada Hyw. #40	80
7		"	4½	760	20 miles northw. Glendale, Nev.on Hyw. #93	65
7		"	7	400	8 miles west of Mesquite, Nev. Hyw. #91	105
9		"	2	1000	36 miles north Glendale on Hyw. #93	60
9		"	3 3/4	420	St. George, Utah Hyw. #91	130

[redacted]

[redacted]

Road blocks were established on Highways 93 and 91 following shots numbers seven and nine of Upshot-Knothole. The highest reading on a private automobile was 100 mr/hr (gamma) inside and 110 mr/hr outside at H plus 3½ hours. About 75 cars were washed (roughly 1/8 of the total monitored). All of the cars that were washed except the one mentioned above, had outside dose rate readings less than half of the highest. The ratio of dose rate readings on the outside of the car to inside varied from unity to about 4/1. Probably one of the important factors here is the difference between driving with windows and/or ventilators opened or closed.

One bus read 250 mr/hr outside and average of 100 mr/hr inside with a high inside reading over the rear seat of 140 mr/hr at H plus 8 3/4 hours.

Considering the amount of time one normally spends in an automobile, these dose rates do not necessarily represent a health hazard in terms of gamma doses. What is probably a more limiting factor is the direct contamination one might acquire by rubbing against the outside of the car, especially when changing a tire.

It is assumed that monitoring will be accomplished outside a general radiation field. Theoretical calculations (appendix D) indicate that gamma dose rate readings taken at four inches from a surface will be 51%, 42%, and 27% of those by a meter at three feet above an equally contaminated infinite field when the radii of contamination are respectively 3 feet, 2 feet, and 1 foot.

These data suggest that when the gamma dose rate reading at four inches from a generally contaminated car is about one half that for an infinite plane taken at three feet, the degree of contamination per unit area will be about equal; and when the wheels are being monitored 1/2 to 1/4 of a

[redacted]

gamma dose rate reading will represent equivalent contamination (depending on the gamma contribution from the body of the contaminated vehicle).

Another factor to be considered is that the probability of collecting fallout material on the body from a generally contaminated area in which one lives is greater than from one's automobile. On the other hand, it has been noted in the past that significantly higher amounts of contamination have been found on the tires and under parts of fenders than on the remainder of the car. (Undoubtedly, this is a simple phenomenon of picking up the activity from the highway.) If one were to change a heavily contaminated tire, significant amounts of radioactive material might accumulate on the hands, and later be transferred to the hair or eyes by a simple rubbing of the hands over those parts.

A comparison might be made here between recommended maximum dose rates found on personnel and the establishing of levels of activity for automobiles. There is one obvious difference, however; in the first case the material is already on the person while in the second case one has to introduce the factor of probability of transfer of contamination (and to what degree) from the car to the body.

The dose rates (measured as stated) in graph IV would represent about equal contamination per unit area for a car as for an infinite plane if the car were rather uniformly contaminated. If the activity were confined say principally to the tires and under parts of the fenders, the dose rate readings might represent nearly twice the degree of contamination. One must weigh this condition with the probability that a tire will be changed before the activity has decreased significantly.

A given dose rate reading inside a vehicle may represent less contamination per unit area due to the contribution of gamma radiation

[redacted]

[redacted]

from the exterior of the vehicle. On the other hand, contamination within a vehicle would more probably be picked up by personnel than if it were on the outside. Further, it is recognized that significantly high concentrations of radioactive fallout may accumulate in such parts as the air filters of an automobile. Again, this has to be weighted against the probability that they will be handled before the activity has decreased to low levels plus the fact that it is relatively difficult to monitor such parts on a mass basis. The uncertainties present in estimating possible hazards from vehicle contamination would not justify fine distinctions in monitoring the various parts. A thorough cleaning, inside and outside, would appear to be the best solution.

One of the obvious ways to avoid much of the problem discussed in Criteria IV is to prevent vehicles entering an area during the time of fallout. This will not prevent the first vehicles passing through from picking up activity on the tires from the highway. It is believed, however, this will not constitute such a troublesome problem and past experience has indicated that the activity found on the tires noticeably decreased after several cars had passed over the highway. Further, if vehicles are not present in the fallout it will help reduce contamination of the passengers and of the insides of the vehicles.

Operational Feasibility

In the past, the criteria used for washing cars has been 7 mr/hr, and at a later time 20 mr/hr (gamma), inside a vehicle. This resulted in washing about 75 cars (roughly 1/8 of the total monitored) following the seventh and ninth detonations of Upshot-Knothole. Under the recommendations given in Criteria IV, the bus mentioned above, but probably none of the cars, would have been washed.

[redacted]

The data given in graph IV.b. indicate that if these radiation levels given had been predicted before the fallout, Highways #91 and 93 would have been closed prior to the fallout from the seventh detonation and possibly Highway #93 for the ninth detonation.

CRITERIA V

Contamination of Water, Air and Foodstuffs

In any area where the theoretical gamma infinity dose exceeds 10 roentgens, adequate sampling of the water, air, and foodstuffs should be made to ascertain the conditions of possible contamination. Based on past data, however, it is not expected that under those conditions of fallout where the radiation levels are below those stipulated for possible evacuation, that the degree of contamination will be a health hazard. (Nor is it implied here that any level above this *does* constitute a serious contamination of water, air, or foodstuffs.) Therefore, it is recommended that no action be taken in regard to limiting intake except to advise the washing off of such exposed foods as leafy vegetables when that action seems desirable.

CRITERIA V

Contamination of Water, Air and Foodstuffs

DISCUSSION

Water

Table VI.a. lists the six locations having the highest concentrations of fission products in water sources during Upshot-Knothole, and for comparative purposes the estimated external theoretical maximum gamma infinity doses.

TABLE VI.a.

Locality	Concentration (microcuries per milliliter extrapolated to 3 days after detonation)	External Theoretical Maximum Whole-body Gamma Infinity Dose (roentgens)
Virgin River Irrigation Canal, Nev.	8.7×10^{-5}	6.
Irrigation Ditch, 56 mi.no.of Pioche, Nev.	4.5×10^{-5}	0.15
Lower Pahranagat Lake, Nev.	3.2×10^{-6}	2.
Virgin River at Mesquite, Nev.	2.6×10^{-6}	2.5
Bunkerville, Nev. (tap water)	1.2×10^{-6}	7.0
Crystal Springs, Nev. (tap water)	1.1×10^{-6}	0.15

Due to weather and to attenuation of the gamma rays by buildings, the whole-body gamma dose estimated to have been actually delivered was probably closer to one-half of the values shown.

