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

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

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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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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.

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

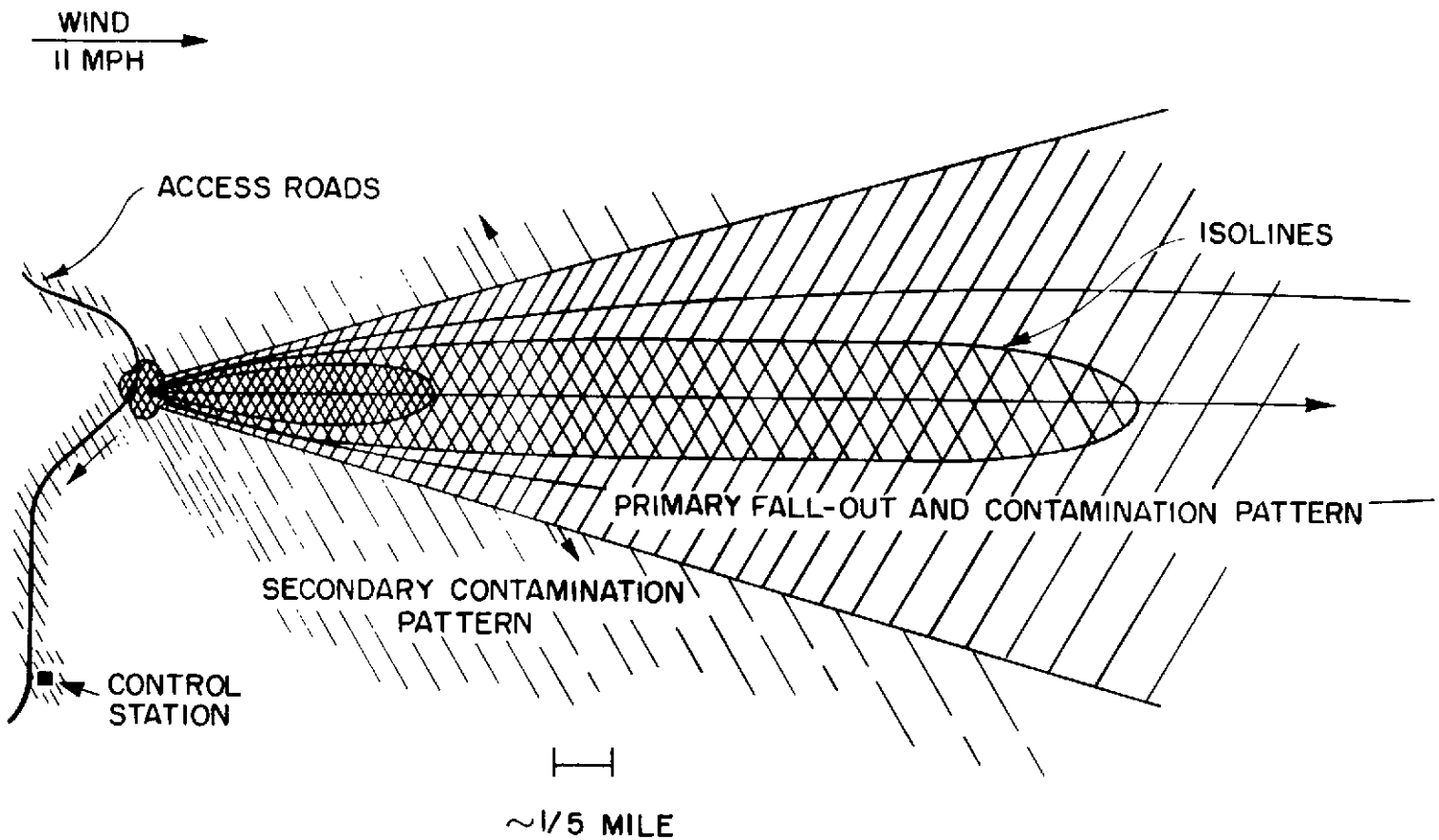

Fig. 1 Idealized fall-out and ground contamination pattern as might be expected from Sutton's formula, assuming release at ground level and wind speed of 11 mph

