403007

Preliminary Report

RADIOLOGICAL SAFETY

FOR THE

NEVADA TEST SITE

0043156

August 1957

INTRODUCTION

The purpose of this brochure is to review briefly the (a) radiological safety criteria, (b) data on radiation exposures from fallout, and (c) measures to protect the public related to nuclear weapons tests at the Nevada Test Site. The radiological safety criteria are under constant surveillance and probably will be revised as a result of additional data from OPERATION PLUMBBOB. The exposure data, of course, will be up-dated after OPERATION PLUMBBOB.

It is not the intent to cover here Project Sunshine or exposures from low level long-lived gamma emitting isotopes. Rather, this brochure is concerned almost entirely with the more immediate aspects of nuclear weapons testing at the Nevada Test Site.

This is a preliminary report. Suggestions are most welcome.

Gordon M. Dunning

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I. HISTORY OF RADIOLOGICAL SAFETY CRITERIA FOR THE NEVADA TEST SITE

Below are pertinent abstracts and condensations from past deliberations on the radiological safety criteria relating to nuclear weapons tests.

I. Ranger (January-February 1951)

"It had been previously agreed that exposures up to 3.0 r would be permitted for the Operation (2.0r for individuals planning to participate in Operation Greenhouse)." WT-204 Operation Ranger Vol. 5 Program Reports - Operational.

[There was no statement on off-site exposures]

II. Buster Jangle (Fall 1951)

A. "1. The external dose to non-participating inhabitants, of radiation from gamma rays, shall not exceed the accepted international permissible dose level of 300 mr/wk (1.8 mr/hr).

"2. At any point of human habitation, the activity of radioactive particles in the atmosphere, averaged over a period of 24 hours, shall be limited to one microcurie per cubic meter of air (corresponding approximately to a ground level gamma intensity of 0.3 mr/hr).

"3. The 24-hour average radioactivity per cubic meter of air, due to suspended particles having diameters in the range 0.5 micron to 2.0 microns, shall not exceed 10^{-2} microcuries; nor is it desirable that any individual particle in this size range have an activity greater than 10^{-2} microcuries calculated to 4 hours after the blast.

Note: It is assumed that the particulate matter comprising the allowable activity of one microcurie per cubic meter of air will have a normal distribution of particle sizes ranging from a few tenths of a micron to possibly several hundred microns. (See Appendices II and III."

Meeting Jangle Feasibility Committee, Washington, D. C., May 21 and 22, 1951.

B. "1. The external dose to non-participating inhabitants, of radiation from gamma rays, shall not exceed the accepted international permissible dose level of 300 mr/wk, which may be (integrated) over a maximum of 10 weeks.

"2. 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).

"3. 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."

Meeting Jangle Feasibility Committee, Washington, D. C., July 13, and 22, 1951).

C. "This Division authorizes a permissible exposure of 3.9 r of gamma radiation for Buster-Jangle test personnel, without regard to the rate at which the dose is accumulated, providing this exposure represents the total integrated gamma dose over any period of 13 consecutive weeks which includes the test period. Specifically, this permissible dose of 3.9 r is not an extra allotment for people who might otherwise receive radiation during the 13-week period."

Memorandum from Dr. Shilds Warren to Carroll Tyler, Manager SFOO, October 11, 1951.

III. <u>Tumbler-Snapper</u> (Spring 1952)

B. "---An ad hoc committee composed of authorities in the fields of medicine and roentgenology has given careful study to the exposures which may be safely received by the public as a result of nuclear test detonations. This committee advised the United States Atomic Energy Commission that a total dose of 3 roentgens in any period of 10 weeks would not exceed safe levels. The dose of 3 roentgens may be received as a result of a single exposure or a number of successive, smaller exposures, but the total exposure during the 10 weeks should not exceed 3 roentgens.---"

"---A maximum permissible air concentration for mixed fission products following a nuclear detonation has been established by the United States Atomic Energy Commission upon the recommendation of an advisory panel of experts. This concentration is 100 microcuries per cubic meter of air, averaged over a 24-hour period.---"

"---It is estimated that water containing total fission product activity amounting to 0.005 microcurie per milliliter 3 days after the fission products were formed could be used safely for any period of time.---"

Atomic Energy Commission's 13th Semi-Annual Report to Congress, July-December 1952, pp. 113-116.

IV. <u>Upshot-Knothole</u> (Spring 1953)

"---the Commission has adopted a policy of limiting exposures whenever possible to a total of not more than 3.9 roentgens over a period of 13 weeks, approximately the length of the 1953 test period."

Atomic Energy Commission's 14th Semi-Annual Report to Congress, January-June 1953, p. 49.

V. Spring 1954

"On-Site exposure standard should be 3.9r/13 weeks, with the Test Director authorized to approve exceptions if required.

"Off-Site exposure standard should be 3.9r/yr, the figure being one of actual gamma exposure as measured by a reliable indicator of total body irradiation and corrected by a factor to reflect the effects of shielding and weathering."

Committee to Study Nevada Proving Ground, Spring 1954.

VI. Jangle Feasibility Committee, January 20, 1954.

Criteria for air concentrations were dropped since they were originally proposed as a means of estimating external gamma dose rates at ground level and better methods to do this were now apparent. Collection of data on air concentrations were to be continued for documentary purposes.

VII. Operation Teapot (Spring 1955)

Radiological Safety Criteria and Procedures for Protecting the Public During Weapons Testing at the Nevada Test Site, February 1955 approved by the Commission February 11, 1955 for Operation Teapot. These were revised (See Section II B) page 8 for Operation Plumbbob.

VIII. Operation Plumbbob (Spring 1957)

Staff paper AEC 141/33 November 13, 1956, as amended, establishes as an operational guide of 3.9 roentgens whole body gamma radiation for off-site exposures resulting from Operation Plumbbob.

II. CURRENT RADIOLOGICAL SAFETY CRITERIA

A. Radiological Safety Criteria for Occupational Exposures at the Nevada Test Sit

"In light of the recent National Committee on Radiation Protection recommendations concerning maximum permissible radiation exposures to man, we recommend the following criteria for whole-body external gamma exposures incurred onsite by personnel at the Nevada Test Site:

a. A maximum of 3 r within a 13-week period. This period may encompass any 13 consecutive weeks at NTS.

b. A maximum of 5 r total within a period of one year.

As in the past we agree that the prerogative of permitting exposures greater than these limits for exceptional cases lies only with the Test Manager and Test Director.---"

Letter from Dr. Charles L. Dunham
to Mr. James E. Reeves, dated
February 20, 1957

II. B. Radiological Safety Criteria for the Public

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.

These criteria are not established with the expectation that the coming tests at the Nevada Test Site actually will result in radiation levels which will be greater than heretofore. Rather, they formalize past criteria to give even clearer guides for protecting the public. With improved methods of predicting fallout and with the use of balloons and 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 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 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.

SECTION I

Evacuation

Background

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, weather conditions, means of transportation and routes of evacuation, disposition of ambulance 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 until 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. They are intended to apply principally to relatively large populations since small groups may be evacuated without equivalent potential hazards.

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. This necessitates making rough approximations in advance of the effects of weathering and of shielding from normal housing, in reducing the radiation exposure. The variable nature of these two parameters makes impossible the establishment of a precise rule covering all situations. Therefore, the following may be used in making conservative estimates of these effects:

a. For weathering -- the measured gamma dose rates at three feet above the ground be assumed to decay according to $(t)^{-1.2}$ for the first week after a detonation, $(t)^{-1.3}$ for the second week, and $(t)^{-1.4}$ thereafter.*

b. For shielding -- the accumulated dose per day be 25% less than the out-of-doors dose.**

In the case of a truly emergency situation where potential hazards may exist either from the fallout or from mass evacuation of large populations, it would seem proper that due consideration be given to the biological repair process that takes place with radiation doses distributed

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* This concept was suggested after analyzing data from both the Nevada Test Site and the Eniwetok Proving Ground and was intended to give generalized estimates to cover a wide variety of situations. It is recognized that with the smaller fallout patterns around the Nevada Test Site and with the sandy soils, the effective decay constants may be greater than these. However, rather than attempt further estimates for NTS at this time, these values will be used until the results of the expanded radiological monitoring program for Operation PLUMBBOB can be analyzed.

** This is based on an average 12 hours per day stay in a frame house having an attenuation factor of two. It is recognized that some individuals will be in buildings having higher attenuation factors and for longer periods of time. On the other hand, this is generally an area where people may live an appreciable amount of time out of doors and where windows and doors are left open, so the fallout material may enter buildings. Again revision of this estimate will await the results of the expanded radiological program of Operation PLUMBBOB.

in time (recognizing that such effects from radiation as genetic changes and life shortening may not be time dependent). The estimates for biological repair for man are quite uncertain so a conservative value is used here of a half-time of repair of about four weeks.

Graph I incorporates the above factors of weathering, shielding, and biological repair into a single curve. This graph may be linearly extrapolated to other dose rate readings. For example, if fallout occurs three hours after detonation and the dose rate is 10 r per hour, then about 67 r (effective biological dose) may be accumulated, i.e.,

$$\frac{10}{0.15} \times 1.0 = 67$$

CRITERIA I

Effective Biological Doses may be calculated according to Graph I

Table I may be used in evaluating the feasibility of evacuating relatively large populations.

TABLE I

RADIOLOGICAL CRITERIA FOR EVALUATING FEASIBILITY OF EVACUATION

Effective Biological Dose	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, providing adequate shelters are not available and the estimated hazards concomitant with the evacuation are acceptable.)

SECTION II

PERSONNEL REMAINING INDOORS

Background

By remaining indoors (a) the gamma exposure will be reduced, and (b) there is less possibility that the fallout material will come into contact with the skin. (Beta burns have occurred in the past only when the fallout material has remained in direct contact with the skin.) To prevent or greatly reduce this latter effect, it is highly desirable to make decisions before or very shortly after the start of the fallout. Likewise, partial shielding at these early times will be of optimum benefit due to the relatively high gamma dose rates. Thus, the decisions must be based on predicted fallout in an area, or on dose-rate readings from field monitors' reports.

These predictions are of course subject to varying degrees of uncertainty so that personnel may be asked to remain indoors unnecessarily. On the other hand decisions and action must be taken relatively quickly if optimum benefits are to be derived and remaining indoors until the radiological information is more accurately evaluated probably represents one of the easiest and effective ways of meeting an emergency situation.

Due to uncertainties in our knowledge, and recognizing the usual unequal distribution of fallout, it has not been possible to establish precisely the amount of fallout in an area that could produce beta burns. The Marshallese experience showed such effects for those people exposed to 175 r and 69 r whole body gamma radiation, but none for those individuals on the Island of Utirik (370 miles from ground Zero) receiving 14 roentgens. Whether these results would hold true for other situations is not known, i.e., different particle size distribution, different type skin, etc. At one location, Riverside Cabins, Nevada, about 15 people were in an area receiving fallout in an amount equivalent to infinity dose of 15 roentgens, with no known cases of beta burns, although it is not known if anyone was out-of-doors during the time of fallout. Until more is learned of this phenomenon, it would appear advisable to remain out of the direct fallout when the amount would be such as to produce about 10 roentgens gamma infinity dose as measured at three feet above the ground. In the event personnel are out-of-doors during the time of this amount of fallout, the possibility of beta burns could be greatly reduced by the simple expedient of changing clothing and of bathing.

If people were not asked to remain indoors during the period of highest dose rates in an area where the infinity dose was 10 toentgens or more, their actual exposure might be in excess of 3.9 roentgens of whole-body gamma This would not necessarily be hazardous but would exceed the established criteria for Plumbbob (Criteria VI).