The maximum permissible concentration of fission products in drinking water is 5×10^{-3} μc/ml extrapolated to three days after detonation. This is considered a safe concentration for continuous consumption.

Whereas, the monitoring of water sources is of value for documentary purposes it should be recognized that the concentrations found may vary widely within small geographical areas and even at the same location at different times (taking into account radioactive decay). Thus, confidence cannot be placed in precise values. Table VI.a. suggests that even if one were to have stored up the water listed at Virgin River Irrigation Canal and subsisted entirely on this for a lifetime, the concentration would be about 58 times less than the maximum permissible amount. Normal factors of dilution by additional rainfall and/or by the influx of lesser contaminated ground water would be expected to reduce the level of activity.

Air

Considerable effort has and is being made to evaluate hazards from airborne radioactive materials, including fission products. There are certainly many unanswered problems including the possible hazard from a single particle in the lungs. Despite the uncertainties and as yet incomplete analysis of the inhalation hazard, the preponderance of evidence today is that the external gamma hazard from fallout is the more limiting factor of the two*. (However, see discussion on food contamination.)

During Upshot-Knothole quite complete data were collected of concentrations of airborne activity on about 150 occasions in some 40 different localities within 200 miles of the Nevada Proving Grounds. These included monitoring of all detonations. Histograms were made of air concentrations versus time after detonation for 30 occasions and estimates were made of doses to the lungs. These data for the five communities showing the highest air concentration are given in Table VI.b. The histogram for St. George (the highest 24 hour average concentration of fallout ever measured in a populated area) is reproduced in appendix J.

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*Ad Hoc Committee Meeting. Washington, D. C. January 20, 1954.

TABLE VI.b.

Locality	24-hour Average Concentration (microcuries per cubic meter)	Dose to Lungs (13 weeks) Based On 20% Deposition and 100% Retention Thereafter (mreps)*	Theoretical Maximum Whole-body Gamma 13-week Dose (roentgens)
St. George, Utah	1.29	130	3.5
Lincoln Mine, Nev.	4.0×10^{-1}	12	1.5
Mesquite, Nev.	1.7×10^{-1}	13	1.0
Groom Mine, Nev.	3.4×10^{-2}	7	0.35
Pioche, Nev.	2.0×10^{-2}	3	0.015

*The method used in estimating doses to the lungs is given in appendix K.

The criteria previously established by an Ad Hoc Jangle Feasibility Committee (Washington, D.C., July 13, 1951), for air concentrations was

> "At a point of human habitation, the activity of radioactive particles in the atmosphere, averaged over a period of 24 hours, shall be limited to 100 microcuries per cubic meter of air (corresponding approximately to a ground level gamma intensity of 30 mr/hr).
>
> "The 24-hour average radioactivity per cubic meter of air, due to suspended particles having diameters in the range 0 micron to 5.0 microns, shall not exceed 1/100 of the above; nor is it desirable that any individual particle in this size range have an activity greater than 10^{-2} microcuries calculated 4 hours after the blast."

In the January 20, 1954 meeting of the Ad Hoc Committee the basis for recommending the above air concentrations was discussed. Essentially, these criteria were selected by estimating the gamma dose that might be delivered by the passing of a radioactive cloud. Since there are better methods of estimating gamma doses and since there are uncertainties in evaluating the hazards of such transitory air concentrations as experienced from fallout, and since the preponderance of evidence from past nuclear test series indicates that the external gamma hazard is more limiting than the inhalation one, it was recommended in the January 20, 1954 meeting to strike from the record the past recommendations for maximum permissible air concentrations. It was recommended that an air monitoring program be continued for documentary purposes and for whatever value the data might have in the future when new analyses might be made in the light of additional knowledge.

A further discussion of the single particle problem may be made. In arriving at the recommendation "... nor is it desirable that any individual particle in this size range have activity greater than 10^{-2} microcuries calculated four hours after the blast" a computation was made that the average radiation dose from such a particle to a sphere one-half a millimeter in radius would be 385 reps.* However, the conclusions may be misleading. In the case of a single particle, relatively large doses are delivered near the particle and small doses at a greater distance. Appendix L suggests one possible estimate of this phenomenon. The parameters involved here are many and difficult to evaluate. For example, how long will a particle remain in one place in the lung and what dose will be delivered during that time?

It has been suggested** that in the upper respiratory passage 20-micron diameter particles are the upper limit of size for deposition and that "Cilia sweep 4 to 6 cycles per second. The probability of a particle remaining within one millimeter zone for as much as one-half hour appears to be vanishing small. ... Protection will also be provided by the mucus lining which is itself renewed several times an hour." Accepting the estimates above and the methods illustrated in appendices E and F, it may be computed that about 8 reps would be delivered to the surface of an imaginary stationary sphere one millimeter in radius by a 20-micron particle (0.5

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*Minutes, Meeting of Committee to Consider the Feasibility and Conditions For A Preliminary Radiologic Safety Shot for Jangle. LASL. May 21-22, 1951.

**HW-33068. A status report. Sept. 15, 1954. (CONFIDENTIAL).

microcurie) in 30 minutes (appendix L). Larger doses will be delivered closer to the particle but with the relatively rapid movement of the particle, it does not appear that large doses will be delivered to a great number of cells. Multiple exposures might occur from additional particles but again this risk is difficult to evaluate.

Food

Considerable effort is being directed toward the study of contamination of food from fallout. One element of major concern is Sr^{90}. It has been estimated that if one were to subsist entirely on food grown from soils containing about one-tenth to one microcurie per square foot of Sr^{90} (1,000 pounds of calcium per acre to an average depth of six to seven inches), that over a period of years there would accumulate in the human skeleton a body burden of one microcurie of Sr^{90}*. The highest Sr^{90} activity found in soils from agricultural areas, about 100 miles from the Nevada Test Site, now shows a concentration of about 3.4×10^{-3} microcuries per square foot. This is a factor of 30-300 times less than the one-tenth to one microcurie of Sr^{90} quoted above. The calcium content of soils around the Nevada Test Site is several times greater than the 1000 pounds per acre used as a basis for calculations, which would materially reduce the strontium uptake.

