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LOS ALAMOS SCIENTIFIC LABORATORY
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University of California

LOS ALAMOS • NEW MEXICO

Plutonium Dispersal by Accidental or Experimental Low-Order Detonation of Atomic Weapons

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LOS ALAMOS SCIENTIFIC LABORATORY
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Plutonium Dispersal by Accidental or Experimental Low-Order Detonation of Atomic Weapons

by

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ABSTRACT

Accidental or experimental detonation of atomic weapons that contain plutonium under conditions such that the degree of criticality produced is insignificant may create an immediate and a residual or delayed plutonium health hazard. Uranium, which is also consistently present, is not a radioactive health hazard. The immediate hazard is associated with the inhalation of plutonium during cloud passage and on the basis of theoretical considerations appears to be relatively insignificant. The delayed hazard results from residual plutonium deposited in the fall-out pattern, which may produce chronic contamination over a long period of time. The magnitude of the residual hazard is not easily evaluated on a theoretical basis, since it depends on a number of parameters which are not readily established. Theoretical curves for maximum allowable air concentrations as a function of time of exposure, based on the assumption of a maximum permissible level of 0.008 μc of plutonium in the lung and a maximum permissible total body level of 0.5 μg, have been developed. These curves may be quite useful in assessing the magnitude of the immediate and residual hazards. Suggestions are made as to the course of action that should be followed in the event of an accidental detonation of the type under consideration.

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CONTENTS

		Page
	Abstract	3
1.	Introduction	7
2.	General Statement of the Problem	7
	2.1 Immediate or acute hazard	8
	2.2 Residual hazard	8
3.	General Considerations of the Fall-Out and Contamination Pattern	10
4.	Biological Considerations of Maximum Permissible Levels	13
	4.1 Biological fate of inhaled radioactive particles	13
	4.2 Calculation of the maximum permissible level in the lung	17
	4.3 Calculation of maximum permissible level for total body burden	18
	4.4 Calculation of the maximum permissible level in air based on lung exposure	20
	4.5 Calculation of the maximum permissible level in air based on maximum permissible total body burden	22
5.	Discussion	24
	5.1 Biological considerations	24
	5.1.1 Immediate hazard	27
	5.1.2 Residual hazard	28
	5.2 Course of action indicated by existing information in the event of accidental or experimental low order detonations	32
6.	Proposals for Experiments to Evaluate Certain Specific Conditions	39

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ILLUSTRATIONS

		Page
Fig. 1	Idealized fall-out and ground contamination pattern as might be expected from Sutton's formula, assuming release at ground level and wind speed of 11 mph	11
Fig. 2	General model for the fate of radioactive particles (0.5-10 μ) in the lung	15
Fig. 3	Maximum permissible air concentration as a function of time of continuous exposure using the lung as the critical organ	23
Fig. 4	Maximum permissible air concentration as a function of time of continuous exposure based on maximum permissible level of 0.5 μg for the total body	25
Fig. 5	Maximum permissible air concentration as a function of time of continuous exposure assuming the more conservative of the two limiting conditions	26
Fig. 6	Change in total body burden as a function of time of continuous exposure using maximum permissible amount in the lung as the limiting factor for air concentration	29

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1. Introduction

Recent shots fired at the Nevada Test Site (NTS) enable a preliminary analysis of the hazards from accidental or experimental detonation of atomic weapons when little or no fission occurs, i.e., when the yield is essentially that of the high explosive component. The health hazard arises from the plutonium which may be present. Uranium, although consistently present, affords no radiological health hazard in the quantities and degree of dispersion involved because of its very much lower specific activity and because of its behavior in biological systems.

2. General Statement of the Problem

The majority of the plutonium undoubtedly will be converted to the oxide by the heat of the explosion. The heat of the explosion and the pyrophoric nature of plutonium metal may result in the generation of an oxide fume consisting of a high relative percentage of fine particles. The oxide produced will be carried out in all directions by the shock front and taken up in the cloud which will produce a fall-out condition in the immediate vicinity and downwind from the point of detonation. The fall-out condition will produce two different types of plutonium hazard, (1) immediate or acute, and (2) residual.

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2.1 Immediate or acute hazard

Within the limits of the fall-out pattern including the downwind vector, there may be high plutonium concentrations (in fine particulate form) in the air for several minutes after the detonation. This high concentration of plutonium in the air will create an immediate or acute plutonium inhalation hazard to anyone caught in or entering the area before all of the particulate matter has settled to the ground. As the majority of the plutonium suspended in the air may be primarily in the form of fine insoluble plutonium oxide particles, radiation exposure of the lung probably will be the primary hazard. The magnitude of the immediate hazard will depend on the plutonium concentration per unit volume of air, the respiratory rate of the individual, the time the individual is in the fall-out, and to some extent the size distribution of the particles carrying the radioactive material.

2.2 Residual hazard

Settling of the suspended matter in the fall-out pattern will result in a primary area of surface contamination essentially the shape and size of the original fall-out plane. This residual contamination will result in a potential plutonium health hazard to persons living or

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working in the area for a relatively long time after the detonation. It should be emphasized strongly that any amount of plutonium deposited on the surface constitutes no hazard whatsoever so long as it remains deposited. The actual plutonium hazard to persons living or working in the contaminated area is, therefore, directly dependent on the amount of plutonium on the surface and the fraction of the surface contamination which is subsequently disturbed and resuspended in a manner which will enable it to gain entrance into the body.

Plutonium may enter the body in three different ways, by ingestion, by inhalation, and through fresh breaks and abrasions of the skin surface. Since the absorption of plutonium from the gut is extremely small compared to absorption from the lung (about 0.003% of the ingested dose from the gut, compared to 2-10% of the inhaled dose from the lung), and since the possibility of contaminated cuts and wounds is low, the residual hazard to persons living or working in a contaminated area is primarily one of inhalation. The inhalation hazard produced in such a contaminated area is, therefore, directly dependent on the plutonium concentration in the area, the time one remains in the area, and the degree of disturbance or resuspension of the deposited plutonium into the atmosphere. Especially is the above

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statement true for persons entering and working in the area, performing operations that produce considerable dust. In the case of persons living indefinitely in such a contaminated area, contamination and ingestion of food and water could become a small contributing factor to the hazard.

3. General Considerations of the Fall-Out and Contamination Pattern

As mentioned earlier, an accidental or experimental explosion of the type being considered will result in plutonium being carried out in all directions by the shock front and taken up into the cloud which will produce a fall-out condition in the immediate vicinity and downwind from the point of detonation. An idealized picture of the fall-out and contamination pattern might be expected to be similar to that shown in Figure 1.

This illustration was modeled after a similar one depicted in "Meteorology and Atomic Energy"* and represents the situation as it might be expected to occur, based on Sutton's formula, applied to the instantaneous condition, assuming release at ground level and a wind speed of 11 mph.