CRITERIA II

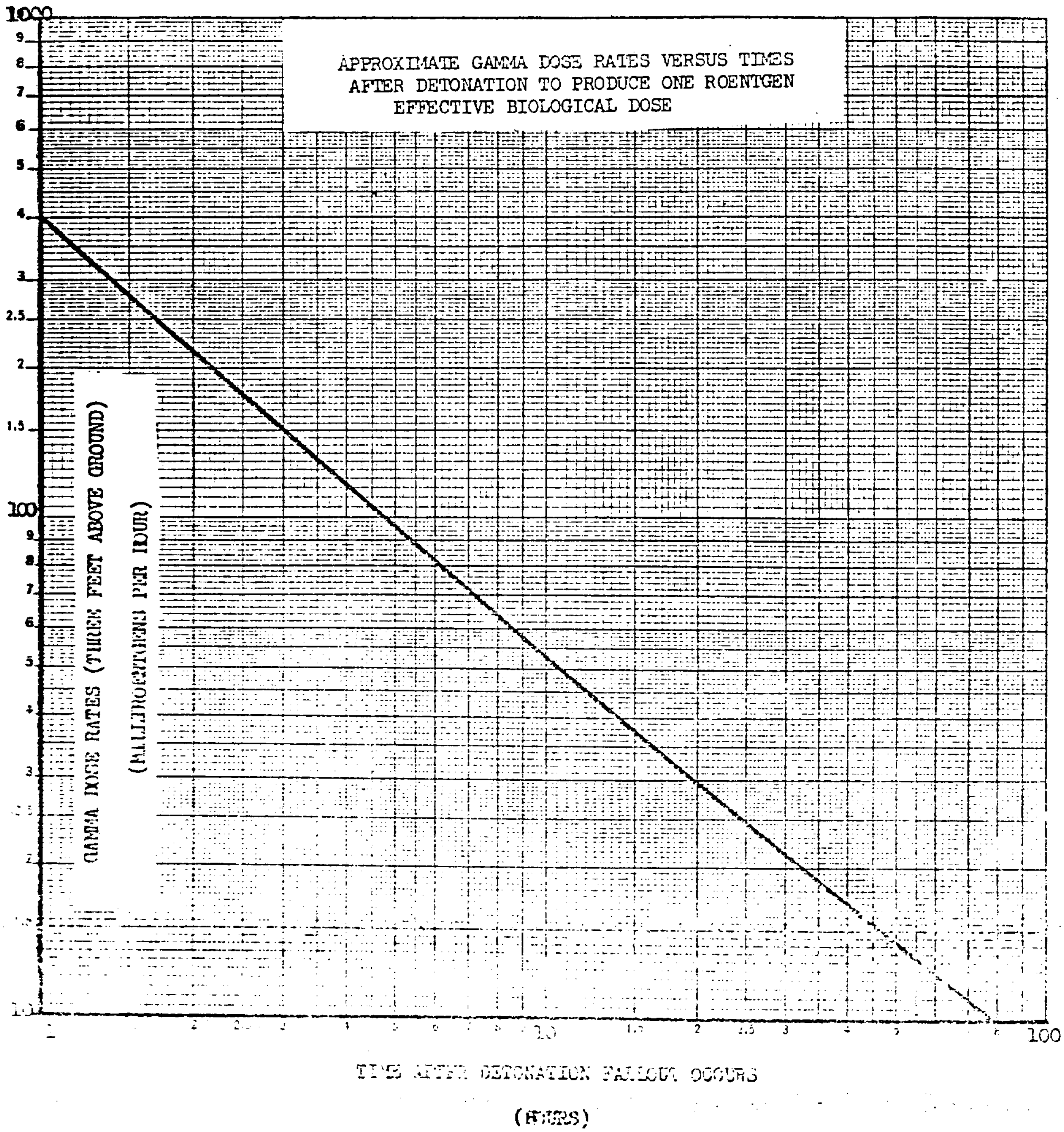
When the gamma dose rate reading as measured by a survey meter held three feet above the ground reaches the values given in Graph II at the times indicated, it is recommended that personnel be requested to remain indoors with windows and doors closed. Release from this restrictive action should be made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

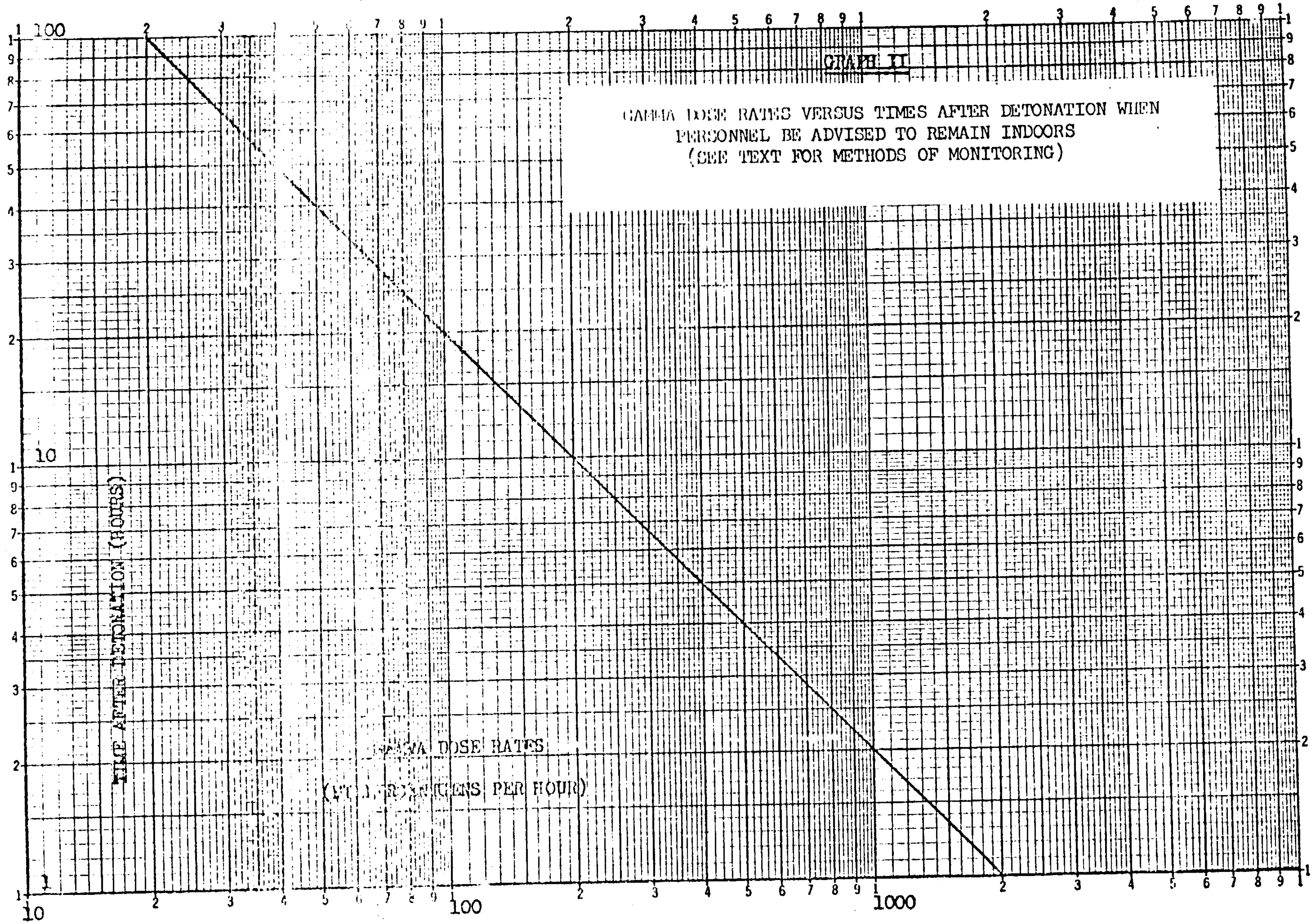
In the event that there be convincing evidence that the radiation levels given in the graph will be reached, it is recommended that personnel be requested to remain indoors BEFORE fallout occurs or before the radiation levels equal those in Graph II. Release from this restrictive action should be made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

GRAPH I


APPROXIMATE GAMMA DOSE RATES VERSUS TIMES AFTER DETONATION TO PRODUCE ONE ROENTGEN EFFECTIVE BIOLOGICAL DOSE
GAMMA DOSE RATES (THREE FEET ABOVE GROUND)
1000
100
100



GRAPH II
GAMMA DOSE RATES VERSUS TIMES AFTER DETONATION WHEN PERSONNEL BE ADVISED TO REMAIN INDOORS
(SEE TEXT FOR METHODS OF MONITORING)
TIME AFTER DETONATION (HOURS)
DOSE RATES
PER HOUR)
100
10
1
10
100
1000

S E C T I O N III

DECONTAMINATION OF PERSONNEL

Background

The principal purposes for decontaminating personnel are to reduce the potential beta doses to the skin, and to a lesser degree reduce the external gamma exposure. The discussion on beta doses in Section II is applicable here. In addition, there is much unknown about monitoring methods for personnel contamination. The following criteria were previously developed on the basis of measuring the gamma radiations (and then extrapolating to the accompanying beta radiations) with existing instruments. Recently new field instruments have been developed for direct beta measurement, but there remains considerably more work necessary to calibrate them in terms of beta dose rates to the body. Until this is accomplished, the past criteria may be used.

CRITERIA III

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 during the time of fallout. 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 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 are 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.

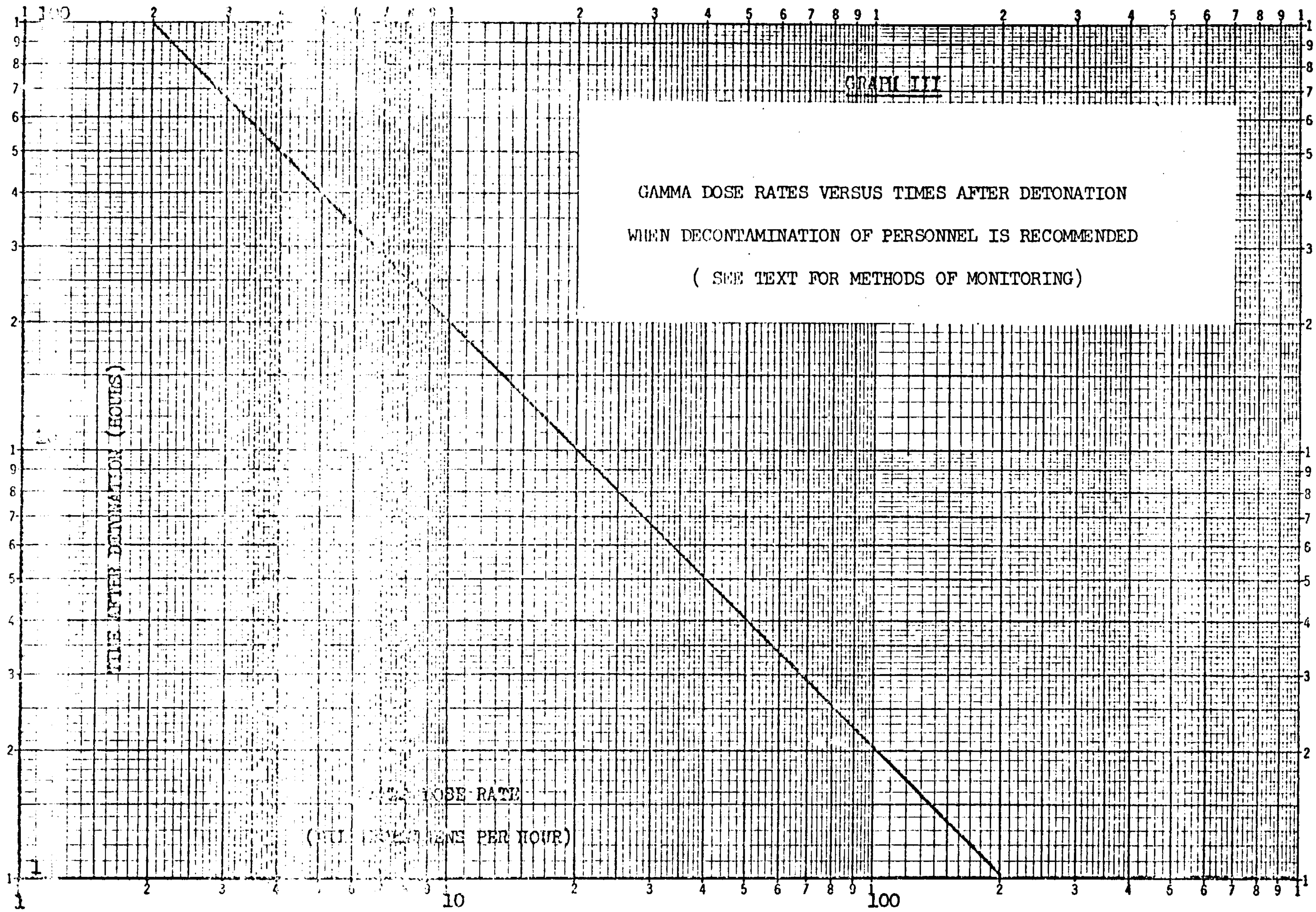
For personnel being monitored outside the general radiation field, and the contamination exists over only spots of EXPOSED body (about the size of a half-dollar or less):

> The recommended maximum values are 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 are 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 should 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 apposed to such an act as walking only between a building and a vehicle) should 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 should be advised to wash their hands at least after the final return indoors each day, and more frequently, if possible.