(Although not of direct concern to the Nevada Test Site, it is of interest to note that soils were collected from the Marshall Islands following the fallout in early March 1954. Appendix M summarizes these data.)

A recent report** strongly suggests that contamination of leaf sur-

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*Private communication, L. A. Dean, U. S. Department of Agriculture, Beltsville, Maryland, April 23, 1954.

**<u>Report on Gabriel</u>. USAEC. Division of Biology and Medicine, Washington, D. C. July 1954 (SECRET) faces followed by either direct consumption or intake by way of milk is a far more important pathway of intake than the soil-plant-animal cycle, at least for those times of year when plants may be in a state of growth to collect the fallout. Further analysis is being planned.

This same report* raises a new problem. Based on stated assumptions, the data presented indicate relative doses of:

thyroid: tens of thousands of reps
Sr^{89-90}: 300 reps
external gamma: 40 roentgens

High radioiodine doses to the fetus and baby may be particularly important, Additional evaluation will be given this problem.

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*Report on Gabriel. USAEC. Division of Biology and Medicine, Washington, D. C. July 1954 (SECRET)

CRITERIA VI

Routine Radiation Exposures

The whole-body gamma effective biological dose for off-site populations should not exceed 3.9 roentgens over a period of one year. This total dose may result from a single exposure or series of exposures.

If integrations of dose-rate readings are used in estimating the effective biological doses, then table V may be used.

TABLE V

	Multiplication Factor	Effective Biological Dose
Maximum theoretical radiation dose from time of fallout to 15 days later	3/4	
Maximum theoretical radiation dose from 15th day to one year	1/2	
	TOTAL (best estimate of effective biological dose)	

If film badges or dose meters are worn on personnel and the evidence of their use supports the view that the readings are a reasonably accurate account of the radiation dose received, then the values recorded on the film badge may be accepted with a correction factor of 3/4 to account for the difference between the dose received by the film badges or dosimeters (including backscatter) and that received at the tissue depth of five centimeters.

[redacted]

CRITERIA VI

Routine Radiation Exposures

DISCUSSION

In 1953 the following recommendation was made in the "Report of Committee to Study Nevada Proving Ground":

> "It is recommended, and found to be in conformity with the present principles of determining permissible exposure limits, that for test operation personnel the total body gamma exposure be limited to 3.9 r in thirteen weeks, and that the same figure be applied to the off-site communities with the further qualification in the latter case that this is the total figure for the year. In general, this implies a single test series in any given year."

On the basis of this recommendation and the reasoning discussed under Criteria I, the criteria for estimating the whole-body gamma effective biological dose are summarized in table V. It will be noted that the biological factor included under Criteria I is omitted in Criteria V. In the first case we are dealing with relatively high doses that may require emergency measures with their attendant hazards. It is a situation where one wishes to estimate all pertinent factors in evaluating radiation doses even though they may not be known with preciseness, before recommending an emergency action that may produce greater problems. In the case of Criteria V one is concerned with relatively lower doses during routine operations. It would be difficult to justify on the one hand the proposition that weekly doses for general populations may be integrated and taken in a single exposure without penalty and on the other hand, that a given dose received over a period of a year may be administratively reduced because of biological repair. Therefore, the biological factor is omitted.

The general effects of backscattering on measured radiation doses are fairly well established. Further, knowledge of depth (tissue)-dose curves has advanced to a quantitative state.* Thus, there seems to be

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*Permissible Dose From External Sources of Ionizing Radiation. National Bureau of Standards Handbook 59. September 24, 1954.

[redacted]

little doubt that a film badge or dosimeter worn on the person will overestimate the gamma radiation dose delivered at a depth of five centimeters (assumed depth of blood-forming organs). A major factor in determining this difference is the quality of radiation under consideration. One report* dealing explicitly with radiation in a fallout field suggests a factor of about 3/4.

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*WT-814. Effective Energy of Residual Gamma Radiation. January 1954. CONFIDENTIAL.

APPENDIX A

Sample Estimation of Gamma Radiation Doses Saved by Remaining Indoors

EXAMPLE I

Assume: Time of fallout = H+3 hrs
Dose rate at H+3 = 667 mr/hr

Then:	Theoretical maximum dose from time of fallout to three hours later	1.30 r
	Savings by remaining indoors for three hours	0.65 r
	One year effective biological dose if personnel did not remain indoors during the three hours (based on same assumptions contained in section on evacuation)	~5.5 r
	Per cent of one year effective biological dose saved by remaining indoors for the three hours	~12%

EXAMPLE II

Assume: Time of fallout = H+3 hrs
Dose rate at H+3 = 667 mr/hr

Then:	Theoretical maximum dose from time of fallout to eight hours later	2.30 r
	Savings by remaining indoors for eight hours	1.15 r
	One year effective biological dose if personnel did not remain indoors during the eight hours (based on same assumptions contained in section on evacuation)	~5.5 r
	Per cent of one year effective biological dose saved by remaining indoors for the eight hours	~21%

APPENDIX B

CALCULATIONS

Of Beta Dose Rate at Depth of Seven Milligrams per Square Centimeter from a Thin Extended Source

Assume: 1.5 Mev Beta (Mean energy = 0.5 Mev)
$\mu = 10$ cm^2/gm
(This assumes a single mass absorption coefficient.)

$$N = No\ e^{-\mu x}$$

where: No = number of betas at surface per cm^2 per sec.
N = " " " " depth x
μ = mass absorption coefficient
x = distance (depth) under consideration

$$\frac{dN}{dx} = -\mu\ No\ e^{-\mu x}$$

$$R = \frac{\mu No\ e^{-\mu x} E}{2}$$

where: R = dose rate at depth X
E = mean energy of betas

$$R = \frac{(10) No\ e^{-(10)(0.007)} (0.5)}{2} = 2.33\ No\ \text{Mev/gm-sec.}$$

$No = 3.7 \times 10^4 C$ where: C = activity in microcuries per cm^2
$R = 8.65 \times 10^4 C$ Mev/gm-sec.
$R = (1.39 \times 10^{-1})(C)$ ergs/gm-sec.
$\cong 5.4$ C reps/hr
or $\cong 5.0$ C rads/hr