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*Report AECU 3066, July 1955, for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

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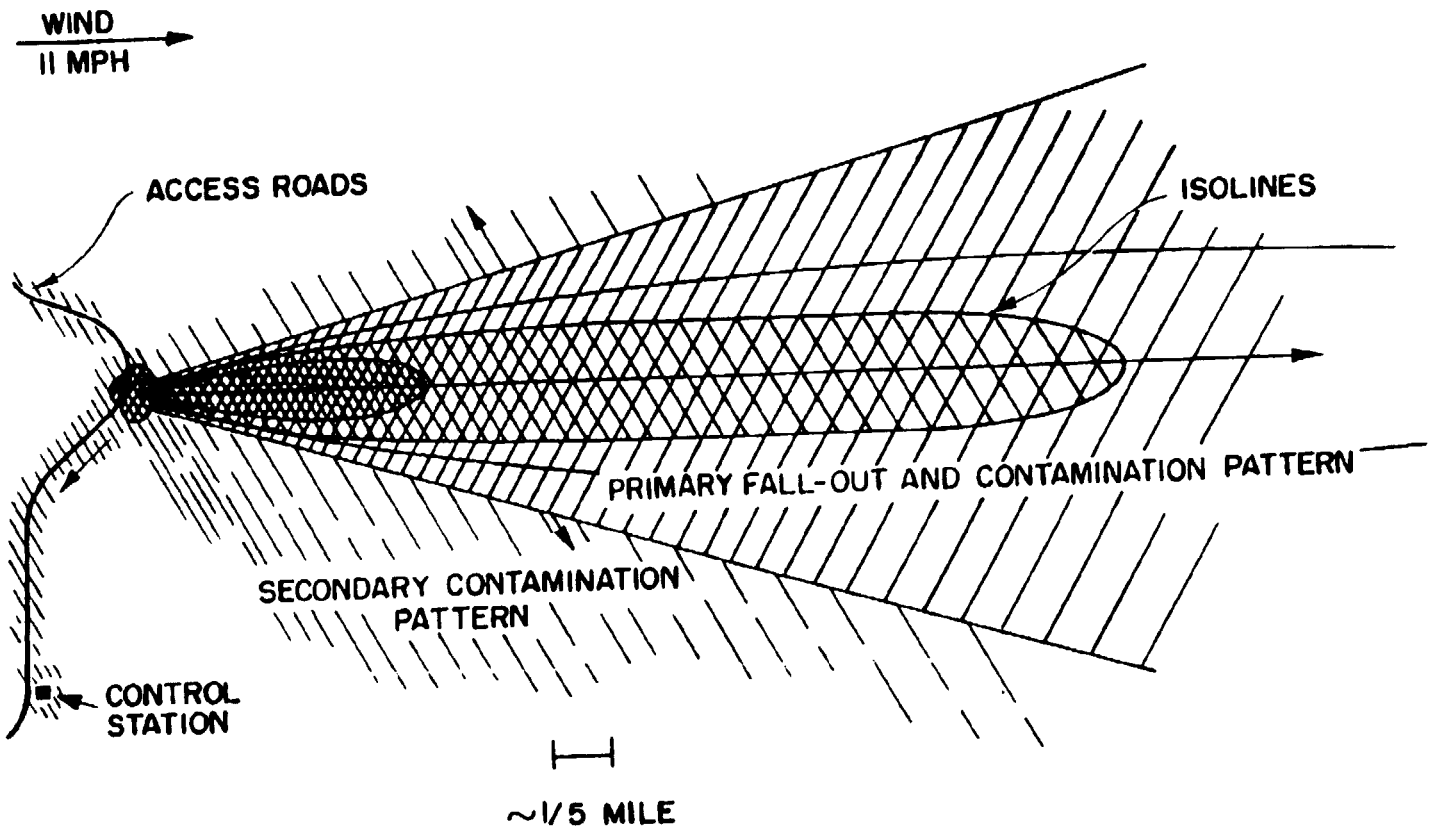

Fig. 1 Idealized fall-out and ground contamination pattern as might be expected from Sutton's formula, assuming release at ground level and wind speed of 11 mph

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In actuality, the primary fall-out and contamination pattern may be far from the idealized picture given in Figure 1, which requires the assumption that the fall-out of the particulate matter in the cloud is in accordance with Stokes' law. If, however, much of the plutonium oxide is formed as a fume, a high relative percentage of particles will be too fine to obey Stokes' law, and local turbulence, small-scale eddy motions, and effects of local terrain may completely dominate the gravitational settling. The above conditions may result in the deposition of relatively high concentrations of plutonium at much greater distances from the point of detonation than would be expected on the basis of the idealized picture.

The length and the shape of the downwind vector may be expected to be dependent on the specific meteorological conditions at the time of the detonation, the particle size distribution, and the height to which the cloud rises. The amount of plutonium per unit volume of air during the fall-out and the amount of plutonium contamination deposited per unit of surface area would be expected to be directly proportional to the amount of plutonium involved in the detonation, and inversely proportional to the dilution factor which might be expected to depend on the size of the detonation and the specific meteorological conditions.

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The primary surface contamination pattern may be spread and diluted with time in relation to the degree of disturbance of the surface area. Meteorological conditions and the amount of personnel activity in the area will be the principal contributing factors to the disturbance of the surface and, thus, to the spread of the contamination field.

Specific answers as to the magnitude of air and surface contamination as a function of distance from the detonation and the effect of wind, etc., on the size and spread of the contaminated area can best be obtained by experimental firing of high explosives with plutonium under a variety of anticipated meteorological and other applicable conditions.

4. Biological Considerations of Maximum Permissible Levels

4.1 Biological fate of inhaled radioactive particles

As indicated previously, the principal hazards involved in the situation being discussed are respiratory. It is necessary, therefore, to give careful consideration to the biological fate of inhaled radioactive particles. The fate of particulates in the lungs is obviously an extremely complex subject and only the general aspects which are essential to the present problem will be considered.

At the Harriman Tripartite Conference held in September

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of 1954, representatives of the United States, Canada and Great Britain, on the basis of the best available experimental information, devised a general model for the fate of radioactive particles in the lung. Figure 2 shows the general model adapted to the problem of inhaled soluble and insoluble particles of plutonium of 10 microns or less, which is the optimum range for the production of a health hazard. According to this figure, when 100 particles are inhaled, 25 are exhaled without deposition on the respiratory surfaces. Obviously, these are of little or no concern to the question of the production of a health hazard. Of the 75 particles that deposit on the respiratory surfaces, 50 deposit out in the bronchial tree and are worked up and out of the bronchi by the ciliary epithelium and swallowed, passing out of the body via the gut. The half-time of elimination of these 50 particles from the bronchial tree is estimated at about 18 hours. Twenty-five of the original 100 particles are deposited on the alveolar surfaces of the lung, where no ciliary epithelium exists. If these particles are insoluble (which is the case in the problem under consideration), 15 (15% of the originally inhaled dose) are phagocytized and otherwise removed up the bronchial tree and eliminated from the body via the gut with an elimination half-time estimated to be about 140 days. The remaining 10 particles (10% of the