GRAPH III
GAMMA DOSE RATES VERSUS TIMES AFTER DETONATION
WHEN DECONTAMINATION OF PERSONNEL IS RECOMMENDED
(SEE TEXT FOR METHODS OF MONITORING)
AFTER DETONATION (HOURS)
DOSE RATE
PER HOUR)
1
10
100

SECTION IV

DECONTAMINATION OF MOTOR VEHICLES

Background

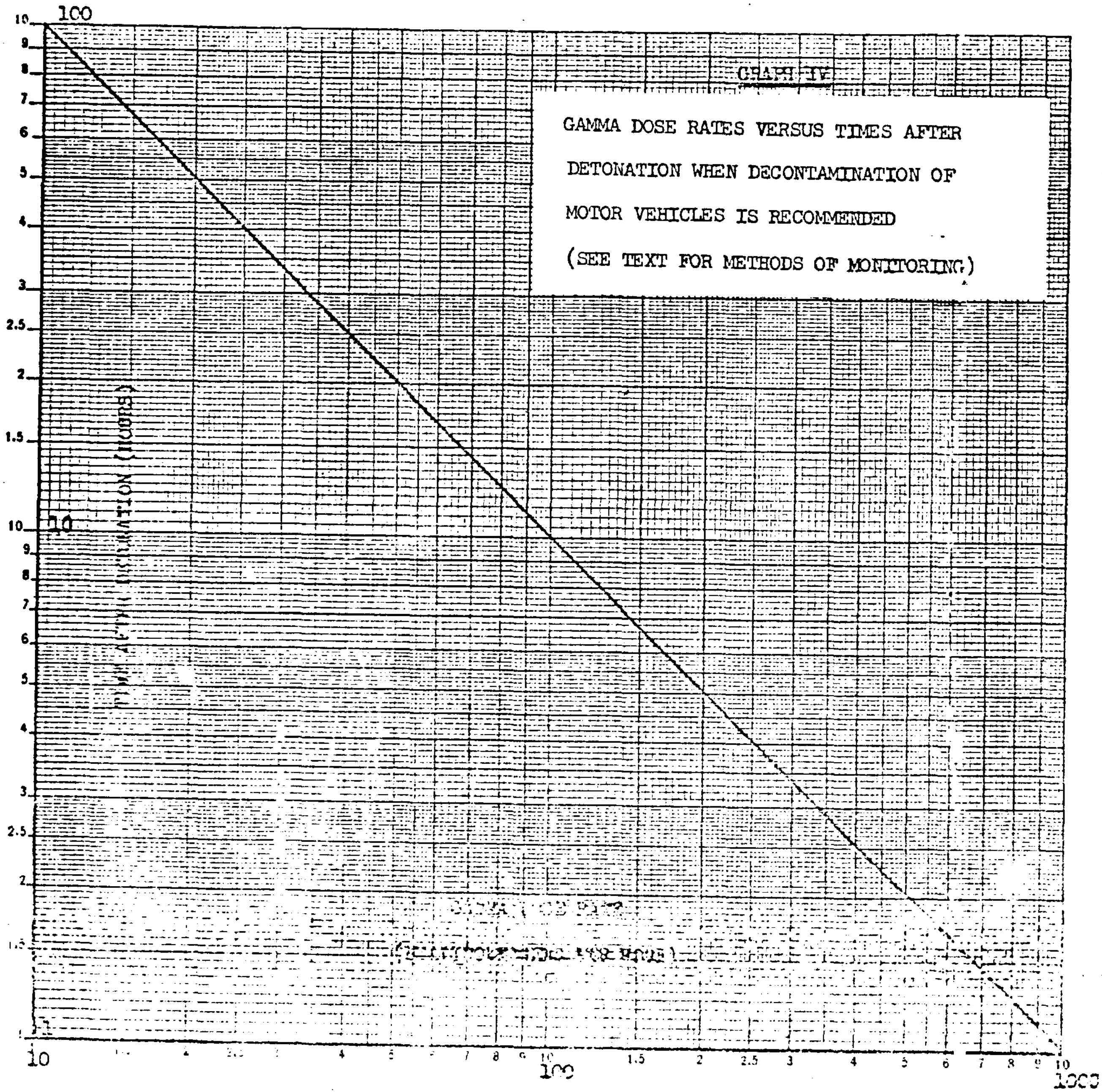
The principal purposes for decontaminating motor vehicles are to reduce the potential beta doses to the skin by contact with the vehicle, and to reduce the external gamma exposure. All of the uncertainties inherent in personnel monitoring are applicable here plus additional ones, such as estimates of the probability of contact and the amount of transfer of radioactive material from the vehicle to the skin. The following criteria for monitoring motor vehicles (Graph IV) were previously developed, and until the new beta measuring instruments (see Section III) are calibrated, will continue to be recommended.

One method of avoiding or significantly reducing vehicle contamination is to prevent their being in an area during the time of actual fallout. It is possible that fallout across a highway may be higher than that permitted for populated areas. When such a condition is predicted, it would be advisable to hold vehicular traffic until after the fallout had essentially ceased. Past experience has shown that very significantly less vehicle contamination occurs when it passes through an area afterwards compared to being present during the fallout time, although appreciable amounts can still be picked up on the tires and under the fenders. Obviously, there is not a precise value that may be given, but it is recommended that if the amount of fallout across a main highway is predicted to be in an amount equivalent to 10 roentgens or greater infinity dose, that traffic be temporarily halted until the fallout has essentially ceased.

CRITERIA IV

It is recommended that when the predicted fallout across a main highway be equivalent to 10 roentgens or greater infinity gamma dose, vehicles be held until the fallout has essentially ceased.

Graph IV may be used in determining the advisability of decontaminating motor vehicles. The survey instrument should be held with the center of the probe or center of the ionization chamber four inches from any readily accessible surface.


GRAPH IV
GAMMA DOSE RATES VERSUS TIMES AFTER
DETONATION WHEN DECONTAMINATION OF
MOTOR VEHICLES IS RECOMMENDED
(SEE TEXT FOR METHODS OF MONITORING)
100
10
100
1000

S E C T I O N V

CONTAMINATION OF WATER, AIR AND FOODSTUFFS

Background

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, if for no other reasons than as precautionary and documentary measures. 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 would be a health hazard. Nor is it implied here that any level above this does constitute a serious contamination of water, air, or foodstuffs. One good point of reference is the Marshallese experience where the whole-body gamma exposure was 175 roentgens yet the internal deposition from ingestion and inhalation was relatively small. In the event of a relatively heavy fallout, but less than one calling for evacuation, a common sense rule would be to wash exposed foods, such as leafy vegtables, since this is the most probable mode of intake of activity.

CRITERIA V

Monitoring of air, food and water should be made as soon as possible in areas where the infinity dose equals or exceeds 10 roentgens. There need be no restrictive action imposed on food and water intake in areas where the fallout is less than that calling for evacuation. Washing off of such exposed foods as leafy vegtables may be advised when such action seems desirable.

SECTION VI

ROUTINE RADIATION EXPOSURES

Background

The Atomic Energy Commission has adopted, as an operational guide, 3.9 roentgens whole body external gamma radiation for off-site exposures resulting from Operation Plumbbob.

The discussion in Section I on effects of weathering and shielding on determining the actual radiation exposure is applicable here. However, the factor of biological repair is not considered for routine exposures. This factor bears on somatic effects and may justifiably be considered in emergency situations when it is necessary to weigh the relative hazards from radiation versus mass evacuation. However, for routine exposures, the actual (estimated) roentgen dose should be used. To distinguish from the Effective Biological Dose and the Infinity Dose, this exposure will be expressed as the Estimated Dose.

Graph V incorporates the assumed effects of weathering and of shielding according to the discussion in Section I. The graph may be linearly extrapolated to other dose-rate readings. For example, if fallout occurs three hours after detonation and the dose rate is 360 milliroentgens per hour, then about three roentgens (estimated dose) may be accumulated, i. e., $\frac{360}{120} \times 1 = 3$

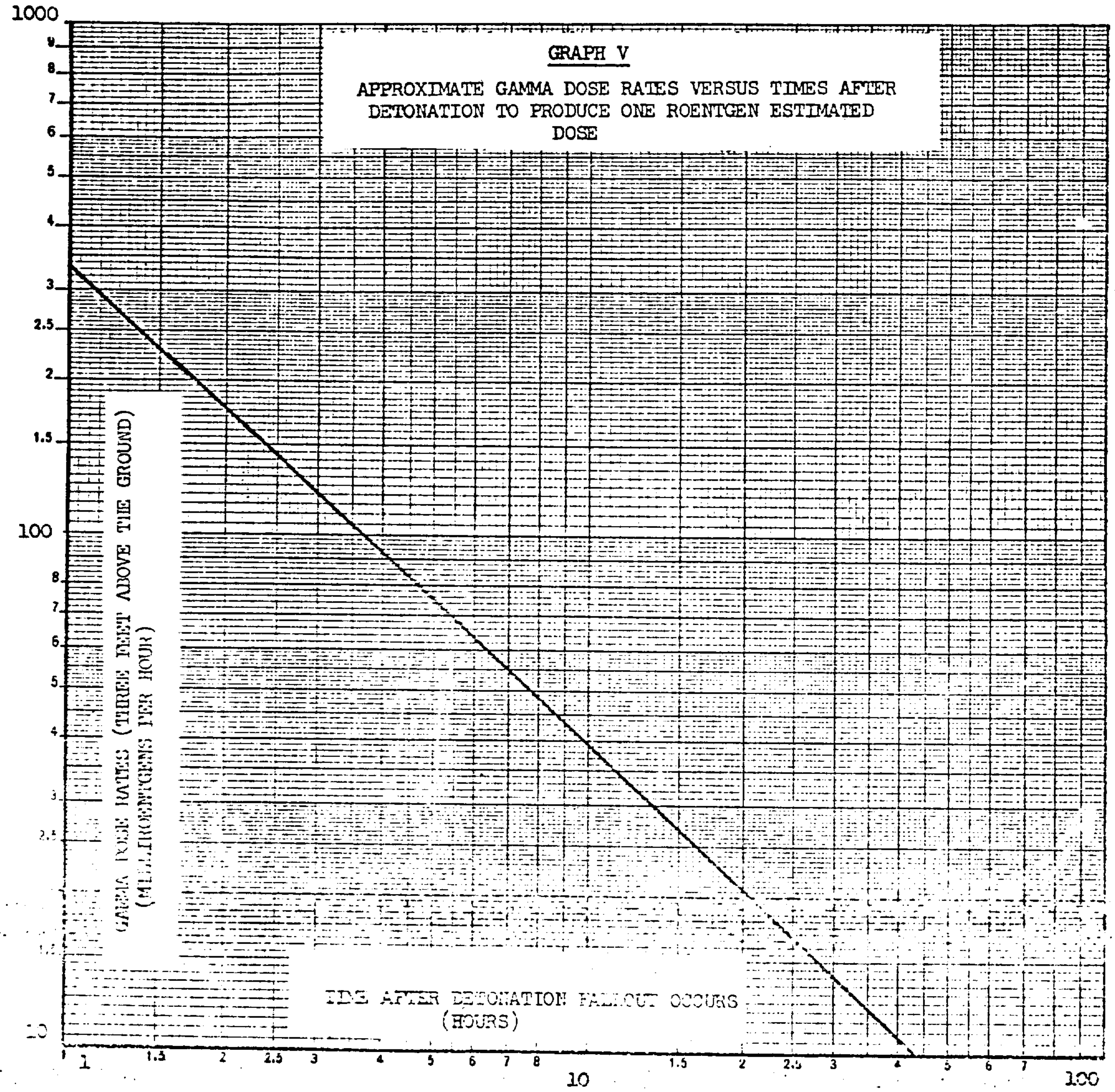
As discussed in Section I, the estimates of the effects of weathering and of shielding are conservative for areas around the Nevada Test Site. A range of radiation doses is to be expected for these people since they will not all be living under identical conditions. The radiation doses estimated by the present method is expected to fall within and toward the upper end of such a range. The information obtained from the expanded radiological monitoring program for Operation Plumbbob, should yield refinements in the method of estimating the radiation exposures.

In those cases where film badges are worn properly by personnel, the values recorded may be accepted as the Estimated Dose.

CRITERIA VI

Estimated Doses may be determined according to Graph V. In those cases where film badges are worn properly by personnel, the values recorded may be accepted as the Estimated Dose.

The whole-body gamma Estimated Dose for off-site populations should not exceed 3.9 roentgens resulting from Operation Plumbbob. This total dose may result from a single exposure or series of exposures.



GRAPH V
APPROXIMATE GAMMA DOSE RATES VERSUS TIMES AFTER DETONATION TO PRODUCE ONE ROENTGEN ESTIMATED DOSE
GAMMA DOSE RATES (THREE FEET ABOVE THE GROUND) (MILLIROENTGENS PER HOUR)
TIME AFTER DETONATION FALLOUT OCCURS (HOURS)
1000
100
10
1
10
100

APPENDIX TO RADIOLOGICAL SAFETY CRITERIA

FOR THE PUBLIC

The operational guide for concentrations of fallout material in drinking water shall be 5×10^{-3} microcuries per milliliter extrapolated to three days after a detonation.

A method of estimating radiation doses to the lungs and of evaluating these doses in contained in Appendix V-A.

III. RADIATION EXPOSURE RECORDS

A. External Gamma Doses

The map following page 25, and the tabulation on pages 26 and 27, presents the estimated external gamma radiation exposures around the Nevada Test Site from all tests except Operation Plumbbob.

The highest exposure has been at a motor court near Bunkerville, Nevada, where about 15 people might have accumulated up to 8 roentgens if they had continued to live there indefinitely.

"---The average exposure to only those communities around the Nevada Test Site that experienced the greatest amount of fallout (0.2 roentgens or more) is 0.6 roentgens for the six years since the regular nuclear tests were started. The round numbers are 58,000 man-roentgens for 100,000 people. If the area considered around the Nevada Test Site is enlarged to include 1,000,000 people the average exposure is about 0.1 roentgens for the six years, or at a rate of about 1/2 roentgen per thirty years. This is 1/20 of the recommendation of the National Committee on Radiation Protection and Measurement for maximum exposures.---" *

* _Radiations from Fallout and Their Effects:_ Testimony of Dr. Gordon M. Dunning before Congress, May 28, 1957.