Example
Assume: C = 80 μc/cm^2 (beta)
R = 5.4 C where: R = dose rate at depth 7 mg/cm^2 in reps
C = activity/cm^2 in μc
= (5.4)(80)
= 432 reps/hr
or = 400 rads/hr

* *

Comparison Beta Dose Rate (Reps/hr) at 7 Mg/cm^2 to Gamma Dose Rate Measured in Infinite Field at Three Feet Above the Surface

Assume: 80 μc/cm^2 (beta), equivalent to
1 megacurie/mi^2 (gamma)

$$\frac{432}{4.1} \cong 105$$

APPENDIX C

Experimental Data Versus Theoretical Calculations (Appendix B) in Estimating Beta Doses

In one relevant experiment, a thin P^{32} source was prepared by soaking a filter paper in a solution of phosphates and allowing it to dry. The surface dose rates were then measured with a surface ionization chamber.* Pertinent data are abstracted as follows:

Thickness of source	9.6 mg/cm^2
Activity of source	77.0 µc/cm^2
Surface dose rate	0.127 rep/sec 457 reps/hr
Dosage rate at depth of x centimeters	$e^{-9.5x}$

A. Theoretically

Using the equation from Appendix B

$$R = \frac{[illegible]}{2} \quad (\text{for } P^{32})$$

Substituting above data:

$$R = \frac{9.[illegible](9.5)([illegible]) [illegible]}{2}$$

$$= 7.0\ C \text{ reps/hr}$$

Let C = 77 µc/cm^2

Then R = 7.0 x 77
= 539 reps/hr at 7 mg/cm^2 (P^{32})

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*Effects of External Beta Radiation. Zirkle, Raymond E. McGraw-Hill Book Company. 1951.

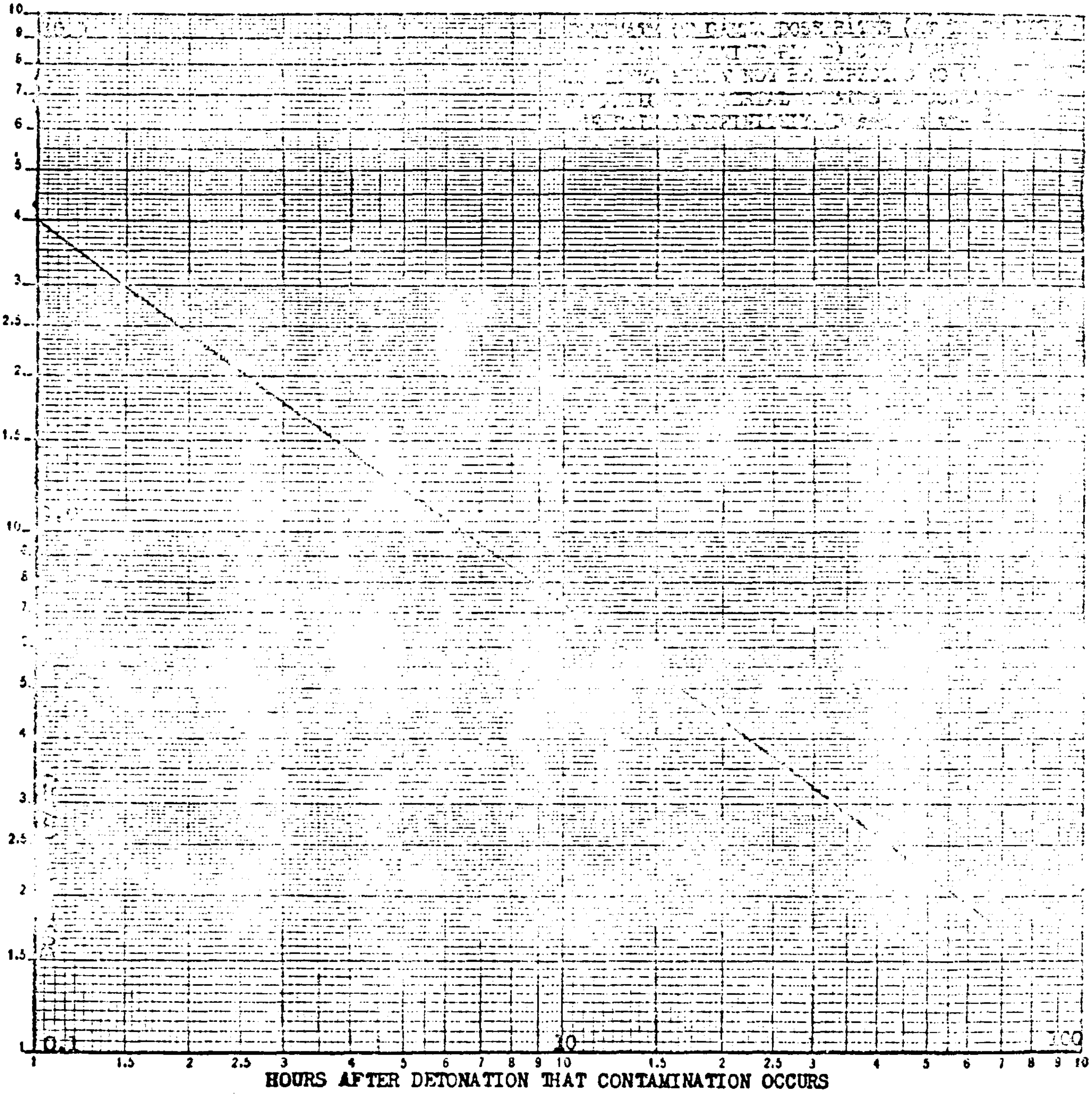
B. Experimentally

$$R = 457\ e^{-(9.5)(0.007)}$$

$$= 427 \text{ reps/hr at } 7 \text{ mg/cm}^2 \ (P^{32})$$

The two above approaches are within 26% of each other. If one extrapolates the experimental data from a source of 9.6 mg/cm² to a thin source (for comparative purposes) the two methods are within 20%..