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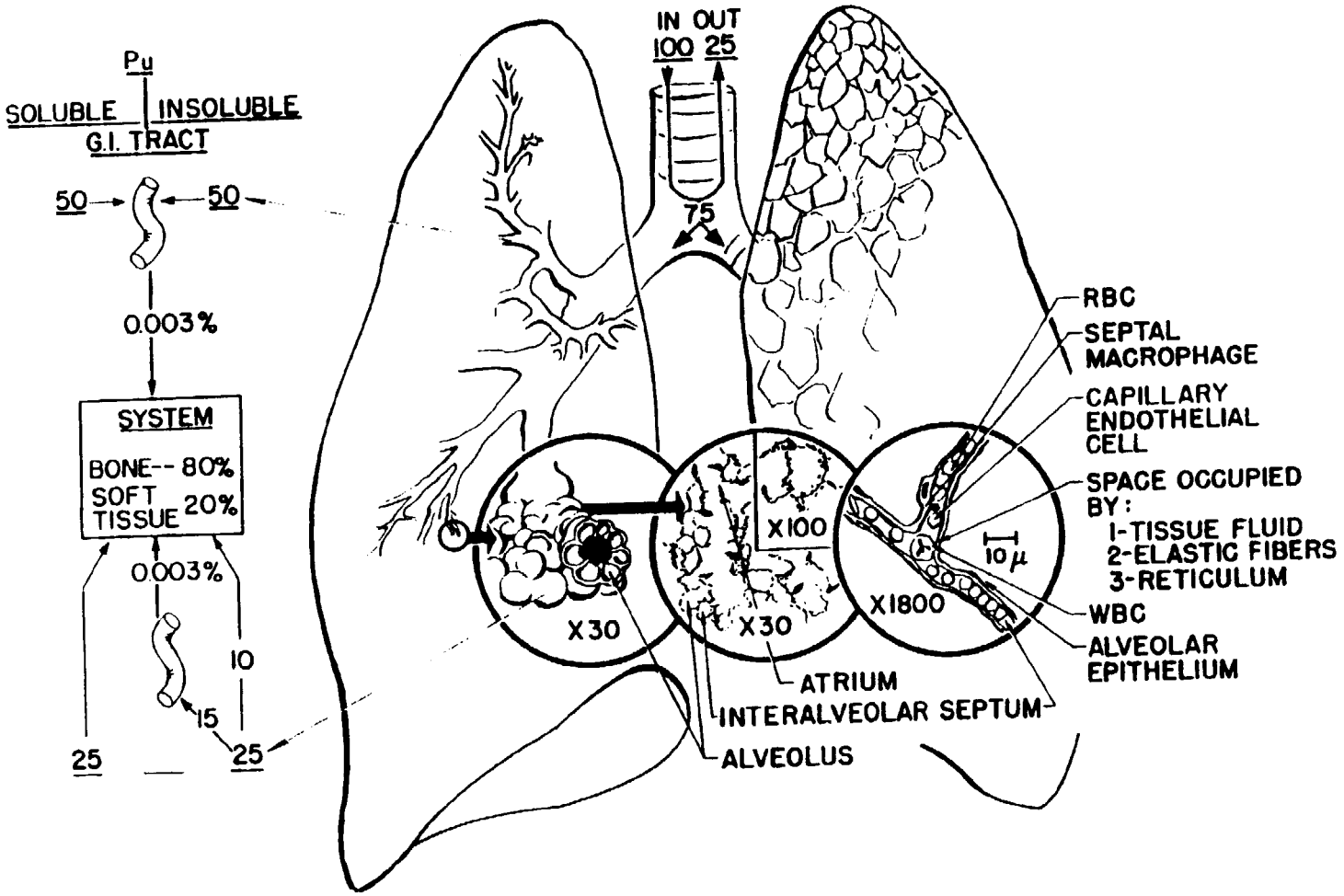

Fig. 2 General model for the fate of radioactive particles (0.5-10 μ) in the lung (Tripartite Conference, Harriman, N. Y., 1954)

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originally inhaled dose) are absorbed or otherwise taken from the lung into the blood stream where they contribute to the systemic or total body burden, about 80% of which is fixed in the skeleton. The absorption half-time of these 10 particles is estimated to be about 60 days.

The above situation creates two different hazards, the first of which is the direct radiation hazard to the lung by the deposition of 75% of the originally inhaled dose, taking into account the respective abundances and the half-times of the three components of the elimination process. The second hazard is that produced by absorption into the blood stream and subsequent deposition of 10% of the originally inhaled dose in the skeleton. On the basis of this model, it is possible to calculate the magnitude of these two hazards as a function of air concentration and time of exposure.

It is imperative, therefore, to know the plutonium air concentration during the fall-out period in order to assess the immediate hazard produced by experimental or accidental one-point detonation of the weapons under consideration, and it is likewise imperative to know the chronic plutonium air concentration created in the environment of persons working and living in the contaminated area, in order to assess the residual or long-term hazard.

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4.2 Calculation of the maximum permissible level in the lung

If the lung itself is considered to be the critical organ, the maximum permissible level (MPL) in the lung will depend upon the concentration of the radioactive material per gram of tissue and the effectiveness of the radiating particle so that the dose will not exceed 0.3 rem/week under continuous exposure. The information given in Handbook 52* must be used as the criteria for such a determination. The MPL is given by the following formula:

$$q = \frac{2.6 \times 10^{-3}\ mW}{(bE)f_z}$$

where q = total μc of activity allowable

m = lung mass = 10^3 g

W = dose in rem/week = $\frac{0.3}{RBE}$ rep/week

RBE = effectiveness of alpha particles = 20

b = fractional absorption of energy = 1 for alphas

E = energy in Mev = 5.16 for Pu^{239}

f_z = fraction in critical organ of that in total body = 1 in the present case

*National Bureau of Standards Handbook 52, March 20, 1953, for sale by the Superintendent of Documents, Washington 25, D. C.

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For Pu^{239}, q = 0.008 μc = 1.76 x 10^4 dpm in the total lung mass. This value is, therefore, the maximum permissible level for continuous exposure to insoluble Pu^{239} over a lifetime. The above value is probably extremely conservative in that continuous exposure is assumed and the RBE of the alpha particles is assumed to be 20, which from present experimental information appears to be too large by as much as a factor of 5 to 10.

4.3 Calculation of maximum permissible level for total body burden*

The presently accepted MPL for deposition of plutonium in the total body is 0.5 μg (0.036 μc). On the basis of the human experience resulting from the radium dial painting industry, the maximum permissible body burden for radium was set at 0.1 μc. The maximum permissible (total body) level for plutonium was established by estimating the amount of plutonium equivalent biologically to 0.1 μc of radium. The estimation was based on the following considerations:

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*Although somewhat ambiguous, "total body burden" is commonly used to designate that material which has been absorbed into the blood stream and subsequently deposited in the tissues. It does not, therefore, include unabsorbed material residing in the lungs or the gut.