ESTIMATED EXTERNAL GAMMA EXPOSURES FOR COMMUNITIES AROUND THE NEVADA TEST SITE

NEVADA

Location	roentgens	Location	roentgens
Acoma	3.0	Hoover Dam	0.05
Alamo	1.3	Indian Springs AF Base	
Apex	0.1	Johnnie	0.05
Ash Meadows	0.05	Kimberley	0.5
Ash Springs	0.6	Lake Mead Resort	0.05
Austin	0.05	Las Vegas	0.2
Baker	0.8	Lathrop Wells	0.05
Barclay	2.0	Lincoln Mine	4.0
Beatty	0.05	Lockes Ranch	1.3
Boulder City	0.08	Logandale	0.4
Buckhorn Ranch	0.9	Lund	0.8
Bunkerville	4.3	Camp Mercury	0.1
Cactus Spring	0.03	Mesquite	1.8
Caliente	0.7	McGill	0.4
Carp	3.6	Moapa	0.8
Charleston Lodge	0.15	Nellis AF Base	0.05
Clarks Station	0.8	North Las Vegas	0.2
Crestline	0.7	Myala	1.7
Crystal	4.0	Overton	0.35
Crystal Springs	1.0	Pahrump	0.2
Currant	0.5	Panaca	0.65
Camp Desert Rock	0.05	Pioche	0.7
Dry Lake	1.0	Preston	0.7
Duckwater	0.8	Reed	4.0
East Ely	0.6	Round Mountain	0.05
Eden Creek Ranch	0.7	Rox	3.0
Elgin	3.5	Ruth	0.5
Ely	0.6	Sharp's (Adaven)	1.2
Eureka	0.2	Shoshone	0.7
Fallini Ranch	0.8	Springdale	0.02
Glendale	0.7	Sunnyside	1.2
Goldfield	0. to 0.015	Tonopah	0. to 0.015
Green	2.0	[illegible]	0.6
Henderson	0.02	Warm Springs	0.5
Hiko	1.0	Warm Springs Ranch	1.0
		Whitney	0

ARIZONA

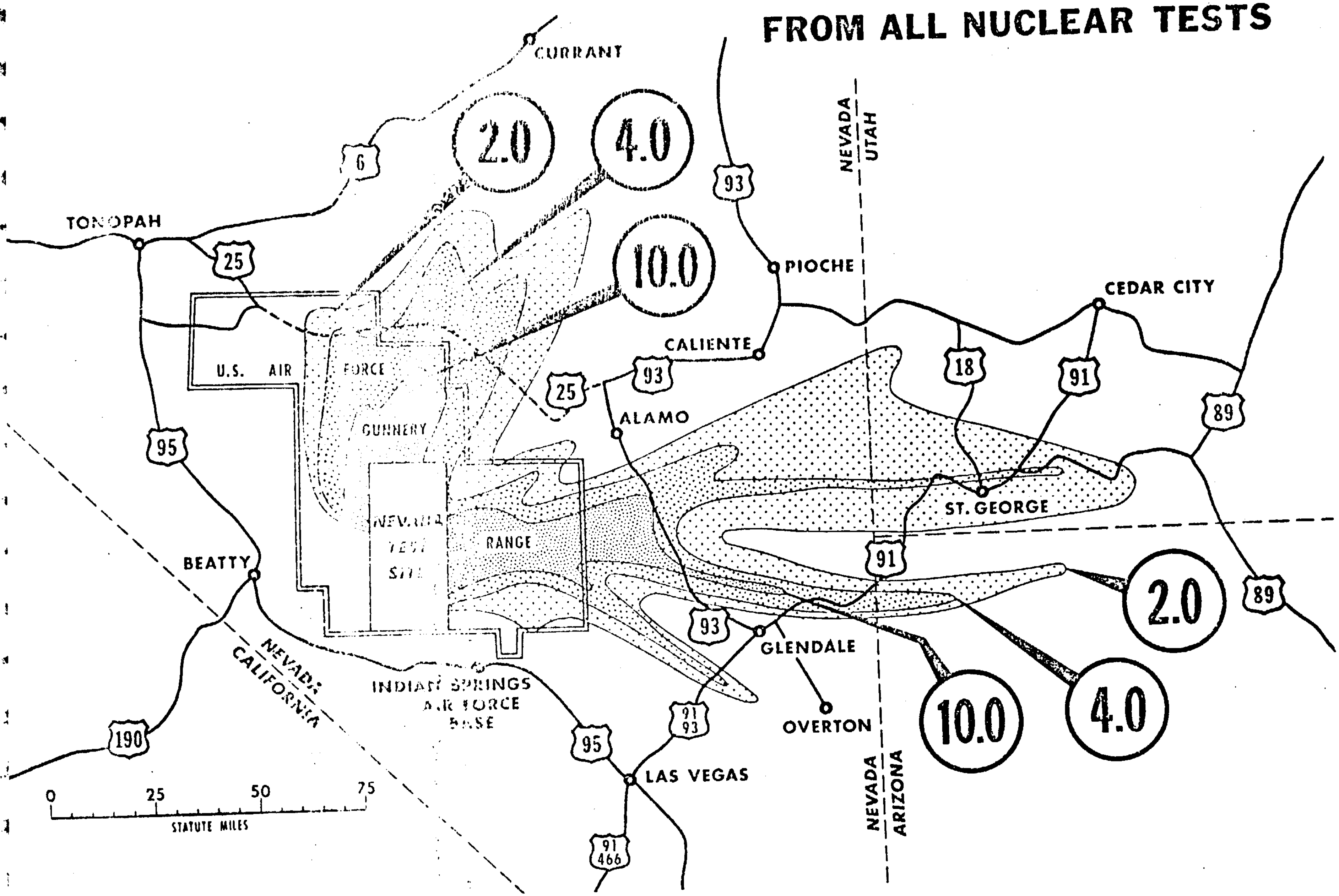
Location	roentgens	Location	roentgens
Beaver Dam	2.0	Peach Springs	0
Kingman	0.03	Short Creek	1.6
Littlefield	1.6	Wolf Hole	1.3
Mt. Trumbull	0.16		

UTAH

Location	roentgens	Location	roentgens
Alton	0.8	Modena	0.5
Anderson Junction	1.2	Mount Carmel	0.85
Bear Valley Junction	0.4	New Castle	0.6
Beaver	0.25	New Harmony	1.2
Beryl	0.5	Orderville	1.5
Beryl Junction	1.0	Panguitch	0.2
Cedar City	0.4	Paragonah	0.4
Enterprise	0.7	Parowan	0.4
Garrison	0.7	Pintura	1.2
Glendale	1.2	Rockville	3.0
Gunlock	2.6	Saint George	3.0
Hamilton Fort	0.6	Santa Clara	3.5
Hurricane	4.2	Shivwits	2.8
Kanab	1.6	Springdale	2.6
Kanarraville	1.2	Toquerville	2.0
Leeds	3.0	Veyo	2.0
Long Valley	0.8	Virgin	1.5
Lune	0.5	Washington	3.0
Milford	0.1	Zane	0.3
Minersville	0.2		

ESTIMATED RADIATION DOSES (Roentgens)

FROM ALL NUCLEAR TESTS



III. B. Activity Concentrations in Air

The highest measured concentration of fallout activity in the air of populated areas was at Saint George, Utah on May 19, 1953, amounting to 1.29 microcuries per cubic meter averaged over 24 hours. A calculation of the possible lung doses from this fallout indicates a value probably greater than 115 mrems and less than 230 mrems. This is less than the dose to the lungs each month from naturally occurring radioactive substances in the air, contained in Appendix V. A. An inspection of the other data in concentrations in air shows that this single lung dose is also higher than the accumulated lung doses from multiple fallouts in other populated areas for all tests.

Buster-Jangle (Fall 1951)

The highest measured concentration of fallout debris in air was at Ely, Nevada amounting to 0.202 microcuries per cubic meter averaged over 24 hours. All other measurements were in order of magnitude lower (Data taken from WT-425 Radiological Safety).

Tumbler-Snapper (Spring 1952)

Detonation	Locality	24-hour average concentration (Microcuries per cubic meter)
May 7, 1952	Ogden, Utah	0.030
May 25, 1952	Price, Utah	0.001
June 1, 1952	Elko, Nevada	0.004
June 1, 1952	Elko, Nevada	0.014

Atomic Energy Commission's 13th Semi-Annual Report to Congress, July-December 1952.

Upshot-Knothole (Spring 1953)

Locality	24-hour average concentration (Microcuries per cubic meter)
Saint George, Utah	1.29
Lincoln Mine, Nevada	4.0×10^{-1}
Mesquite, Nevada	1.7×10^{-1}
Groom Mine, Nevada	3.4×10^{-2}
Pioche, Nevada	2.0×10^{-2}
Nellis AF Base, Nevada	1.7×10^{-2}
Ely, Nevada	1.6×10^{-2}
Las Vegas, Nevada	1.0×10^{-2}

Atomic Energy Commission's 14th Semi-Annual Report to Congress, January-June 1953

Teapot (Spring 1955)

"---The highest concentration of radioactivity in the air following any one detonation was at Ely, Nevada. This amounted to about 6/100 of a microcurie per cubic meter averaged over the 28 hours that the material was present in significant quantities. The highest concentrations in air, averaged for the entire series, occurred at Ely, Nevada and Alamo, Nevada where the total additional radiation doses to the lungs from inhaling fallout material were estimated to be about equivalent to that expected from breathing air containing normal amounts of naturally radioactive materials, for a period of several days."

Atomic Energy Commission's 18th Semi-Annual Report to Congress, July 19[illegible]

III. C. Activity Concentrations in Water

The highest measured concentration of fallout debris in water was 1.4×10^{-4} microcuries per milliliter extrapolated to D + 3 days after detonation. As noted in the Commission's 18th Semi-Annual Report to Congress, this "--- is about 1/36 of the operational guide - an amount that is still considered safe even if the water were to be stored and used as the sole source of supply for a lifetime." (See Appendix V. B. for discussion of criterion)

Buster-Jangle (Fall 1951)

Six samples from Lake Meade showed negative results.

Tumbler-Snapper (Spring 1952)

Date		Approximate distance from ground zero (air miles)	Analysis (microcuries per milliliter at 3 days after detonation)
May 1, 1952	Crystal Springs Pond	63	0.5×10^{-8} microcuries
May 1, 1952	Pahranagat Lake	56	1.0×10^{-8} microcuries
May 2, 1952	Caliente - Drinking Water -	95	0.28×10^{-8} microcuries
May 2, 1952	Creek North of Caliente	97	1.1×10^{-8} microcuries

Atomic Energy Commission's 13th Semi-Annual Report to Congress
July-December 1952, p. 117.

Upshot-Knothole (Spring 1953)

Locality	Concentration microcuries per milliliter extrapolated to 3 days after detonation
Virgin River Irrigation Canal, Nevada	
Irrigation Ditch, 56 miles north of Pioche, Nevada	8.7×10^{-5}
Lower Pahranagat Lake, Nevada	4.5×10^{-5}
Virgin River at Mesquite, Nevada	3.2×10^{-6}
Bunkerville, Nevada (tap water)	2.6×10^{-6}
Crystal Springs, Nevada (tap water)	1.2×10^{-6}
	1.1×10^{-6}

Atomic Energy Commission's 14th Semi-Annual Report to Congress,
January-June 1953, p. 51.

Teapot (Spring 1955)

Locality	Concentration (Microcuries per milliliter extrapolated to 3 days after detonation)
Upper Pahranagat Lake, Nevada	1.4×10^{-4}
Waterhold near State (Nevada) Highway 25	9.2×10^{-5}
Meadow Valley (Nevada) Wash	3.3×10^{-5}

Atomic Energy Commission's 18th Semi-Annual Report to Congress,
January-June 1955, p. 80.

IV. MEASURES TO PROTECT THE PUBLIC

The Nevada Test Site covers an area of about 600 square miles, with the adjacent 4,000 square miles being a U. S. Air Force Gunnery range. Surrounding these areas are wide expanses of sparsely populated land. For general safety, as well as security, the Nevada Test Site is closed to the public. Aerial and surface surveys are made to insure that no persons or animals wander into the area. Each nuclear detonation is publicly announced ahead of time.

As a part of the Test Organization there is an advisory panel of experts in the fields of biology and medicine, blast, fallout prediction and meteorology. A series of meetings is held before the firing of each shot to weigh carefully all factors related to the safety of the public.

A complete weather unit is in operation at the Nevada Test Site, drawing upon all of the extensive data available from the U. S. Weather Bureau and the Air Weather Service, plus six additional weather stations ringing the test site. These data are evaluated for the current and predicted trends up to one hour before shot time. A shot can be cancelled at any time up to a few seconds before the scheduled detonation. In the past, more than [illegible] postponements have been made due to unfavorable weather conditions.

Several measures have been used to reduce the radioactive fallout off the test site. First, of course, only small nuclear devices are tested at Nevada. Since the greater the height of the fireball above the surface the less is the fallout in nearby areas, the test towers have been extended to 500 feet, and during Operation Plumbbob (Spring 1957) there will be at least one 700-foot tower. Also, a new technique of using captive balloons is being developed. Extensive tests are being conducted to determine the feasibility of detonating nuclear devices so far underground that all of the radioactive material will remain captured and thus, of course, completely eliminate any fallout.