APPENDIX C (a)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1.5
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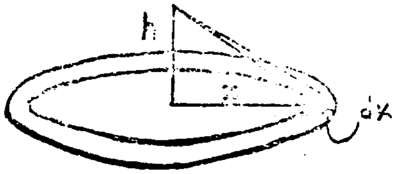
HOURS AFTER DETONATION THAT CONTAMINATION OCCURS

APPENDIX D

CALCULATIONS

Gamma Dose Rate from a Field Six Inches in Radius and Center of Chamber Four Inches Above Surface



Dose rate of gamma from a point source

$r \cong 6CE$ where: $r = r/hr$
$C =$ activity in curies per square foot
$E =$ average energy of gammas (Mev)

$$D = 6CE\, 2\pi \int_0^x \frac{x\,dx}{h^2 + x^2}, \text{ where } D = \text{dose rate in r/hr}$$

$$D = 18.8\ CE\ \ln\left[\frac{h^2 + x^2}{h^2}\right]$$

Example:
Let: $x = 1/2$ foot
$C = 40\ \mu c/cm^2$ or $3.6 \times 10^{-2}\ c/ft^2$ (gamma)
$E = 0.7$ Mev
$h = 1/3$ foot

$$D = (18.8)(3.6 \times 10^{-2})(0.7)\ \ln\left[\frac{(1/3)^2 + (1/2)^2}{(1/3)^2}\right]$$

$$= 0.56\ r/hr$$

Comparison Gamma Dose Rates from Infinite Plane at a Height of Three Feet Above the Ground to Area of Six Inch Radius and Height of Four Inches

Assume: 1 megacurie/mile^2
$(3.6 \times 10^{-2}\ c/ft^2)$

$$\frac{4.1\ r/hr}{0.56\ r/hr} = 7.3$$

APPENDIX E

Estimate of Dose Delivered by a Single Particle of Fallout Material

Assume:
a. Point source
b. 0.5 Mev average beta energy
c. $\mu = 10\ cm^2/gm$
d. Rate of decay follows $t^{-1.2}$

The dose delivered at the surface of an imaginary sphere at distance R from a point source.*

$$(1)\quad K(R) = \frac{CE\mu}{4\pi R^2}\, e^{-\mu R}\ \frac{Mev}{gram}$$

where: K(R) = dose delivered at the surface of an imaginary sphere at distance R
E = average energy of beta particles
C = total number of disintegrations
μ = mass absorption coefficient

Substituting: $\mu = 10\ cm^2/gm$
$E = 0.5$ Mev

Then: $$(2)\quad K(R) = 0.4\ \frac{e^{-10R}}{R^2}\ \frac{Mev}{gm\text{-}disintegration}$$

or $$(3.a.)\quad K(R) = 6.9 \times 10^{-6}\ \frac{e^{-10R}}{R^2}\ \frac{millireps}{disintegration}$$

or $$(3.b.)\quad K(R) = 6.4 \times 10^{-6}\ \frac{e^{-10R}}{R^2}\ \frac{milli\ rads}{disintegration}$$

Note: Equation (3.a.) is plotted on the attached graph.

FOR FISSION PRODUCTS:

$$(4)\quad A_a = A_1 t_a^{-1.2}$$

where: A_a = disintegrations per unit time at time "a" after detonation
A_1 = disintegrations per unit time at one unit of time after detonation

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*Rossi, H. H. and Ellis, R. H. "Distributed Beta Sources in Uniformly Absorbing Media". Nucleonics. July 1950, V. 7, No. 1.

80

Integrating equation (2),

(5.a.) $C = 5A_1 (t_a^{-0.2} - t_b^{-0.2})$

and (5.b.) $C = 5A_a t_a^{1.2}(t_a^{-0.2} - t_b^{-0.2})$

where: C = total number of disintegrations from time "a" to "b"
t_a = time after detonation
t_b = later time after detonation.