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$$MPL_{Pu} = MPL_{Ra} \times \frac{1}{RBE_{Pu}} \times \frac{F_{Pu}}{F_{Ra}} \times \left[\frac{E_{Ra} + F_{RnH}(\Sigma E)}{E_{Ra} + F_{RnM}(\Sigma E)}\right]$$

$$= 0.1\ \mu c \times \frac{1}{15} \times \frac{75}{25} \times \left[\frac{4.8 + 0.5\ (5.5 + 6.0 + 7.7)}{4.8 + 0.15(5.5 + 6.0 + 7.7)}\right]$$

$$= 0.04\ \mu c\ (\sim 0.5\ \mu g)$$

In the above expression MPL_{Pu} is the maximum permissible total body level for plutonium; MPL_{Ra} is the maximum permissible level for radium = 0.1 μc; RBE_{Pu} represents the relative biological effectiveness of plutonium when compared with radium in chronic experiments in mice when radium and plutonium were injected in equal amounts; F_{Pu} is the fraction of plutonium retained in the mouse = 0.75; F_{Ra} is the fraction of radium retained in the mouse = 0.25; E_{Ra} is the energy of the radium alpha particle; F_{RnH} is the fraction of radon retained by the human = 0.5; F_{RnM} is the fraction of radon retained by the mouse = 0.15; and ΣE represents sum of the energies of all the alpha decays in the radium decay chain beyond radon.

The value of 0.5 μg (7×10^4 dpm) for the MPL of plutonium in the total body is believed to contain a safety factor of at least 10. It should be pointed out, however, that the turnover half-time of plutonium in the skeleton (the major site of deposition) of man is of the order of 200 years.

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Technically, therefore, any individual who is permitted to acquire a MPL of plutonium should be removed from further work with radioactive materials for the rest of his life. Removal of such an individual from further work in the field may produce a rather sensitive personnel and medico-legal problem.

4.4 Calculation of the maximum permissible level in air based on lung exposure

The MPL in air for continuous exposure based on the lung as the critical organ may be calculated from information given in Sections 4.1 and 4.2. Such a calculation is given in Handbook 52 using the following formula:

$$(MPC)_a = \frac{3 \times 10^{-8}\, q f_z}{T f_a (1 - e^{-0.69t/T})}$$

where $(MPC)_a$ = air concentration in μc/ml

T = effective half-time of the material in the lung

f_a = fraction reaching critical organ

t = time of exposure

In this formula T is assumed to be 360 days and $F_a = 0.12$. No account is taken of the rapid turnover material in the bronchial tree which, over short times of exposure in particular, contribute an appreciable portion of the total dose.

If all of the inhaled particles are considered, using

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the values given in Section 4.1 for the retention and turnover of the components of the elimination process, a more complete equation may be developed. The activity in the lungs in dpm at any time may be calculated from the rate equation of the type

$$du/dt = f(u,t) - h(u,t)$$

where u is the activity, and the rate is equal to the rate of uptake minus the rate of elimination. If,

C = air concentration in dpm/m^3

$0.75\ C$ = fraction taken up by the lung,

A = air intake by lung = $1\ m^3/hr$,

n = material disappearing by ciliary action from bronchi with a half-time of T_1 = 18 hours and equal to $0.50\ C$,

m = material disappearing by phagocytic and ciliary action from lung with a half-time T_2 = 140 days = 3.36×10^3 hours and equal to $0.15\ C$,

p = material disappearing from lung via blood to bone with a half-time T_3 = 60 days = 1.44×10^3 hours and equal to $0.10\ C$,

then $$du/dt = Ane^{-0.693t/T_1} + Ame^{-0.693t/T_2} + Ape^{-0.693t/T_3}$$

and $$u = 13\ C(1-e^{-0.0385t}) + 725\ C(1-e^{-0.0002t}) + 210\ C(1-e^{-0.0005t}).$$

It was shown in Section 4.2 that the allowable value of $u = 1.76 \times 10^4$ dpm and, therefore, the allowable air concentration in dpm/m^3 is:

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$$(MPL)_a = \frac{1.76 \times 10^4}{13(1-e^{-0.0385t}) + 725(1-e^{-0.0002t}) + 210(1-e^{-0.0005t})}$$

This result differs somewhat from that used in Handbook 52 and is more conservative for short-time exposure since the short half-life fraction is included. For life-time exposures the values obtained are somewhat larger, mainly because the shorter half-time of 140 days was used instead of the 360-day half-time quoted in Handbook 52. The allowable air concentration to produce maximum permissible exposure of the lung as a function of time of exposure is shown in Figure 3.

4.5 Calculation of the maximum permissible level in air based on maximum permissible total body burden

The permissible air concentration based on the maximum permissible total body burden of 0.5 μg depends only on the fraction inhaled which passes from the lungs into the blood, subsequently depositing largely in the skeleton, and the extremely small increment which is absorbed from the G. I. tract. On the basis of information given previously, 10% of the air concentration passes the lung-blood barrier whereas only about 0.003% of the remaining 65% leaving the lung via the G. I. tract will be absorbed from the gut into the blood stream. This fraction may be neglected and a formula for

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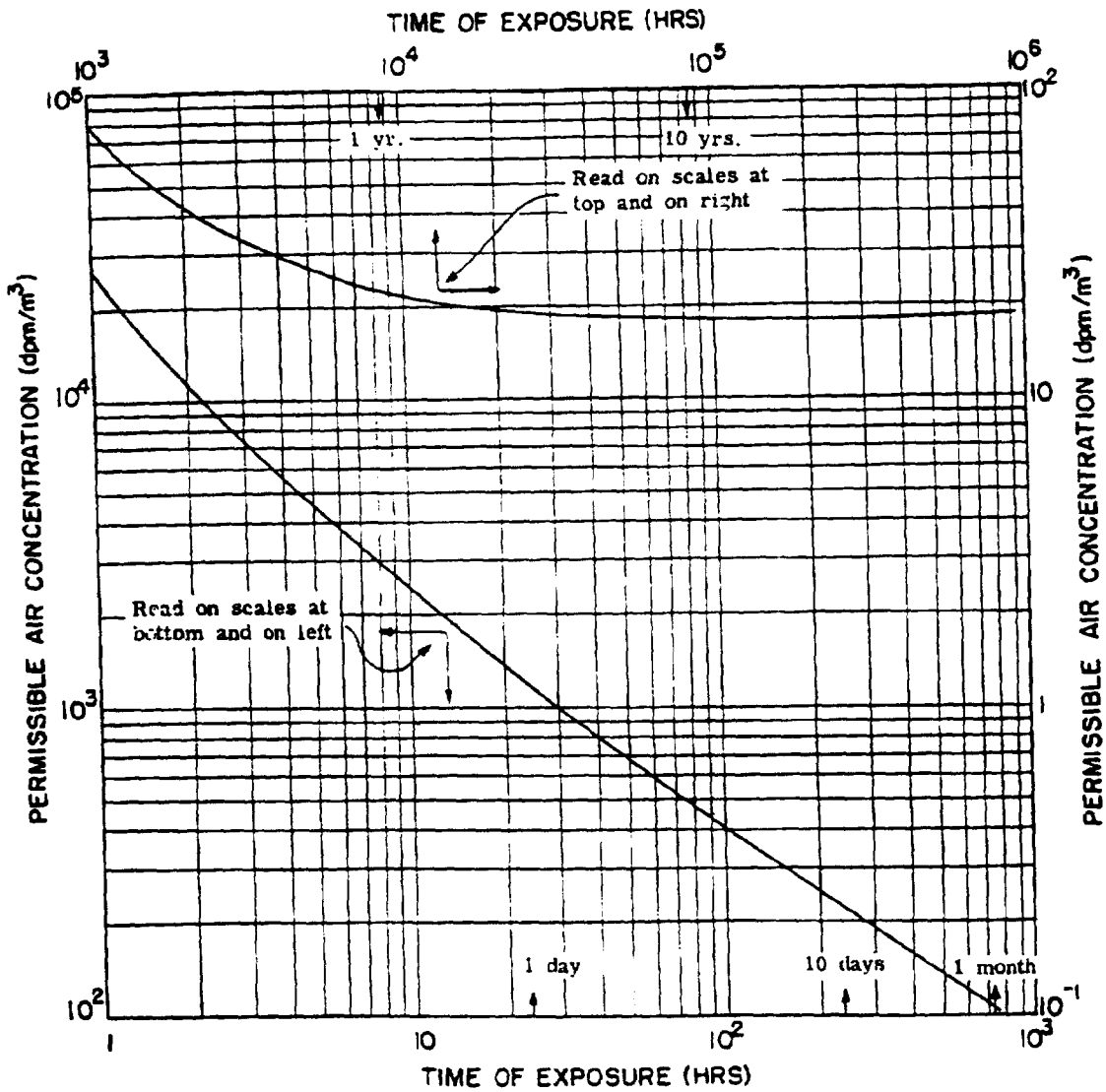