Prior to each nuclear detonation a "warning circle" is established for aircraft, designed to provide control of aerial flights within the area of predicted path of the atomic cloud. A representative of the Civil Aeronautics Administration is assigned to the test organization and assists in establishing the controlled area. This may typically extend about 150 miles in radius and be in force for a period from about H minus one-half hour to H plus 10 hours. All aircraft are required to check through the Civil Aeronautics Administration before flying in this area.

After each nuclear burst, aircraft from the Test Organization track the cloud until it is no longer readily detectable. Behind this come other aircraft to plot the fallout pattern on the ground. This survey is repeated on H plus one day.

The off-site monitoring program during Operation Plumbbob (Spring 1957) illustrates the extensive system organized not only to take numerous radiological measurements but also to provide close liaison with the citizens of nearby communities. The Atomic Energy Commission and the U. S. Public Health Service jointly organized a program wherein the areas around the test site are mapped out into 17 zones. A technically qualified man has been assigned to live in each zone. His duties consist not only of normal monitoring activities but also, prior to and during the test series, of learning the communities and families in his zone, getting to know the people and having them know him. In addition to the 17 zone commanders, as they are called, there are eight mobile monitoring teams on call to go to any locality to assist if needed or to travel to areas outside the 17 zones.

Four additional monitoring programs are also in operation. One of these projects is primarily of research nature yet provides radiation monitoring data out to 160 miles or more from the test site. A second program is a unique system of telemetering, whereby instruments are placed in about 30 communities around the test site and connected to commercial telephone wires. The operator sits at the control point and, by placing a normal telephone call, receives back signals that are translated in a matter of seconds into gamma radiation dose rates. A third project consists of automatic instruments located in another 15 communities that permanently record the gamma dose rates continuously from the beginning to the end of the test series. A fourth program consists of aerial surveys with special gamma detection instruments.

Extending outward from the Test Site across the country are 38 U. S. Public Health Service monitoring stations established in cooperation with the Atomic Energy Commission, and 12 AEC installations (See p. and p. 34). In addition, through the cooperation of the U. S. Weather Bureau 93 stations in the United States make gummed paper collections of fallout (See p.35). These gummed paper collections are also made world-wide at 73 other locations by arrangement with the Department of State, U. S. Weather Bureau, U. S. Air Force and Navy. (See p.36)

From, Radiations From Fallout and their Effects. Testimony of Dr. Gordon M. Dunning before Congress, May 28, 1957.

U. S. PUBLIC HEALTH SERVICE MONITORING STATIONS

Albany, New York
Anchorage, Alaska
Atlanta, Georgia
Austin, Texas
Baltimore, Maryland
Berkeley, California
Boise, Idaho
Cheyenne, Wyoming
Cincinnati, Ohio
Denver, Colorado
El Paso, Texas
Gastonia, North Carolina
Harrisburg, Pennsylvania
Hartford, Connecticut
Honolulu, T. H.
Indianapolis, Indiana
Iowa City, Iowa
Jacksonville, Florida
Jefferson City, Missouri
Juneau, Alaska
Klamath Falls, Oregon
Lansing, Michigan
Lawrence, Massachusetts
Little Rock, Arkansas
Los Angeles, California
Minneapolis, Minnesota
New Orleans, Louisiana
Oklahoma City, Oklahoma
Phoenix, Arizona
Pierre, South Dakota
Portland, Oregon
Richmond, Virginia
Salt Lake City, Utah
Santa Fe, New Mexico
Seattle, Washington
Springfield, Illinois
Trenton, New Jersey
Washington, D. C.

AEC MONITORING STATIONS

Berkeley, California	Radiation Laboratory, University of California
Cincinnati, Ohio	General Electric Company - Aircraft Nuclear Propulsion Department
Idaho Falls, Idaho	Idaho Operations Office
Lemont, Illinois	Argonne National Laboratory
Los Alamos, New Mexico	Los Alamos Scientific Laboratory
New York, New York	New York Operations Office
Richland, Washington	Hanford Operations Office
Oak Ridge, Tennessee	Oak Ridge National Laboratory
Rochester, New York	The Atomic Energy Project, University of Rochester
Salt Lake City, Utah	Radiobiology Laboratory, University of Utah
West Los Angeles, California	Atomic Energy Project, UC-Los Angeles
Sandia Corporation	Albuquerque, N. M.

U. S. WEATHER BUREAU FALLOUT SAMPLING STATIONS

Abilene, Tex.
Albany, N. Y.
Albuquerque, N. Mex.
Alpona, Mich.
Amarillo, Tex.
Atlanta, Ga.
Bakersfield, Calif.
Baltimore, Md.
Billings, Mont.
Binghamton, N. Y.
Bishop, Calif.
Boise, Idaho
Boston, Mass.
Buffalo, N. Y.
Caribou, Me.
Casper, Wyo.
Charleston, S. C.
Cheyenne, Wyo.
Chicago, Ill.
Cleveland, Ohio
Colorado Springs, Colo.
Concord, N. H.
Corpus Christi, Tex.
Concordia, Kan.
Los Angeles, Calif.
Louisville, Ky.
Lynchburg, Va.
Marquette, Mich.
Medford, Oreg.
Memphis, Tenn.
Miami, Fla.
Milford, Utah
Milwaukee, Wisc.
Minneapolis, Minn.
Mobile, Ala.
Montgomery, Ala.
New Haven, Conn.
New Orleans, La.
New York (La Guardia), N. Y.
Philadelphia, Pa.
Phoenix, Ariz.
Pittsburgh, Pa.
Pocatello, Idaho
Port Arthur, Tex.
Portland, Oreg.
Prescott, Ariz.
Providence, R. I.
Pueblo, Colo.
Dallas, Texas
Del Rio, Tex.
Denver, Colo.
Des Moines, Iowa
Detroit, Mich.
Elko, Nev.
Ely, Nev.
Eureka, Calif.
Fargo, N. Dak
Flagstaff, Ariz
Fort Smith, Ark.
Fresno, Calif.
Goodland, Kans.
Grand Junction, Colo.
Grand Rapids, Mich.
Green Bay, Wisc.
Hatteras, N. C.
Helena, Mont..
Huron, S. Dak.
Jackson, Miss.
Jacksonville, Fla.
Kalispell, Mont.
Knoxville, Tenn.
Las Vegas, Nev.
Rapid City, S. Dak.
Reno, Nev.
Rochester, N. Y.
Roswell, N. Mex.
Sacramento, Calif.
Salt Lake City, Utah
San Diego, Calif.
San Francisco, Calif.
Scottsbluff, Nebr.
Seattle, Washington
Spokane, Wash.
St. Louis, Mo.
Syracuse, N. Y.
Tonopah, Nev.
Tucson, Ariz
Washington, D.C. (Silver Hill, Md.)
Wichita, Kans.
Williston, N. Dak.
Winnemucca, Nev.
Yuma, Ariz.

FOREIGN MONITORING STATIONS

Addis Ababa, Ethiopia
Anchorage, Alaska
Bangkok, Thailand
Beirut, Lebanon
Belem, Brazil
Bermuda
Buenos Aires, Argentina
Canal Zone
Canton Island
Churchill, Manitoba, Canada
Clarke AFB, Philippines
Colombo, Ceylon
Dakar, French West Africa
Deep River, Ottawa, Ontario, Canada
Dhahran, Saudi Arabia
Durban Natal, South Africa
Edmonton, Alberta, Canada
Fairbanks, Alaska
French Frigate Shoals
Goose Bay, Labrador
Guam
Monrovia, Liberia
Montreal, Quebec, Canada
Moosoonee, Ontario, Canada
Nagasaki, Japan
Nairobi Kenya, East Africa
Nome, Alaska
North Bay, Ontario, Canada
Noumea, New Caledonia
Oslo, Norway
Ponape
Prestwick, Scotland
Pretoria, South Africa
Quito, Ecuador
Regina, Saskatchewan, Canada
Rhein Main, Germany
San Jose, Costa Rica
Hilo, Hawaii
Hiroshima, Japan
Honolulu, Hawaii
Iwo Jima
Johnson Island
Juneau, Alaska
Keflavik, Iceland
Koror
Kwajalein
La Paz, Bolivia
Lagens, Azores
Lagos, Nigeria
Leopoldville, Belgian Congo
Lihue
Lima, Peru
Melbourne, Australia
Mexico City, Mexico
Midway Island
Milan, Italy
Misawa, Japan
Moncton, New Brunswick, Canada
San Juan, Puerto Rico
Sao Paulo, Brazil
Seven Islands, Quebec, Canada
Sidi Slimane, French Morocco
Singapore
Stephenville, Newfoundland
Sydney, Australia
Tai Pei, Formosa
Thule, Greenland
Tokyo Air Base, Japan
Truk
Wake Island
Wellington, New Zeland
Wheelus AFB, Tripoli
Winnipeg, Manitoba, Canada
Yap

V. APPENDICES

A. A METHOD OF ESTIMATING DOSES FROM FALLOUT ACTIVITY IN THE AIR

1. Doses to the Lungs

Assumptions:

1. The rate of inhalation is 20 cubic meters per 24 hours.[a]
2. The percentage of initial retention of particles (and activity) is 25%.
3. All of the air-borne activity is associated with particles in the respirable range.[b]
4. The mass of the lungs is 1000 grams and is uniformly irradiated.[c]
5. Mean energy of the beta particles = 0.4 mev. (The relative dose from gamma emission may be roughly 10% of the beta dose. Since this is less than the uncertainties in other estimations described below, it will not be considered here.)
6. The dose rate decreases according to the relationship of $(\text{time})^{-1.2}$.

a. It is recognized that generally there will be higher volumes of intake during working hours than at other times. When such times are known, the assumption usually made is that 10 cubic meters are inhaled during 8 hours of work and 10 cubic meters inhaled for the remainder of the day.

b. Generally, the cascade impactor data has shown 80 - 90+% of the activity has been associated with particles 5 microns or less in size. However, it is quite possible that the high volume air samplers in use collect larger size particles.

c. The mass of children's lungs is smaller but likewise is the rate of air (activity) intake.

Method of Estimating Infinity Doses to the Lungs

Step 1.

Calculate the dose rate for 1.0 $\mu c/M^3$ - hour

A. For each one $\mu c/M^3$ activity present in the air per hour,

(0.83) (0.25) = 0.21 μc of activity are initially retained. (Based on an assumed intake of 20 cubic meters of air per 24 hours)

B. The initial dose rate to the lungs will be:

$$\frac{(0.21)\ (\mu c)\ (1.3 \times 10^{8})\ (d/hr\text{-}\mu c)\ (0.4)\ (Mev)\ (1.6 \times 10^{-6})\ (ergs/Mev)}{100\ (ergs/gm\text{-}rad)\ (1000)\ (grams)} =$$

1.7×10^{-4} rads/hour

Step 2.

Calculate the "infinity" dose to the lungs.

A. $D_{oo} = 5\ A_t\ t$ where: A_t = dose rate at time of deposition "t" after detonation (hours)

t = time after detonation that deposition occurs.

D_{oo} = infinity dose (rads)

B. $D_{oo} = (5)\ (1.74 \times 10^{-4})\ (t)$

$= (8.5 \times 10^{-4})\ (t)$ rads

$= (0.85)\ (t)$ mrads (per 1.0 $\mu c/m^3$/hour)

or $D_{oo} = (0.85)\ (t)\ (\mu c/M^3)$ (hours of inhalation) mrads (20 M^3/24 hours)

$D_{oo} = (1.28)\ (t)\ (\mu c/M^3)$ (hours of inhalation) mrads (10 M^3/8 hours)

$D_{oo} = (0.64)\ (t)\ (\mu c/M^3)$ (hours of inhalation) mrads (10 M^3/16 hours)

Example

The highest measured concentration of fallout activity in air in a populated offsite area was at Saint George, Utah on May 19, 1953. Using this event, sample calculations are made below.

Air Concentrations	Midpoint of Sampling Period (Hours after detonation)	Duration of Sampling	Infinity Lung Dose (mrem)
4.0	4.5	5	115[a]
2.3	8.5	3	75[a]
0.62	12.0	4	19[b]
0.43	16.0	4	18[b]
0.014	24.0	12	2.6[b]
			~ 230

a. Based on 10 M^3/8 hours
D_∞ = (1.28) (4.5) (4.0) (5) = 115 mrem

b. Based on 10 M^3/16 hours

Evaluation of Lung Doses

The above estimates are based on infinity doses. The actual dose will be less than this but the exact value is difficult to estimate. It is probable that some 40% of the material (and activity) will be cleared from the lungs with a half-time of about one day. The remainder may have a half-time of removal of about 150 days.* Fallout that occurs one hour after a detonation will expend about 50% of the potential infinity dose during the first day, while fallout that occurs 10 hours after detonation requires about 15 days to deliver one-half of the infinity dose. The uncertainties in these and other estimates and assumptions do not justify attempting an exact calculation of actual radiation lung dose. However, it seems reasonable to assume the actual dose is less than the infinity dose and more than one-half of the maximum value.