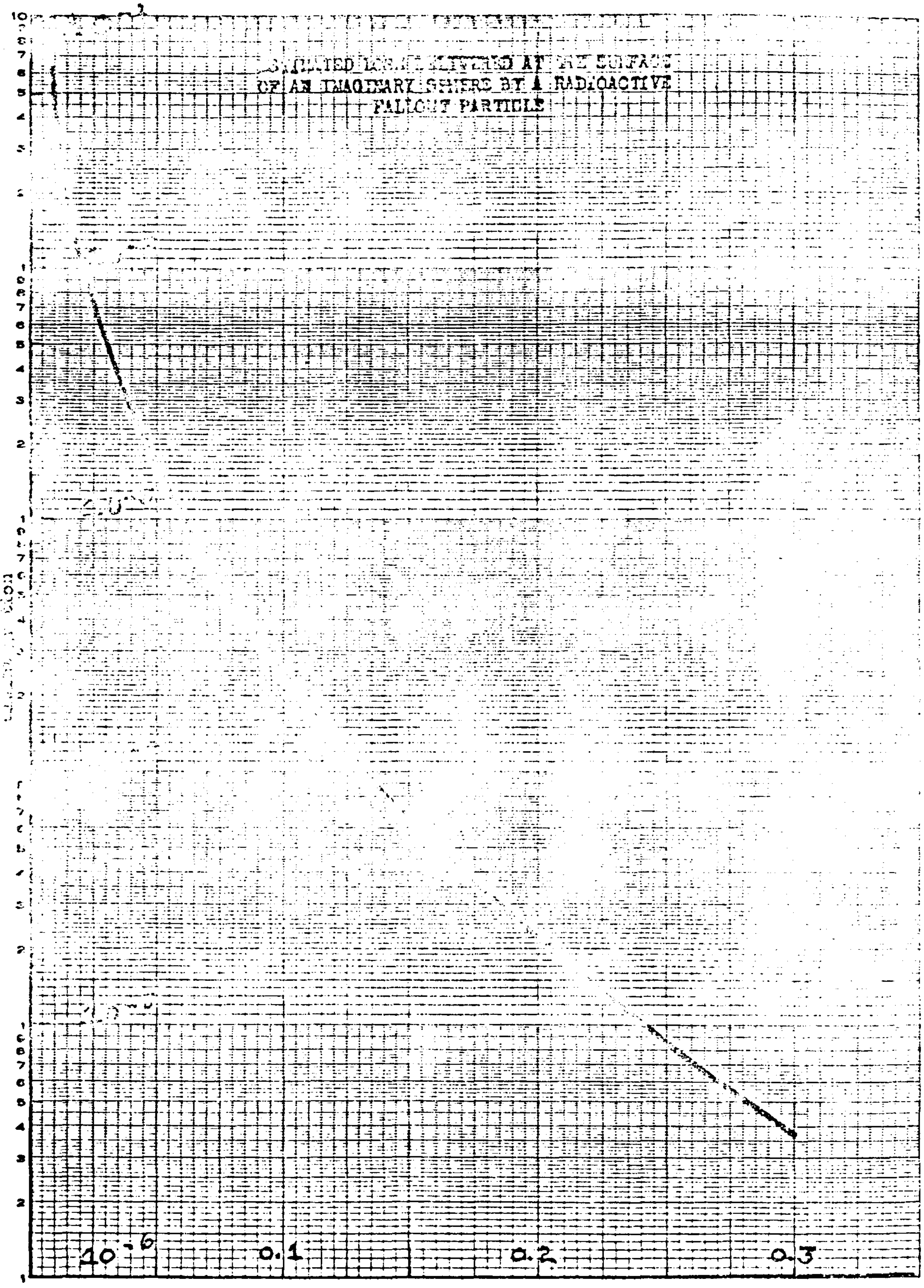
When t_b is infinite,

(6) $C_\infty = 5A_t t.$

By the use of equations (3.a.) or (3.b.) and (5.b.) one may compute an estimated dose at the surface of an imaginary sphere.

Of course, the problem is the determination of "t_a" and "t_b", i.e., how long after detonation will a radioactive particle be deposited and how long will the particle remain in place. The first time (t_a) is much easier to estimate than the later (t_b).

(See text pages 15 and 51.)



ESTIMATED DOSE DELIVERED AT THE SURFACE OF AN IMAGINARY SPHERE BY A RADIOACTIVE FALLOUT PARTICLE

Radius of Imaginary Sphere in Centimeters

APPENDIX F

Estimate of Beta Doses from a Single Particle on the Skin (Possible Production of Recognizable Erythema)

Let: $t_a = 3$ hours (time particle is deposited on skin)

$t_b = 27$ hours (time particle is removed)

Assume: 1500 reps = total dose required in one day to produce recognizable erythema

0.1 cm = radius of imaginary sphere within which cells must receive 2000 reps or larger.

According to appendix E, 2.5×10^{-7} reps/disintegration is delivered to surface of imaginary sphere 0.1 centimeter in radius.

$$\frac{1.5 \times 10^3}{2.5 \times 10^{-7}} = 6 \times 10^9 \text{ disintegrations required}$$

$$C = 5A_a t_a^{1.2} \left[t_a^{-1.2} - t_b^{-0.2}\right]$$

$$6 \times 10^9 = 5A_a 3^{1.2} \left[3^{-0.2} - 27^{-0.2}\right]$$

$$A_a = 1.14 \times 10^9 \text{ d/hr}$$

or about 8.6 μc at H + 3 hours.

Of course, the radius of the imaginary sphere selected will materially affect the calculations. For example, a radius of 0.2 cm would require a particle of about 96 microcuries at H + 3 hours to give the same dose.

APPENDIX G

Estimate of Gamma Dose Rate at Four Inches from a Single Particle of Fallout Material

Assume: a. The average gamma energy of fission products may be compared with radium; that the average energy of fission products is 0.7 Mev; that the average energy from radium daughters is 0.8 Mev with 2.3 photon emissions per disintegration or that the average energy per disintegration is 2.6 times greater than per disintegration of fission products.

b. A particle of 150 microcuries of beta activity or 75 microcuries of gamma activity. (See appendix H.)

$I = \frac{8.4\ \text{mc (hrs)}}{d^2}$ for radium through 0.5 mm of platinum.

where: I = gamma dose rate (r/hr)
d = centimeters

Let: $\text{mc} = 7.5 \times 10^{-2}$

d = 10 cm

$$I = \frac{(8.4)(7.5 \times 10^{-2})}{10^2}$$

$=$ 6.3 mr/hr gamma dose rate at four inches (for radium)

$\frac{6.3}{2.6} \cong$ 2.4 mr/hr for fission products

APPENDIX H

Data and Calculations on Doses from Single Particles of Ruthenium and of Fallout Material

A. Comparison of beta energies from Ru^{103} and Ru^{106} mixture to that from fission products.

Ru^{103} 0.3 Mev beta (T = 42d.)
Ru^{106} ~0.03 Mev beta (T = 1.0y.)
Rh^{106} 3.55 Mev beta (T = 30s.)

Assume: Ru^{103}/Ru^{106} ratio of 0.75*

To estimate a mean average energy of betas from mixture:

Parts	Isotopes	Maximum Energy Beta	Weighted Maximum Energy Betas
1.0	Ru^{103}	0.35	0.35
1.33	Ru^{106}	0.04	0.05
1.33	Rh^{106}	3.35 (avg.)	4.45
			4.85

$\frac{4.85}{3.66} \cong 1.3$

Average energy ~0.43 or roughly equivalent to that assumed for fission products.

(Of course, the average energy of the betas is not the sole consideration. The spectral distribution of the betas from Rh^{106} probably is quite different from that of fission products, thus affecting the depth dose curve.)

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*All of the basic data contained herein on ruthenium is contained in: HW-33068. A status report. Sept. 15, 1954.

B. Data on doses and effects from single particles of Ru^{103} and Ru^{106}

1.	a	b
Size of particle:	40 µ	120 µ
Activity of particle:	1.1 µc	11 µc
Dose rate to 7 mg/cm^2:	6,600 rads/hr	27,500 rads/hr
Time dose delivered:	~ 6 days	~ 6 days

2. Survey Dose Rate (mrads/hr)*	Total Skin Dose (rads)*	Effects
400	~ 500,000	None visible
750	~ 900,000	Reddening
2,500	~ 2,000,000	Desquamation
11,000	~ 6,000,000	Tissue Destruction
21,000	~ 7,000,000	Tissue Destruction— 2 cm across 8 mm deep

C. $\frac{750}{90} \cong 8.3$ µc estimated activity of particle producing reddening effect in about 144 hours. The estimated size is 100 microns.