Fig. 3 Maximum permissible air concentration as a function of continuous exposure using the lung as the critical organ

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total body burden based on absorption from the lung is:

$$q = 0.10\ CAt$$

where q = the MPL for the total body (7×10^4 dpm derived from Section 4.3); C is the air concentration; A is the inhalation rate of 1 m^3/hr and t is the time of exposure in hours.

$$C = \frac{7 \times 10^5}{t}\ dpm/m^3$$

The allowable air concentration required to produce the maximum permissible total body burden as a function of time of exposure is shown in Figure 4.

5. Discussion

5.1 Biological considerations

If Figures 3 and 4 are compared, it will be noted that, especially at early times, the maximum permissible air concentration varies widely depending on whether the MPL for the lung or that for the total body is considered the critical value. With time, however, the maximum permissible air concentrations for the two conditions approach each other and eventually cross. Using the more conservative of the two concentrations as the limit of exposure, the composite curve shown in Figure 5 was developed. The first portion of the curve shows that lung contamination is the limiting factor.

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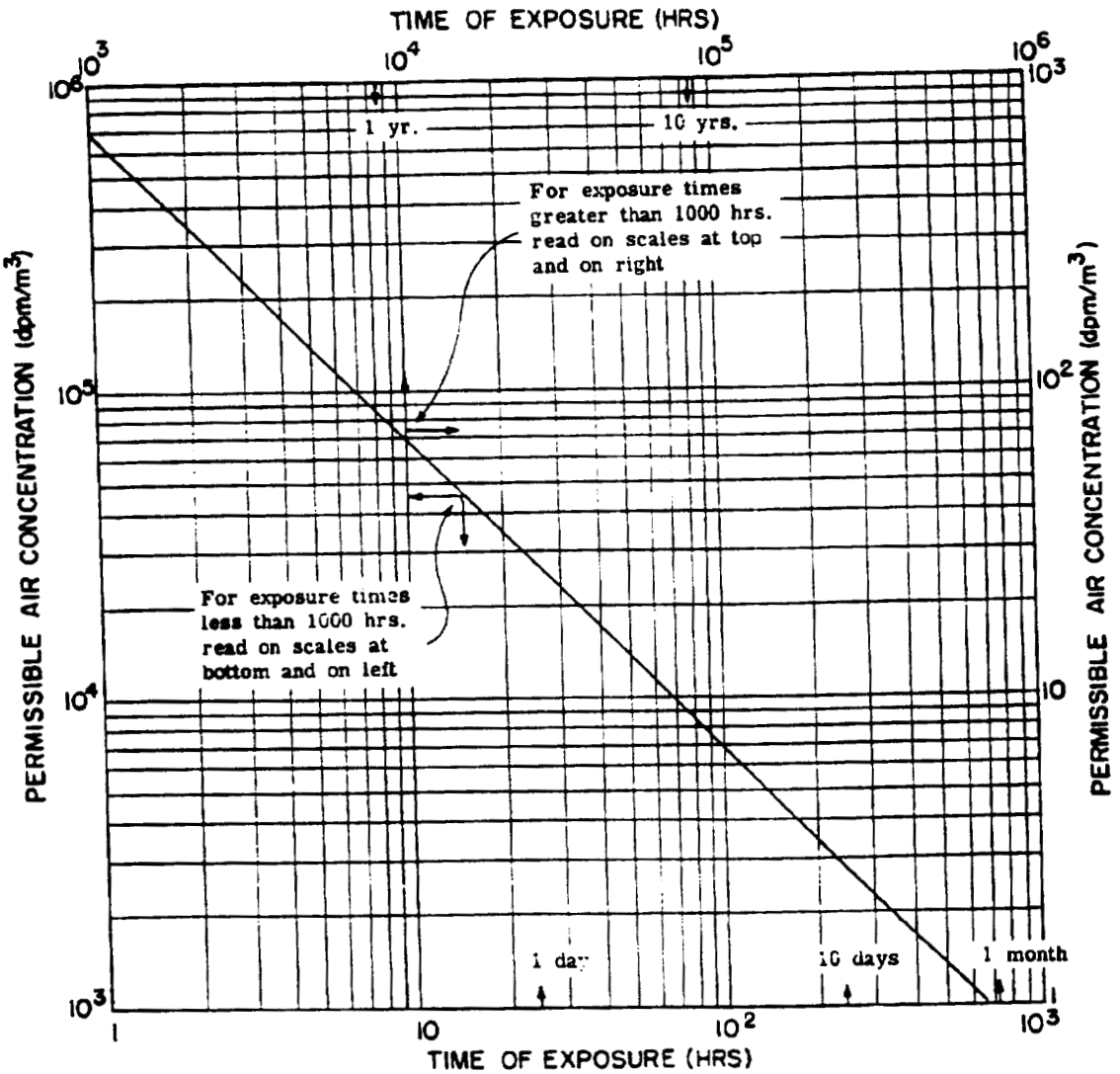

Fig. 4 Maximum permissible air concentration as a function of time of continuous exposure based on maximum permissible level of 0.5 μg for the total body