* Langham, Wright H. "Determination of Internally Deposited Radioactive Isotopes From Excretion Analyses." American Industrial Hygiene Association Quarterly, 17:3, 305-318, September 1956.

Using the infinity lung dose as a basis of discussion, its biological significance may be appraised by comparison with lung doses produced by natural occurring radioactive materials in the air (radon and thoron and their daughter products). These dose estimates vary due to different assumptions as to natural air concentrations and percentages of activity retained in the lungs, but very roughly may be 10 mrem per day. Thus, using the example given above for Saint George, Utah, the infinity dose was calculated as 230 mrads (or mrems in this case); the actual dose may be more than 115 mrems and less than 230 mrems. This is less than the dose to the lungs each month from naturally occurring radioactive substances in the air.

V. A. 2. Doses to the Thyroid

A method of estimating doses to the thyroid from inhalation of fallout material is contained in the attached reprint "Two Ways to Estimate Thyroid Dose from Radioiodine in Fallout."

Two Ways to Estimate Thyroid Dose from Radioiodine in Fallout

By GORDON M. DUNNING

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

reprinted from NUCLEONICS

Feb. 1956, Vol. 14, No. 2, Pgs. 38–41

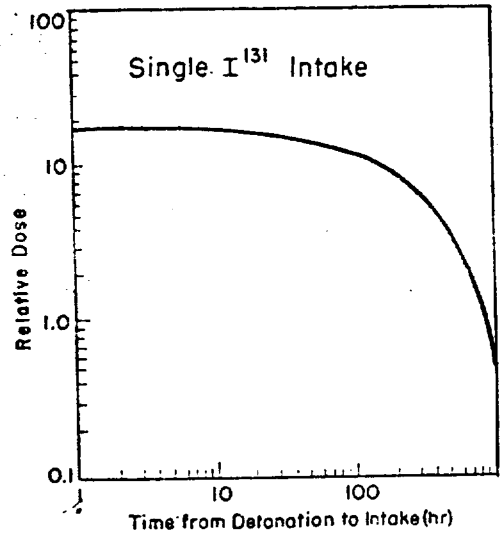


FIG. 2. Approximate infinity dose to thyroid from single intake of the I^{131} and its tellurium precursors from 10,000 fissions. This figure is used with Table 3 in the preparation of Fig. 3

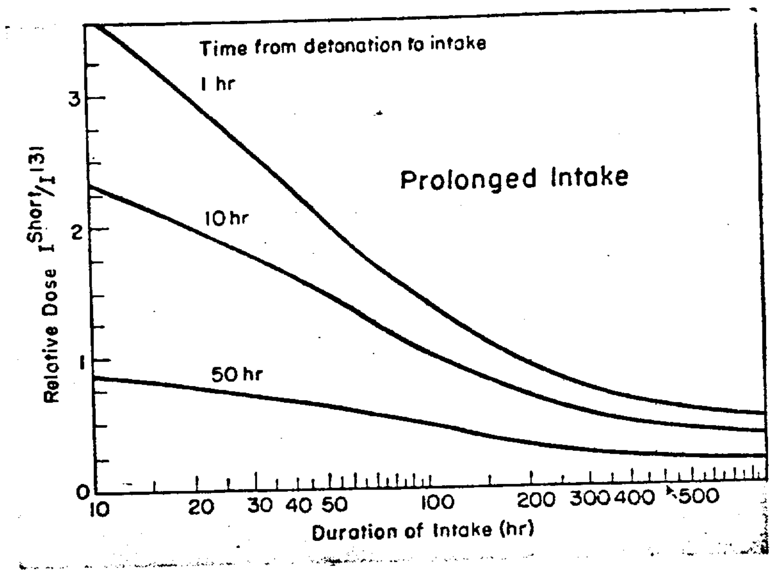


FIG. 3. Approximate relative infinity dose to thyroid from short-lived I isotopes and I^{131} for case of prolonged intake. See Table 3 for sample calculation of these curves

When ingestion or inhalation of radioactive fallout material occurs, it is important to be able to estimate the dose received. Here, for the case of radioiodine, is a procedure for determining the thyroid dose given present activity or initial intake

c. The intake, along with the I^{131}, of Te^{131}, a part of which will disintegrate within the body to I^{131}.

TABLE 1—Isotopes Important to Thyroid Uptake

	Atomic number				
Mass number	*51 (Sb)*	*52 (Te)*	*53 (I)*	*54 (Xe)*	*55 (Cs)*
131		30 hr ↓ 25 min →	8.0 day →	stable	
132	~5 min →	77 hr →	2.4 hr →	stable	
133	<10 min →	60 min →	21 hr →	5.3 day →	stable
134	<10 min →	43 min →	50.8 min →	stable	
135		<1 min →	6.7 hr	↗ 15.3 min (~10%) ↘ 9.2 hr →	2.1×10^6 yr → stable

To estimate the original rate of intake of I^{131} from a known activity in the thyroid at a later date, one can extrapolate according to the physical and biological decays of I^{131} only. This method ignores intake factor **b** and thus overestimates the original intake; it also ignores factor **c** and thus underestimates the original intake. The extent to which these affect the answer depends upon time of original intake after detonation and the duration of intake. However, estimates of the effects of ignoring these two factors indicate that the over-all error would not be any greater than other inherent uncertainties.

The exact steps are given in the following sections. The symbols are defined at the head of page 40. Two examples are given on pages 40 and 41.

1. Initial rate of intake of I^{131}, R_0. Assume that the rate of intake decreases according to the physical decay of the isotope. Then activity in the thyroid changes thusly

$$\frac{dA}{dt} = R_0 e^{-\lambda_r t} - (\lambda_r + \lambda_b) A$$

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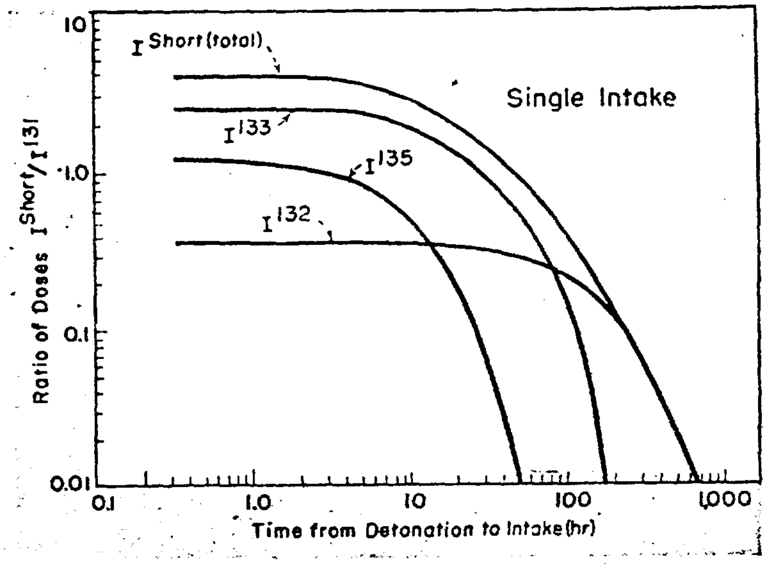


FIG. 1. Approximate ratio of infinity dose to thyroid from short-lived radioiodine isotopes and I^{131} for case of single intake. See Table 2 for sample calculation of these curves

Two Ways to Estimate

Thyroid Dose from Radioiodine in Fallout

CALCULATING RADIATION DOSE from fallout presents unique problems. One of these is how to estimate thyroid dose from intake of the radioisotopes of iodine found in fallout material. Because of uncertainties in the relevant variables, the calculations cannot be made with the precision that is possible in a laboratory or clinical situation. However, it is often essential to make such estimates, even though admittedly based on limited data.

There is disagreement as to the principal mode of entry into the body of the radioactive I contained in fallout, i.e., inhalation or ingestion. For low-yield detonations, such as in Nevada, relatively higher concentrations of fallout material are found in the air for only a matter of a few hours with essentially all of calculated intake by inhalation completed within 24 hours for nearby communities.

When the detonations occur at the Pacific proving ground the activity in the air may persist for somewhat longer times in the U. S. Thus, *for relatively early, short exposures* the amount of intake by inhalation may be comparable to that by ingestion. However, if one considers normal ingestion for a continuing period, it would appear this is by far the dominant factor. This is especially true for grazing animals. In fact, field experiments near the Nevada test site showed there was little I in the thyroid of rabbits, who were restrained so that they could not ingest any material but could continue to inhale during and after fallout.

The problem of dosage calculations is complicated by the presence, at early times after detonation, of short-lived I isotopes in addition to I^{131} and by tellurium precursors for several.

The general approach given below for these problems is to calculate the dose from I^{131} and its precursors and then add to this the contribution from the short-lived isotopes of I and their precursors. Due to relative abundance or short half-lives the only isotopes [illegible] are I^{131}, [illegible], I^{135}, [illegible], [illegible]. Their properties are given in Table 1.

Calculating Dose

The precise calculation of I^{131} intake to the thyroid is difficult because of

a. Uncertainties of the percentage of intake into body that reaches the thyroid.

b. The tellurium precursors that result in the absolute activity of the I^{131} in the environment remaining roughly constant for about a day followed by a period of increasing decay rate until the precursors no longer play a significant role and the decay rate then becomes that of I^{131}.

Symbols Used

$A = A(t)$ = activity in thyroid (μc/gm)

R_0 = initial rate of intake of thyroidal I^{131} (μc/gm/day)

λ_r = radiological (physical) decay constant

λ_b = biological decay constant

t = time

E = average energy of beta particles (Mev)

$K = 55\, R_0 E$ (a constant)

D_s = infinity dose (reps) to thyroid from single I intake

D_t = total infinity dose (rep) to thyroid from continual intake from $t = 0$ to $t = \infty$.

TABLE 2—Sample Calculations for Figure 1

A	B	C	D	E	F	G	H
Radio-isotope	*Half-life (hr)*	*Activity[a] (dpm/10,000 fissions)*	*Number of atoms present per 10,000 fissions*	*Atoms of iodine reaching thyroid per 10,000 fissions*	*Average beta energy (Mev)*	*Max. rel. energies to thyroid ($E \times F$)[b]*	*Ratio: I^{Short} Energy / I^{131} Energy*
I^{131}	192	0.014	230	57.5[d]	0.20	11.5	
Te^{131}	30	0.019	49.4	9.9[e]	0.20	1.9	
Te^{131m}	0.42	1.5	54.3	13.6[f]	0.20	2.7	
I^{132}	2.4	0.026	5.4	0.3[g]	0.52	0.16	0.01
Te^{132}	77	0.056	374	11.2[h]	0.52	5.8	0.36
I^{133}	21	0.14	255	48.5[i]	0.45	21.8	1.35
Te^{133}	1	2.6	226	43.0[j]	0.45	19.4	1.20
I^{135}	6.7	0.88	512	61.6[k]	0.30	18.5	1.15
I(all short-lived)							~4.07

[a] Based on Hunter and Ballou tables (*1*).

[b] The biological fate of the isotopes of iodine is the same. Thus, the same proportions of the total number of atoms of each are taken into the thyroid and then eliminated according to the biological characteristics of the animal. The loss of an atom of a short-lived isotope means a greater loss of energy to the thyroid than does the loss of an I^{131}. However, it is to be expected that the biological half-life of animal thyroids will be much greater than the radiological half-life of even the longest short-lived radioiodine isotope (I^{133} with 21-hr half-life) so that essentially all of these energies will be delivered to the thyroid. For cases where the biological decay constant, λ_b, is significantly large compared with the radiological decay constant, λ_r of I^{131}, (0.0036 hr^{-1}), then the values for energies of I^{131} including Te^{131} and Te^{131m} precursors) given in column *G* should be multiplied by the factor $\lambda_r/(\lambda_r + \lambda_b)$ and likewise the values for the relative energies in column *H* for the short-lived isotopes should be multiplied by the factor $(\lambda_r + \lambda_b)/\lambda_r$.

[c] All of the iodine atoms reaching the thyroid will disintegrate there. Corrections may be necessary according to footnote [b].

[d] 25% of the I atoms taken into the blood reach the thyroid.

[e] 20% of Te^{131} taken into the body reaches the thyroid, i.e., about 80% would have disintegrated to Te^{131} while in the gut of which all disintegrates to I^{131} of which 25% reaches the thyroid.

[f] All of the Te atoms taken into the body will disintegrate to I^{131} of which 25% will reach the thyroid.

[g] 5% of the I [illegible] into the body reaches the thyroid. The biological half-life of I in the blood of humans may be about 7 hr (*2*). According to available data to date [illegible] of I in the blood of [illegible] 16-12 [illegible] [illegible] out of the [illegible]. The proportion of activity reaching the thyroid [illegible] be estimated as [illegible] $\lambda_b + \lambda_r$). The values in Table 1 are based on human data (7-hr biological half-life of iodine in the blood). These also give approximate values for sheep. Assuming a biological half-life of iodine in the blood of sheep of [illegible] hours over a period of 22 hours only, the ratios given in Fig. 1 differ for sheep [illegible] I^{132}, about 30% too high; I^{133}, 20% too low; I^{135}, 10% too low. The ratio of doses from individual short-lived iodine isotopes indicated in Fig. 1 suggests that the ratio of the total short-lived isotopes to I^{131} may be underestimated for sheep by a few per cent in the early times after detonation. At later times the I^{132} contribution predominates, but also the ratio of infinity doses from the total short-lived isotopes to I^{131} has decreased significantly. Thus, the method suggested here may give a fair approximation of the total infinity doses for sheep.