D. $(8.3)(144) \cong 1200$ µc total activity accounted for in the 144 hours that the dose was delivered. (Assuming constant activity during the 144 hours.)

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* 90 mrads/hr $\cong$ 1 µc

**"total dose refers to the hot spot directly below the particle, and is valid only as to order of magnitude."

E. What specific activity of a particle of fallout would be required to deliver the same dose in the same length of time?

The answer to this question depends upon the time after detonation that the particle comes in contact with the skin. Assuming this time to be H+3 hours, the specific activity would have to be about 160 μc for the same size particle.

Since the particle may be washed off before six days have expired, one may consider the problem another way. What must be the specific activity of a particle at H+3 hours to deliver this dose in the next 24 hours?

According to Strandqvist (page 6), only about 70% of a six-day dose need be delivered in one day to produce the same effect (erythema). Accepting this, then a particle with about the same activity (160 μc) at H/3 hours would be sufficient to deliver an erythema dose in one day.

F. The following data are reported for single particles collected during Upshot-Knothole* and Tumbler-Snapper**.

Size of Particle (μ)	Activity Extrapolated to H/3 Hours (μc)	Distance from Ground Zero (miles)
—***	1,000	45
—***	200	130
1,626 x 924	900	10
919	480	11
723	350	14.7
714	400	10.
555	140	14.7
387	250	14.7
234	47	14.7
115	5.2	95
81	3.0	14.7
20	0.5	—

It is not intended here to imply these are the maximum specific activities per particle that existed or could exist. The data at 14.7 miles are reported to show the wide range of specific activity that may occur at one locality.

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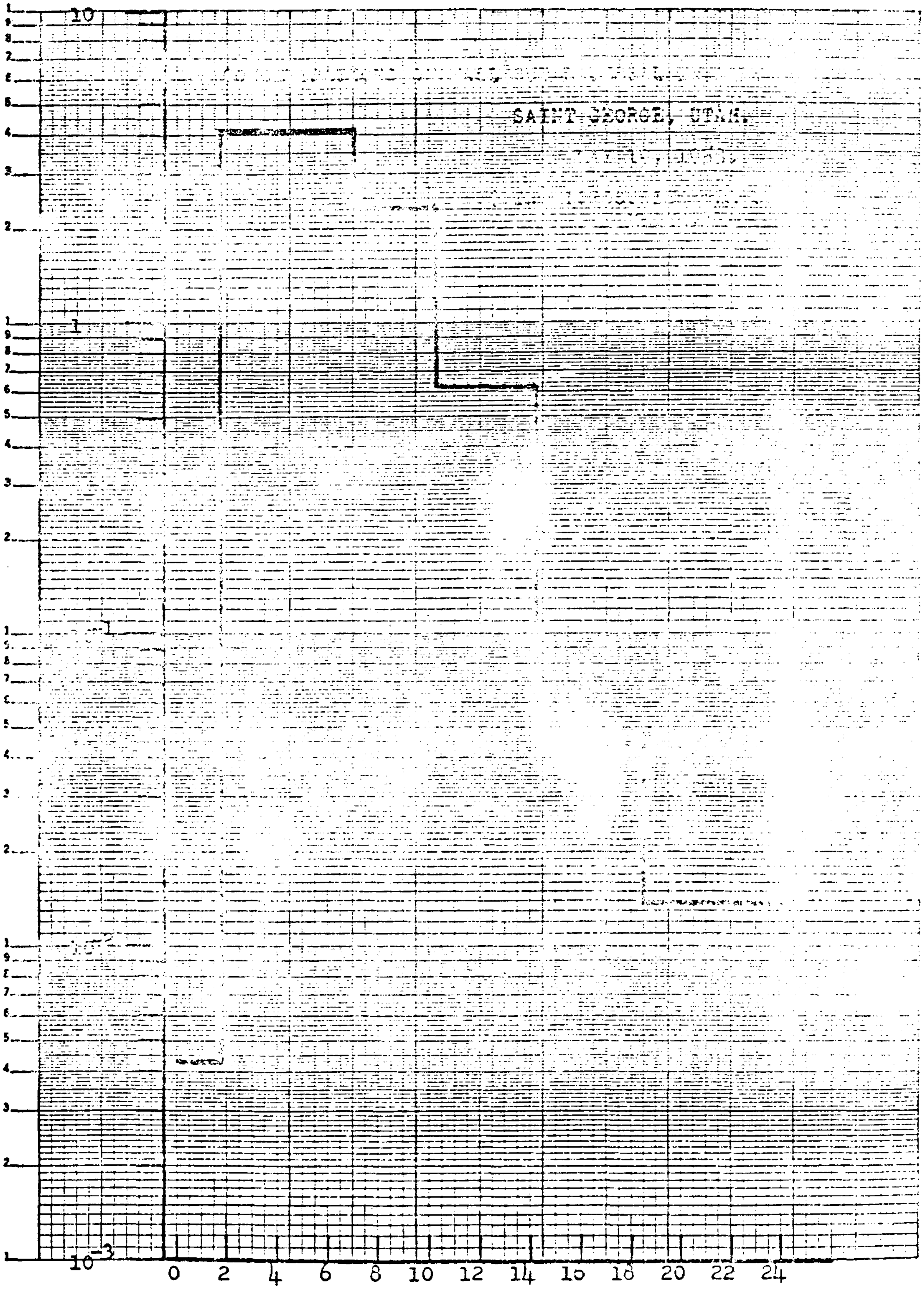
*WT-811. "Distribution and Characteristics of Fallout at Distances Greater than 10 Miles from Ground Zero, March and April 1953", Rainey, C.T., et al. (SECRET) <u>and</u> La-1685.
**UCLA-243. "Preliminary Study of Off-site Airborne Radioactive Materials, Nevada Proving Grounds". February 1953 (SECRET) <u>and</u> LA—1685.
***Data from estimations based on radioautograph methods.