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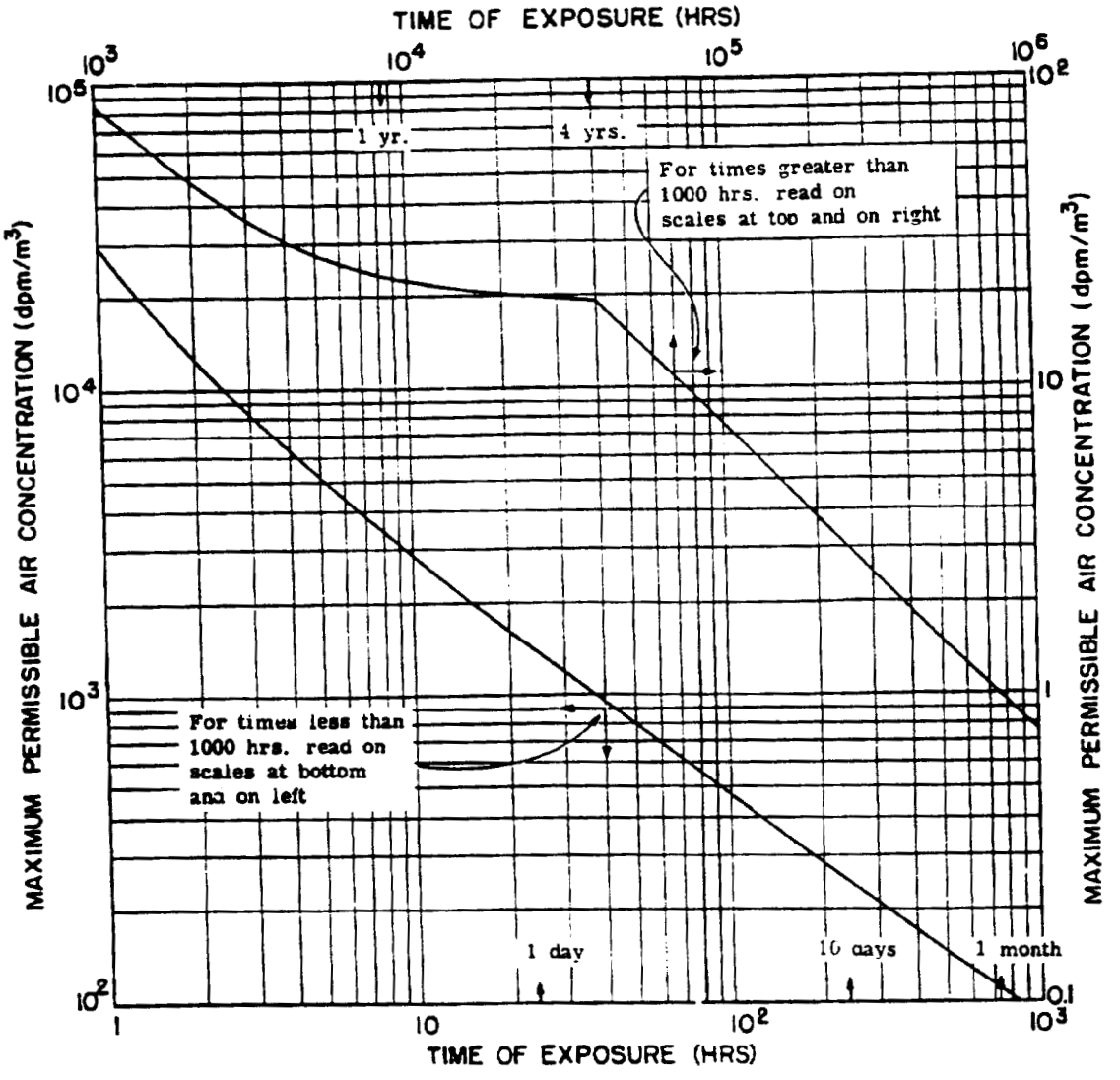

Fig. 5 Maximum permissible air concentration as a function of time of continuous exposure assuming the more conservative of the two limiting conditions

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After about a year the lung is in equilibrium and at four years' continuous exposure a shift in the curve appears. From this time on total body burden limits the permissible air concentration.

While lung exposure is critical over a long period of time, the changing total body burden cannot be neglected. The change in total body burden with time, using lung contamination as the limiting condition of exposure, is shown in Figure 6. These data show that the body burden increases rather slowly up to one year from the beginning of exposure. Beyond that time (when the lung is reaching equilibrium), the body burden increases approximately geometrically to four years, at which time the total body MPL is reached and thus becomes the controlling factor of maximum permissible air concentration.

5.1.1 Immediate hazard

It is apparent in Figures 3, 4 and 5 that in the case of the immediate hazard, which includes only cloud passage outside the region of blast, rather high air concentrations are allowable. If a conservative estimate of cloud passage time, i.e., one hour, is considered, the air concentration allowable is at least 27,800 dpm/m^3 (Fig. 5). Also, this concentration will only give 0.3 rem/week for a short time compared to a continuous life-time exposure and

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is certainly conservative. Similarly at this concentration, the total body burden would be only 2,780 dpm (Fig. 6), which is approximately 4% of the maximum permissible level. Using field test criteria of 3.9 rem delivered in a single short exposure with a retirement period of 13 weeks, the maximum permissible air concentration could be increased to 3×10^5 dpm/m^3, which would finally give a total body burden of $\sim$50% of the maximum allowable level. It is apparent, however, that the application of field test criteria would not be desirable, since Pu^{239} is essentially not excreted after once entering the blood stream and even one-half of a permissible total body burden to be carried for the rest of one's life may present medico-legal problems, especially in the case of civil populations.

5.1.2 Residual hazard

In the case of the residual hazard resulting from the remaining surface contamination, two conditions must be considered. In either condition, however, it must be emphasized that Pu^{239} contamination on the ground is of no consequence except insofar as it may be related to air concentration resulting from surface disturbance and resuspension. The two conditions may be defined as (1) working in a contaminated area under the usual terms of an 8-hour day, 40 hours per week, for purposes of cleanup or routine