[h] 3% of the Te^{132} intake reaches the thyroid as I^{132}, i.e., 50% would disintegrate to I^{132} while in the gut of which 6% will be deposited in the thyroid per footnote *g*.

[i] 19% of the I^{133} taken into the body will be deposited in the thyroid; 25% would be deposited normally, but about 25% of these atoms will decay before deposition[g].

[j] All of the Te^{133} taken in will disintegrate into I^{133} while within the body of which 19% will reach the thyroid according to footnote *i*.

[k] 12% of the I^{135} intake will be deposited in the thyroid: 25% would be deposited normally but about 50% will decay before deposition according to footnote *g*.

This has the solution

$$A = \frac{R_0}{\lambda_b}\left(e^{-\lambda_r t} - e^{-(\lambda_r+\lambda_b)t}\right) \qquad (1)$$

Thus, analyzing the thyroid for its I^{131} activity, A, at any time, t, one can figure back to the initial rate of intake, R_0.

2. **Infinity I^{131} dose.** The dose to infinity from I^{131} intake on the first day is

$$D_s = K \int_0^\infty e^{-(\lambda_r+\lambda_b)t}\, dt = K/(\lambda_r + \lambda_b)$$

The infinity dose from a continuing intake that decreases according to the radiological decay is then given by

$$D_t = K/\lambda_r + \lambda_b \int_0^\infty e^{-\lambda_r t}\, dt$$

$$D_t = K/(\lambda_r + \lambda_b)\lambda_r \qquad (2)$$

3. **Doses from short-lived isotopes.** The additional dose to the thyroid from short-lived isotopes of iodine resulting from a *single* intake is summarized in Fig. 1. A sample of the calculations used to construct Fig. 1 is given in Table 2 at left.

In the case of grazing animals, however, the period of intake may start at different times after detonation and extend for varying periods of time. An estimation of additional doses to the thyroid from short-lived isotopes of iodine under these conditions is summarized in Fig. 3. A sample of the calculations used to construct Fig. 3 is given in Table 3.

Example: Sheep Ingestion

About 3½ hours after the nuclear detonation at the Nevada Test Site on May 19, 1953, fallout occurred in an area around Cedar City, Utah, where sheep were grazing. On June 15 some of these sheep were sacrificed and on July 8 the I^{131} concentrations were measured in specimens of their thyroids. The highest measured I^{131} concentrations on July 8 were about $5 \times 10^{-?}$ μc/gm (c.f. *2*). What might have been the total radiation dose to the thyroids of these sheep from all of the isotopes of radioiodine?

First calculate the I^{131} dose, then the dose from short-lived isotopes. Determine the initial rate of intake of I^{131} activity per gram, R_0 from Eq. 1

$$A = (R_0/\lambda_b)[e^{-\lambda_r t} - e^{-(\lambda_r+\lambda_b)t}]$$

In this case $A_b = 0.37\, \mu c$/gm when sacrificed June 15. (Working back from July 8 measurement.)

t = 27 days (May 19–June 15)

λ_r = 0.0866 day^{-1}

λ_b = 0.0204 day^{-1}*

Thus

$$0.37 = \frac{R_0}{0.0204}\left[e^{-(0.0866)27} - e^{-(0.107)27}\right]$$

R_0 = 0.189 μc/gram/day.

Now we determine the infinity I^{131} dose using Eq. 2.

$$D_{t\infty} = K/\lambda_r(\lambda_r + \lambda_b)$$

where: $K = 55\ R_0E = 55(0.189)(0.2) = 2.08$

Thus $D_{t\infty}$ = 224 reps is the infinity I^{131} dose.

To estimate the dose from short-lived isotopes of I enter Fig. 3 with these parameters:

start of intake = 3.5 hr
duration of intake = infinity.

The graph indicates a ratio of approximately 0.45.

But this is uncorrected for biological decay, i.e., it is based on the assumption that the biological decay constant for the thyroid is significantly less than the physical decay constant. It is necessary to correct this ratio by multiplying by the factor†

$$(\lambda_r + \lambda_b)/\lambda_r = 1.24$$
$$0.45 \times 1.24 = 0.557$$

The infinity dose to the thyroid from short-lived isotopes of iodine is this fraction of the I^{131} dose

$$224 \times 0.557 = 125 \text{ reps.}$$

Thus the total infinite dose is 224 + 125 ≅ [illegible] reps.

[illegible] at Hanford [illegible] 10,000 reps are required to produce minimal changes in the thyroid cellular structure and about 50,000 reps to produce definite cell damage and hypothyroidism.

BIBLIOGRAPHY

1. H. F. Hunter, N. E. Ballou, NUCLEONICS 9, No. 5, C-2 (1951)
2. J. B. Stanbury, et al. "Endemic Goiter," Harvard University Monograph in Medicine and Public Health No. 12 (Harvard University Press, 1954)
3. L. Van Middlesworth, NUCLEONICS 12, No. 9 (1954)
4. [illegible]

* Biological half-life in sheep thyroids is about 34 days (4).

† See footnote b Table 2.

EXAMPLE: Human Inhalation

On May 19, 1953 the highest concentration of activity in the air due to fallout that has ever been recorded in the U. S., outside the Nevada Test Site, occurred at St. George, Utah. It amounted to about 1.3 μc/m³ averaged over 24 hours. The total radiation dose to the thyroids of the people at St. George from inhalation of the isotopes of I is estimated to be 0.302 rep as shown in the following tabular calculation.

Estimate of Radiation Doses to Thyroid of Humans From Inhalation

Time after detonation (hr)	Average fission-product activity (μc/meter³)	Fission-product activity originally retained (μc)[a]	Fraction of fission product that is I^{131b} %	I^{131} activity reaching thyroid (milliμc)	Infinity I^{131} dose to thyroid (rep)[d]	Added dose from short-lived I isotopes[e] (rep)	Total infinity dose (rep)
2–7	4.0	12.4	0.16	5.00	0.0304	0.121	0.155
7–10	2.3	4.3	0.35	3.77	0.0230	0.074	0.097
10–14	0.62	1.56	0.47	1.80	0.0110	0.030	0.041
14–18	0.043	0.104	0.7	0.19	0.0012	0.003	0.004
18–30	0.014	0.105	1.1	0.29	0.0018	0.003	0.005
						Tota	0.302 rep

[a] Based on 0.83-meter³/hr air intake and assuming that 75% of the activity will be initially retained either in the lungs or find its way into the gastrointestinal tract.

[b] Based on assumption that 75% of initial intake of both Te precursors of I^{131} will remain within body until decayed to I^{131}.

[c] Assuming 25% of initial retention of I^{131} (either in lungs or gastrointestinal tract) reaches the thyroid.

[d] Initial dose rate = (55)(0.2)(μc of I^{131} per gram of tissue) in reps per day. Infinite dose = Initial dose rate/$(\lambda_r + \lambda_b)$.

[e] From Fig. 1. Multiply these ratios by $(\lambda_r + \lambda_b)/\lambda_r$ for I^{131} in man.

TABLE 3—Sample Calculations for Figure 3

A	B	C	D	E	F	G
[illegible]	Relative mean [illegible]	Cumulative [illegible] intake	Mean of ratios of [illegible]	Relative energy [illegible] (B × D)	Cumulative I^{short} [illegible] intake	Ratio of total energies I^{short}/I^{131} for infinite thyroid dose intake from 1st hour to end of period [illegible] (Column F ÷ C)[c]
[illegible]11	[illegible]	160	3.6	575	575	3.6
11–21	158	318	2.3	364	939	2.95
21–31	150	468	1.6	240	1,179	2.52
31–41	146	614	1.3	190	1,369	2.23
41–51	140	754	1.0	140	1,509	2.0
51–61	135	889	0.84	115	1,624	1.83
61–71	130	1,019	0.70	91	1,715	1.68
71–81	125	1,144	0.55	69	1,784	1.56
81–91	120	1,264	0.46	55	1,839	1.45
91–101	115	1,379	0.40	46	1,885	1.37
101–201	920	2,299	0.20	184	2,069	0.900
201–301	650	2,949	0.08	52	2,121	0.718
301–401	470	3,419	0.042	19	2,140	0.626
401–601	600	4,019	0.02	12	2,152	0.535
601–801	280	4,299	0.0095	3	2,155	0.500
801–1,001	140	4,439	0.005	1	2,156	0.484

[a] Based on Fig. 2.

[b] From Fig. [illegible]

[c] This is uncorrected for biological decay as described in footnote b Table 1. For cases where biological decay in the thyroid is significant for I^{131}, multiply last column G by the factor $(\lambda_r + \lambda_b)/\lambda_r$.

V. B. A Method of Estimating Doses From Activity in a Water Supply

The value of 5×10^{-3} microcuries per milliliter at D + 3 days after a detonation has been set as an operational guide for activity concentration in water. This may be evaluated in several ways, one of the most extreme being that water containing this amount of activity is stored and used as the sole supply for a lifetime at the rate of 2200 milliliters per day but using the adult skeleton as a basis for calculation). Based on this assumption the following calculations are made as to resultant total doses:

Lower large intestine (lesser doses to the other parts of the G. I. tract according to Graph following page 43.	~9.0 rads
Thyroid	~8.0 rads
Bones	~36.0 rads

The actual doses from the use of a normal water supply containing this amount of initial activity, will be undoubtedly considerably lower.

V. B. 1. DOSES TO THE GASTROINTESTINAL TRACT

Assume: About 22 μc of fallout activity at time of intake will result in one rad of dose to the lower large intestine.*

A. $(5 \times 10^{-3})\ (2200) = 11$ μc intake on D + 3 days

B. $\frac{11}{22} = 0.5$ rads to lower large intestine from the 11 μc intake

C. At a constant rate of volume intake and an activity intake decreasing according to the relationship of $(\text{time})^{-1.2}$, the total dose from the third day on is (assuming 70 years is equivalent to the infinity dose)

$D_{3-\infty} = 5\ A_3 t_3$ where A_3 = daily dose on the third day

t_3 = 3rd day after detonation

$D_{3-\infty} = (5)\ (0.5)\ (3) = 7.5$ rads

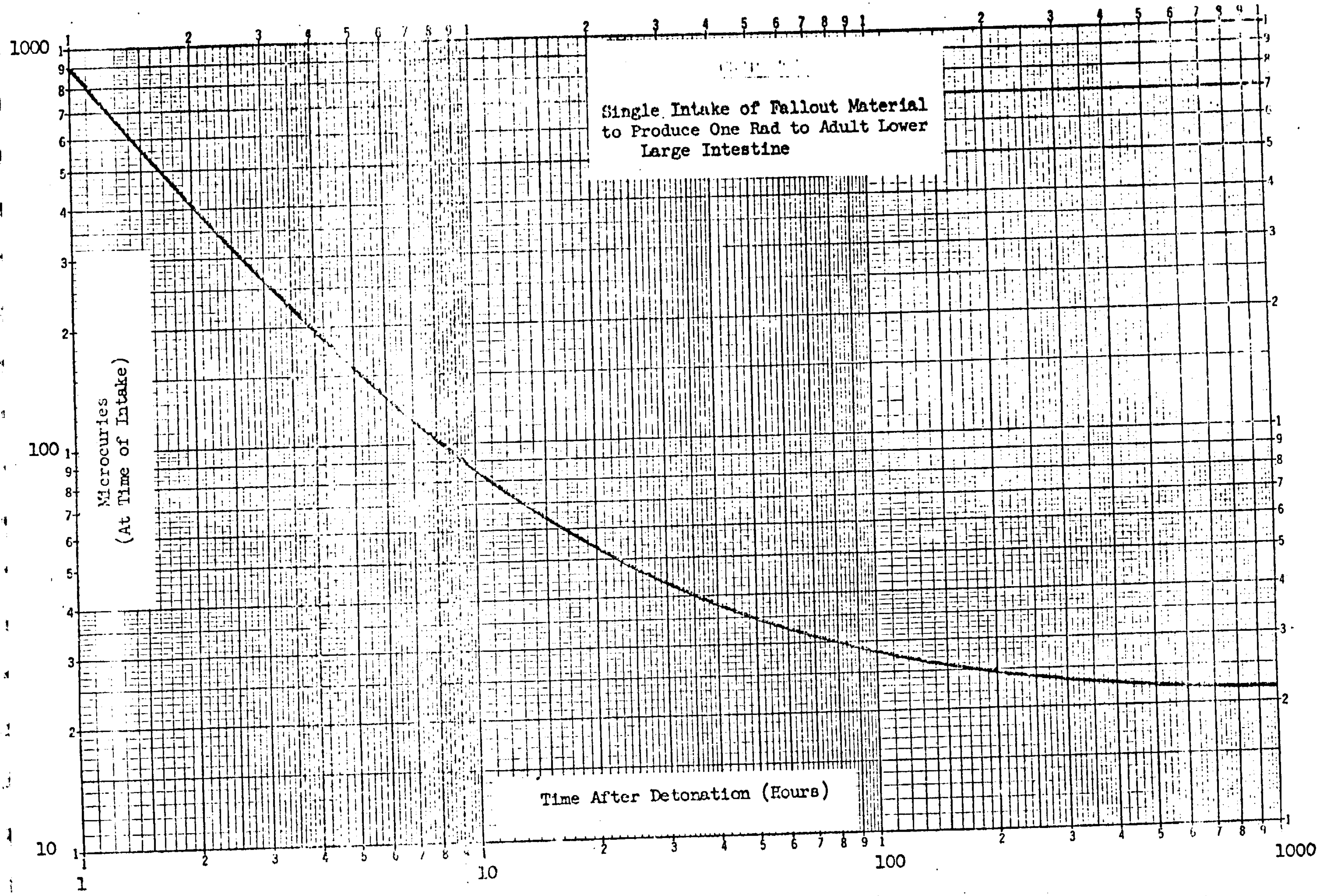
D. According to reference below the expected activity at times earlier than D + 3 days (using the relationship $(\text{time})^{-1.2}$) is roughly matched by the increased required activity to produce the same dose to the lower large intestine, i.e., if 11 μc intake on D + 3 will result in 0.5 rads to the lower large intestine, then drinking the same amount of water per day for the period preceding this will also produce about 0.5 rads per day.