APPENDIX E

Estimation of Ratio of Surface Beta Dose Rate to Gamma Dose Rate at Four Inches from an Object Two Inches in Radius

One may assume a ratio of beta dose rate (at 7 mg/cm^2 depth of skin) to gamma dose rate (three feet above the ground) of 125/1. If a contaminated object of say two inch radius were removed (or shielded) from a general radiation field the gamma dose rate at four inches from the surface might be some 40 times less than from an infinite plane with the same degree of contamination (appendix D), while the beta dose rate might remain almost the same value if the object is in contact with the skin. Thus, the beta to gamma dose rates measured under these conditions might be 5000/1. For other than a plane surface, the gamma dose rates might be higher, thus reducing this ratio.

APPENDIX "J"


SAINT GEORGE, UTAH.
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10^{-1}
10^{-2}
10^{-3}
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8
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18
20
22
24
HOURS AFTER DETONATION.

APPENDIX K

Method Used in Estimating Doses to the Lungs from Inhalation of Fallout Material

Assumptions

The following assumptions are made in estimating radiation doses to the lungs.

A. Twenty per cent of the inhaled activity is deposited.

B. There will be no elimination of particles during their radioactive lifetimes. There is uncertainty as to the biological half-life of particles in the lungs. In those communities showing the highest concentrations of fallout, the peak of airborne material (which accounted for the greatest percentage of total fallout) occurred only a few hours after detonation. If one assumes a radiological decay according to $t^{-1.2}$ and a biological half-life of say 30 days, the omission of biological half-life would not affect seriously the computed total dose.

C. All of the activity is associated with particles in the respirable range of sizes. Past data from cascade impactors indicate that about 90% of the activity is associated with particles 5 microns or less in the communities surrounding the Nevada Test Site.

D.. The lungs are uniformly irradiated.

E. The weight of the lungs is 900 grams.

F. An individual inhales 20 cubic meters per 24 hours.

G. The average beta energy is 0.5 Mev.

H. The gamma dose is negligible compared to the beta dose.

Data at St. George, Utah

I. (Shot Time) 0505	II. Duration	III. Approximate Midpoint after Detonation	IV. $\mu c/M^3$	V. μc Inhaled (Col. II times Col. IV times 0.834)	VI. μc Retained (Col. V times 0.2)
0610 - 1130	4.3 hrs	3 hrs	4.17	15.	3.0
1130 - 1445	3.2 hrs	8 hrs	2.38	6.3	1.26
1445 - 1845	4.0 hrs	11.7 hrs	6.3×10^{-1}	2.1	0.42
1845 - 2300	4.2 hrs	15.6 hrs	4.4×10^{-2}	0.15	0.03
2300 - 0635	7.5 hrs	21.5 hrs	1.4×10^{-2}	0.09	0.02
*0635 - 1835	12.0 hrs	31.5 hrs	1.4×10^{-2}	0.14	0.03

*Assumed

Sample Calculations

$$D = 5At_a^{1.2}\left[t_a^{-0.2} - t_b^{-0.2}\right]$$

Let: $t_a = 3$ hours
$t_b = 2184$ hours (13 weeks)
$A = 3\ \mu c$

$$D = (5)(3 \times 2.22 \times 10^6 \times 60)(3)^{1.2}\left[3^{-0.2} - 2184^{-0.2}\right]$$

$= 4.4 \times 10^9$ disintegrations from 3rd hour to 13th week.

Assume: $E_{avg.} = 0.5$ Mev

$$(4.4 \times 10^9)(0.5)(1.6 \times 10^{-6})\left\{\frac{1}{900}\right\}\left(\frac{1}{93}\right) = 4.2 \times 10^{-2} \text{ reps}$$

$$= 42 \text{ mreps}$$

TOTAL LUNG DOSE FOR 13 WEEKS: ~ 130 mreps

APPENDIX L

Estimate of Dose at Surface of Imaginary Sphere One Millimeter in Radius

Assume: Average activity for 30 minutes is 0.5 μc at H + 3 to H + 3½ hours
(See reference appendix H.)

Then: $0.5 \times 2.2 \times 10^6 \times 30 = 3.3 \times 10^7$ disintegrations/30 minutes.

At surface of imaginary sphere 1.0 mm in radius the dose rate from a point source is

$$2.52 \times 10^{-4} \frac{\text{mreps}}{\text{disintegration}}$$ (See appendix E.)

$$(3.3 \times 10^7)(2.52 \times 10^{-4}) = 8.3 \times 10^3 \text{ mreps/30 min.}$$

$$\cong 8 \text{ reps/30 min.}$$

For particles of higher specific activity, the dose would be correspondingly higher, of course.

APPENDIX M

Estimate of Sr^{90} in Soils of Pacific Islands

Location	I Total Activity ($\mu c/ft^2$) (Measured)	II Sr^{89}-Sr^{90} ($\mu c/ft^2$) (Measured)	III Rough Estimate External [illegible] by Gamma Dose [illegible]
Likiep*	1.2×10^{-1}	8.7×10^{-3}	4
Jemo	3.0×10^{-1}	1.2×10^{-2}	4
Ailuk	1.0	3.8×10^{-2}	12
Mejuit	1.1	2.8×10^{-2}	8
Ormed	3.2×10^{-1}	1.1×10^{-2}	4
Kaven	1.6×10^{-1}	4.8×10^{-3}	2
Wotho	7.8×10^{-2}	1.3×10^{-3}	0.5
Rongelap (Northern)	62.0	1.03	500
(Central)	40.0	5.5×10^{-1}	500
(1 mi.N.Village)	5.0	5.3×10^{-1}	[illegible]
(So. Cistern)	4.5	9.2×10^{-1}	[illegible]
Eriirippu*	230.0	12.5	[illegible]
Eniwetok	50.0	1.2	[illegible]
Kabelle	200.0	4.9	3,300
Utirik	53.0	9.8×10^{-2}	60
Bikar	3.3	4.4×10^{-1}	250
Eniwetak	8.0	6.6×10^{-1}	400
Sifo	6.1×10^{-1}	9.6×10^{-2}	170

*All data as of May 5, 1954, except island of Eriirippu where date is May 20, 1954.