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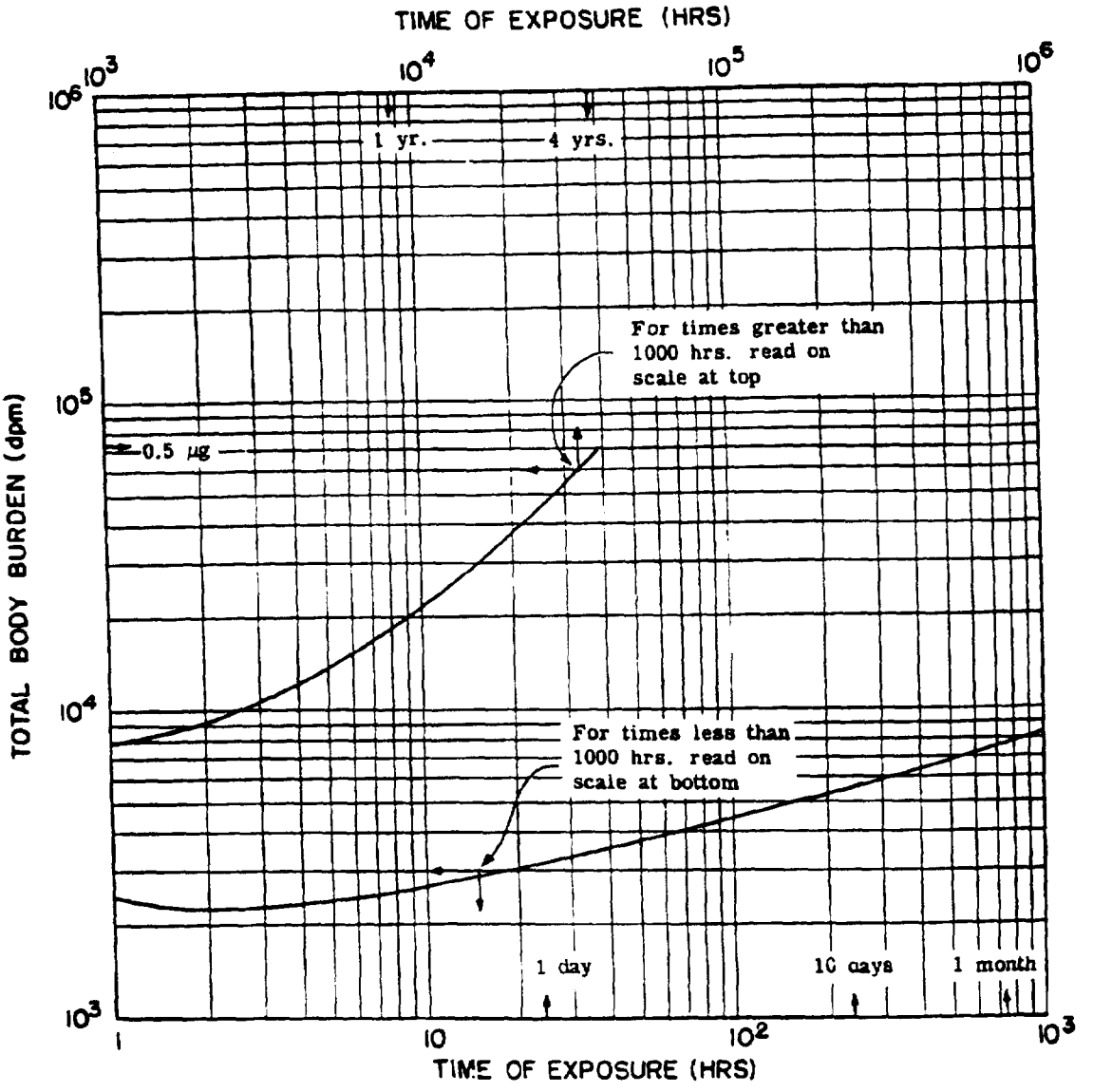

Fig. 6 Change in total body burden as a function of time of continuous exposure using maximum permissible amount in the lung as the limiting factor for air concentration

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activities usually performed in the area, and (2) living continuously in a contaminated region without disturbance of the usual living habits. The nature of the contaminating event is certainly related to these two conditions. As far as the working case is concerned, the area of interest is particularly that of the immediate environs. On the other hand, continued living and normal activities associated with continued living in an area are dependent on the long-range downwind pattern.

For cleanup work which can be assumed to be immediate and to proceed for a relatively short period of time, practically any air concentration is acceptable. It is evident from Figure 5 that the maximum permissible air concentration is high even without the use of respirators and associated equipment used in such work. The problem, therefore, is probably only academic from the hazard point of view and becomes a problem in logistics of having the required equipment available in the neighborhood of a possible contaminating event.

For routine work in a contaminated area without restriction of activity, the maximum permissible air concentration for continuous exposure without respirators may be deduced from Figures 5 and 6. If one sets a limit of one year for such work, assuming that for one year a continuous air level

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would be maintained and that the leaching, transportation, etc., of the material occurring in one year would decrease the air concentration to such an extent that air concentrations post-one year could be neglected, a reasonable value would be 20 x 3 = 60 dpm/m^3. In this case the value from the curves in Figures 5 and 6 have been increased by a factor of three to account for the 8-hour day, 5-day week. In this same period the individual would accumulate approximately 30% of the total body MPL, which appears entirely reasonable. It is suggested that such levels may be also applicable to work in downwind areas at NTS, where airborne contamination downwind from a highly contaminated area may constitute a problem.

For continuous living in a contaminated area, the restrictions must certainly be more drastic. The associated problems are as follows. First, this case almost certainly concerns the civil population. It has been common practice, most likely primarily from the point of view of probability, to decrease all maximum allowable exposures of a large population by a factor of ten. Second, the total life span of about seventy-five years must be considered in any stable community. Third, the natural rate of dissipation of the contaminant by leaching, translocation, etc., all factors which are dependent on local conditions, is of importance.

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Fourth, some consideration must be made of the ingestion problem under conditions of continuous living in a contaminated area. It is apparent that the curves for maximum permissible concentration of plutonium in air and the discussion given in this report apply to only one aspect of the total considerations involved in assessing the health hazards of continuous living in a plutonium-contaminated area, and no good guesses can be made as to the element of risk from the information now available. It is suggested that this problem be considered fully at some other time and be the subject of a separate, well-integrated report.

5.2 Course of action indicated by existing information in the event of accidental or experimental low order detonations

Any attempt to translate the foregoing material into actual policies and procedures, and any endeavor to draw definitive conclusions as to a course of action in the event of accidental or experimental detonations of the type under consideration are uncertain at best. The existing data are admittedly inadequate and they certainly do not necessarily apply to accidental detonations under all conditions. It is not a question of whether or not we are justified in drawing conclusions from the facts that are known, but of being obliged to make at the present time the best guesses possible.

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This necessity is emphasized by the fact that considerable time unquestionably will elapse before enough additional data can be gathered to permit positive conclusions. For obvious reasons, therefore, the following generalities are given with the full knowledge that they are by no means firmly supported by detailed observations and experimental data, and for the same reasons there will be a calculated attempt to avoid giving specific numbers.

There is, however, more information available than one might expect. For the past seven or eight years personnel at Los Alamos have had wide experience with a long series of detonations of a similar order of magnitude in the Bayo Canyon Site experiments, detonations involving large amounts of radioactive material. It is true that this material was a lightweight beta-gamma emitter; nevertheless, this work fits fairly well with data from NTS. Furthermore, data from two detonations in the November 1955 series in Nevada, although far from conclusive, justify some tentative assumptions.

It would be well to point out here the basic difference between contamination with plutonium on the one hand, and a beta-gamma emitter on the other. We are quite familiar with the condition of ground zero following a nuclear detonation, or even following a Bayo Canyon shot. The level of beta-gamma contamination is such that a person can remain in the area

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only a very short time, perhaps a matter of minutes, if he is to avoid a serious over-exposure. With plutonium, the time element is of no importance -- one can remain in a plutonium-contaminated area indefinitely, provided proper precautions are used. The most important precaution is respiratory protection, which must be essentially perfect. Protective clothing is worn primarily to prevent the spread of contaminated material to uncontaminated areas. It might also be well to re-emphasize a statement made earlier, that plutonium contamination on the ground or on objects is of no significance as long as it remains where it is. It becomes of significance to health only when permitted to enter and remain in the body, and the most important portal of entry is via the respiratory tract. It follows, therefore, that necessary procedures can be carried out deliberately, without panic, and after adequate planning.

Let us hypothesize that there has been in fact an accidental detonation in an assembly plant and on the basis of the previous discussion consider the results. Personnel in the immediate blast area may be killed or injured. Were they not killed by the blast, they might quite possibly receive serious doses of plutonium. In the open, this area would cover a radius of some few hundred feet, depending on the order of detonation and the amount of high explosive. Within

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a structure, the results would depend on the type of construction.