Therefore, (3) (0.5) = 1.5 rads for first three days of intake

or

7.5 + 1.5 = 9.0 rads total for intake from the beginning of the first day for a lifetime.

*"Criteria for Establishing Short Term Permissible Ingestion of Fallout Material", Dunning, Gordon M. To be published. (The pertinent graph from this report is reproduced here.)



Single Intake of Fallout Material to Produce One Rad to Adult Lower Large Intestine
Microcuries (At Time of Intake)
Time After Detonation (Hours)
1000
100
10
1
10
100
1000

E. Relative values of doses to the stomach, small intestine, and upper large intestine and lower large intestine are given in reference below. The pertinent graph is reproduced here.

V. B. 2. DOSES TO THE THYROID

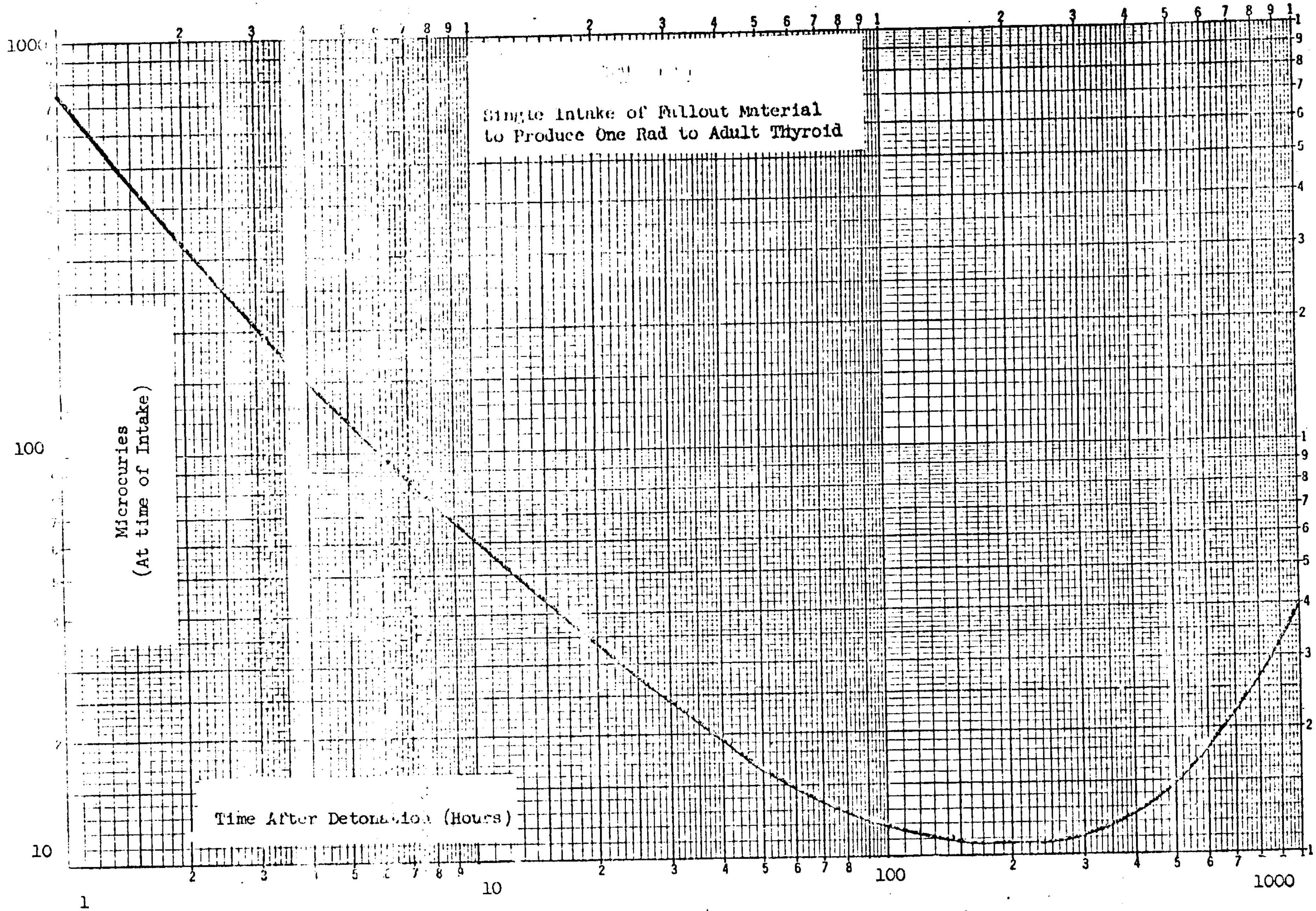
A. According to references below 13.2 μc of intake are required on D + 3 days to produce one rad of dose to the thyroid from the isotope of iodine.

$\frac{11}{13.2}$ = 0.835 rads dose to the thyroid from this one day's intake.

B. Summating from the 1st hour for an infinity dose yields about eight rads total dose to the thyroid.

C. Summating according to the graph (reproduced here) of reference below, from the 1st hour for 70 years yields about eight rads total dose to the thyroid.

"Criteria for Establishing Short Term Permissible Ingestion of Fallout Material", Dunning, Gordon M. To be published.


Single Intake of Fallout Material
to Produce One Rad to Adult Thyroid
Microcuries
(At time of Intake)
Time After Detonation (Hours)
1000
100
10
1
10
100
1000

V. B. 3. Doses to the Bones*

Step 1. Compute the total dose to an organ from a daily intake of constant volume or mass but with the activity intake decreasing according to radiological decay of the isotope.

A. The dose (ignoring for the time any biological decay) to the organ from any day's intake is:

$$D_1 = Ro \int_0^T e^{-\lambda_r \tau} d\tau - Ro \int_0^{\tau} e^{-\lambda_r \tau} d\tau$$

Where: D_1 = dose from any day's intake
Ro = initial daily dose rate
λ_r = radiological decay
T = number of days intake
τ = time in days (variable)

$$D_1 = \frac{Ro}{\lambda_r} \left(e^{-\lambda_r \tau} - e^{-\lambda_r T} \right)$$

B. The total dose (ignoring biological decay) to the organ is:

$$D_T = \frac{Ro}{\lambda_r} \int_0^T \left(e^{-\lambda_r \tau} - e^{-\lambda_r T} \right) d\tau$$

$$D_T = \frac{Ro}{\lambda_r^2} \left[1 - e^{-\lambda_r T} - \lambda_r T e^{-\lambda_r T} \right]$$

C. The dose to the organ considering biological decay is:

$$D_T = \left[\frac{\lambda_r}{\lambda_r + \lambda_b} \right] \frac{Ro}{\lambda_r^2} \left[1 - e^{-\lambda_r T} - \lambda_r T e^{-\lambda_r T} \right]$$

$$D_T = \frac{Ro}{(\lambda_r)(\lambda_r + \lambda_b)} \left[1 - e^{-\lambda_r T} - \lambda_r T e^{-\lambda_r T} \right]$$

Step 2. Compute initial daily dose rate (Ro):

$(5 \times 10^{-3})(2200) = 11 \mu c$ gross fission product intake on D + 3

$(11)(5.8 \times 10^{-5}) = 6.37 \times 10^{-4} \mu c$ of Sr^{90} intake on D + 3 *

$(6.37 \times 10^{-4})(0.25) = 1.59 \times 10^{-4} \mu c$ of Sr^{90} deposited in the bones

$$\frac{(1.59 \times 10^{-4})(\mu c)(3.2 \times 10^{-9})(d/day\text{-}\mu c)(1.0)(Mev)(1.6 \times 10^{-6})\ ergs/mev}{100(ergs/gm - rad)(7 \times 10^{-3})(grams)} \cong$$

$$1.16 \times 10^{-6} \text{ rads/day}$$

*Under the conditions assumed here, that the water is stored and used as the sole source of supply for 70 years, the strontium-90 content accounts for almost all of the total dose.

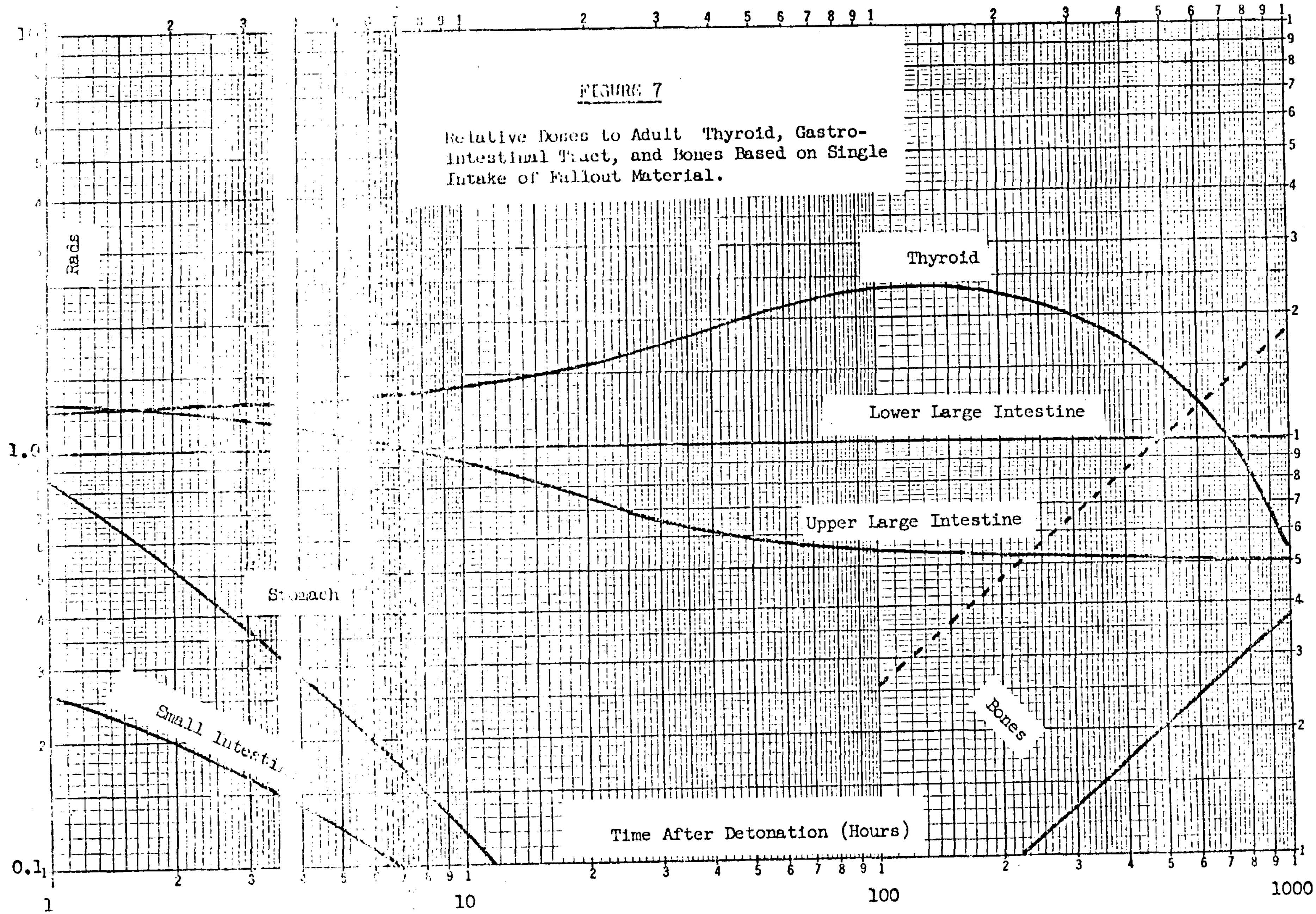


FIGURE 7

Relative Doses to Adult Thyroid, Gastro-Intestinal Tract, and Bones Based on Single Intake of Fallout Material.