The area affected directly by the blast will be highly contaminated with plutonium, so highly contaminated that no entry into it should be permitted without complete protective equipment. For purposes of rescue and damage control, entry requires not only necessary precautions and a suitable decontamination center, but also trained and experienced personnel, individuals who have had specific training in alpha-monitoring.

The requirement for trained personnel cannot be stressed too strongly. Industry and the military establishment now have many people trained for beta-gamma monitoring, but almost none who are familiar with the very different problems and procedures involved in work with plutonium and other alpha emitters. Los Alamos is one of only a few places where one can find a group experienced in monitoring and decontamination procedures for alpha emitters.

Any objects that are removed from the area must be decontaminated or otherwise disposed of. The problem of decontaminating the site of the accident may be insurmountable and it may have to be "written off" permanently with at best an attempt to fix the plutonium and keep it from moving around. Demolition and burial of a building, as was done with D-building at Los Alamos, is difficult but possible.

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The detonation will produce a cloud of contaminated dust and smoke which will move in the direction of existing wind currents (Fig. 1). If we can accept the data from NTS, it would appear from the calculations shown graphically in Figure 3 that this cloud does not present a serious hazard to those who may be in its path, even fairly close (500 to 5000 feet) to the point of detonation. This does not mean that these individuals will not acquire a plutonium dosage; it does mean that this dosage, because of the short duration of the exposure, will presumably not be injurious.

From the above, we think we can state with confidence that an accidental detonation similar to the one-point detonations carried out in Nevada in November 1955 will not present any significant hazard to health in the period immediately following the blast except for the area of blast damage. This does not mean that problems will not be created; personnel and objects in the path of the cloud will undoubtedly require decontamination, primarily to prevent the spread of active material to other uncontaminated areas, and this will be no small job.

As the cloud containing active material passes along, it will more or less consistently deposit active material on the ground. This will result in a zone of contamination similar in general configuration to that shown in Figure 1.

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There will be more or less finite limits to the area where Pee Wee readings on the ground will indicate levels of 500 cpm or greater. This must be regarded as the area of residual hazard and it is the area about which something must be done subsequently. First of all, let us consider how large such an area might be. Information collected at NTS has clearly indicated that contamination of this significant order of magnitude certainly extends for ten miles or more in a downwind direction from ground zero. This distance certainly should not be regarded as a finite limit but simply to indicate a general order of magnitude. Such an area already exists at NTS and considerable portions of the eastern edge of that site are even now contaminated with plutonium to the extent that Rad-safe supervision of activities in this area will be required perhaps permanently. This does not by any means indicate that this piece of real estate is useless for the future; it does indicate that special control measures of one sort or another must remain in effect for a long time to come.

It must be re-emphasized that the situation created in the elongated egg-shaped area described above is no cause for panic. Any undue haste would, as a matter of fact, tend to make the problem worse by producing unnecessary spread of contamination. Days or weeks are available in which one can

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decide on the proper course of action.

Any area contaminated with alpha emitters to a significant degree (above 500 cpm on a Pee Wee) will require special treatment in one or a combination of three ways: (1) decontamination; (2) fixation; (3) arbitrary control of access. The actual removal of alpha contamination over a large area is obviously extremely difficult and probably of questionable value unless practically all of the involved area can be handled in the same way. The fixation of alpha activity by such methods as oiling, painting, etc., is reasonably satisfactory, at least for a considerable period, but we must not forget the fact that plutonium has a half-life of 24,000 years. Control of access to such an area might better be described as control of egress from the area for the purpose of preventing transport on shoes, clothing, and objects of contaminated material to clean areas.

Unquestionably, a health problem does exist in such an area but it is one which must be evaluated with great care. Using the type of calculations given above, may a family be permitted to reside in such an area indefinitely, even under supervision? May an individual be permitted to work eight hours a day in such an area? What precautions will be required? These are questions which can scarcely be answered before the fact.

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As has been stated, the general conclusions given above stem from the experience of LASL personnel in the long series of Bayo Canyon experiments and on the data acquired at the two one-point detonations in November 1955. At the next series of similar detonations in Nevada currently scheduled for January 1956, an augmented program of air sampling and ground monitoring is planned. A far more extensive series of experimental detonations using a tracer technique are now being contrived by members of the Sandia Corporation. One would certainly hope that six months or a year from now it might be possible to draw firmer conclusions on which could be based future policies and procedures for NTS and more definitive advice for the guidance of AEC and Ordnance authorities in connection with their various programs. There seems to be reason to feel that further experimental work will not prove our present conclusions to be seriously wrong.

6. Proposals for Experiments to Evaluate Certain Specific Conditions

Deficiencies in the exact figures necessary to evaluate the hazards associated with experimental or accidental one-point detonation of plutonium-bearing weapons under specific conditions make it paramount that experiments be conducted to relieve these deficiencies if evaluation is highly important. Such field-type experiments are indicated

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because it can be assumed that the biological model given in this report is sufficiently accurate to have an error less than that of other presently available data. At least two types of field experiments are needed.

One type of experiment has to do with the one-point detonation tests now being conducted at NTS. Such an experiment should consist of four parts. The first should include measurement of the actual air concentration in the immediate environs of the point of detonation during the time of cloud passage to provide better numbers for the evaluation of the immediate hazard. These measurements need be conducted downwind only as far as air concentrations might be reasonably expected to approach the limiting concentration for the acute hazard. A second part should consist of alpha detector survey instrument readings of the residual ground contamination within 24 hours of the time of detonation. A third part, a corollary experiment, should also be performed. Over areas in which the ground contamination is measured to be at certain levels, a maximum air hazard condition should be produced and air concentration measurements made. Such studies should be made early (at the times where measurable ground levels are found) and at later times (weeks or months) when no ground levels can be found but contamination may still be present. Such experiments give a correlation between the

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only measurable quantity, ground contamination, and the respiratory hazard actually posed by such contamination levels. These experiments, therefore, assist in the evaluation of the delayed hazard. A fourth experiment should consist of the use of fall-out trays. By subsequent analysis it is possible to get good reference points, to correlate with ground and air surveys, and to perhaps get an idea of the subsequent dissipation of activity in the NTS, where continued work on a restricted or open basis is very important in the continuity of test programs.

The second type field experiments needed are concerned particularly with the evaluation of the hazard parameters associated with continuous living in a contaminated area. These experiments might be called "tracer" experiments in which a certain set of conditions are studied by the use of a contaminating radioactive material in a cheap mocked-up assembly. These experiments must be done on a continuing basis depending on the sets of conditions to be satisfied. First, the tracer system used must give results which will correlate with NTS results in the immediate region of detonation. Only in this way may reliance be placed on the result. Second, the conditions of detonation must be varied to simulate the varying factors to be expected under various accident conditions or site. Third, a variety of meteorological

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conditions must be satisfied including downwind spread, rainfall, etc. Finally, it is necessary that area and weather criteria be chosen so as to give some idea of the dissipation rate and its relation to the life-time hazard.

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