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

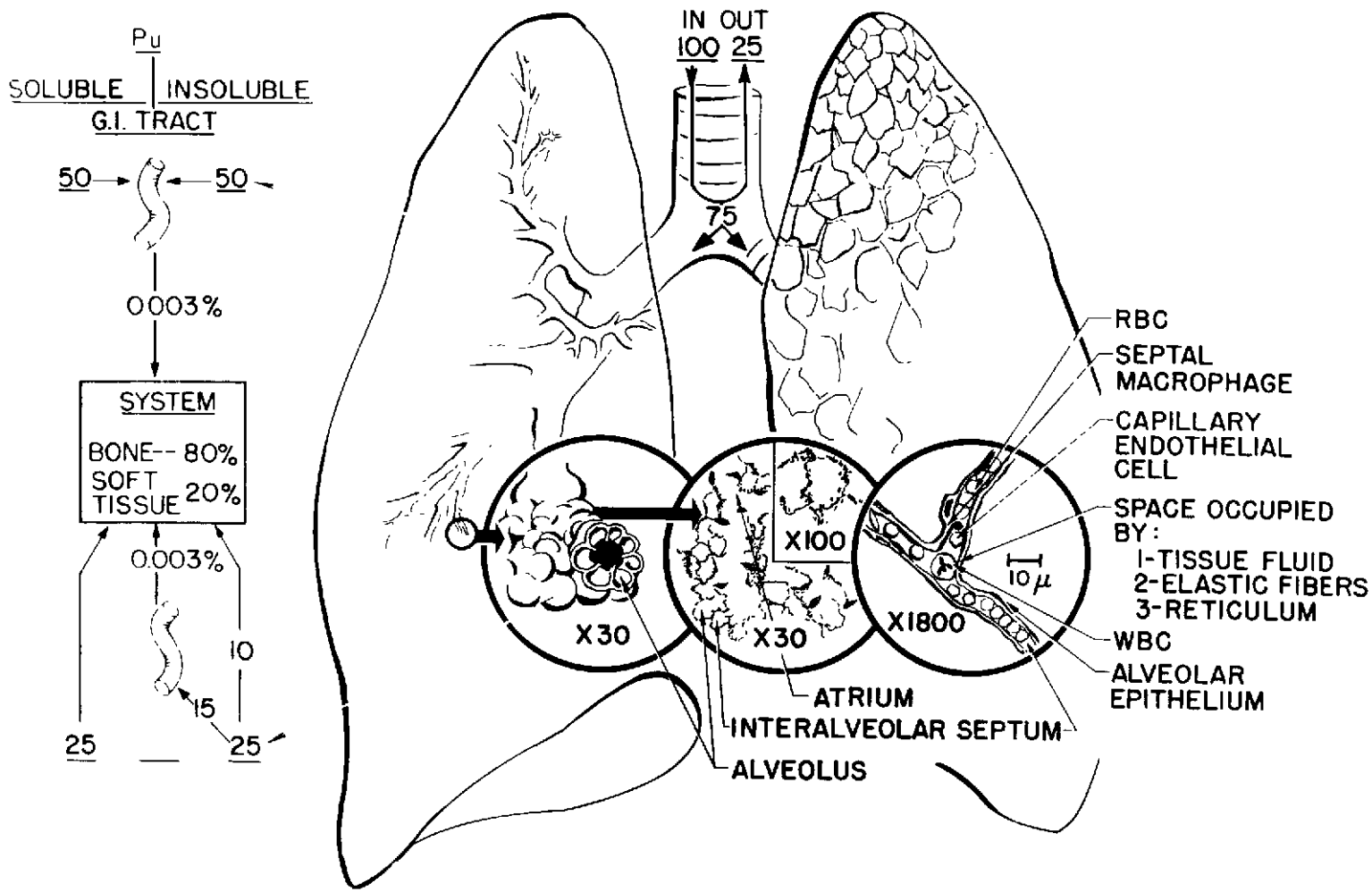

Fig. 2 General model for the fate of radioactive particles (0.5-10 μ) in the lung (Tripartite Conference, Harriman, N. Y., 1954)

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.

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

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

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

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.

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:

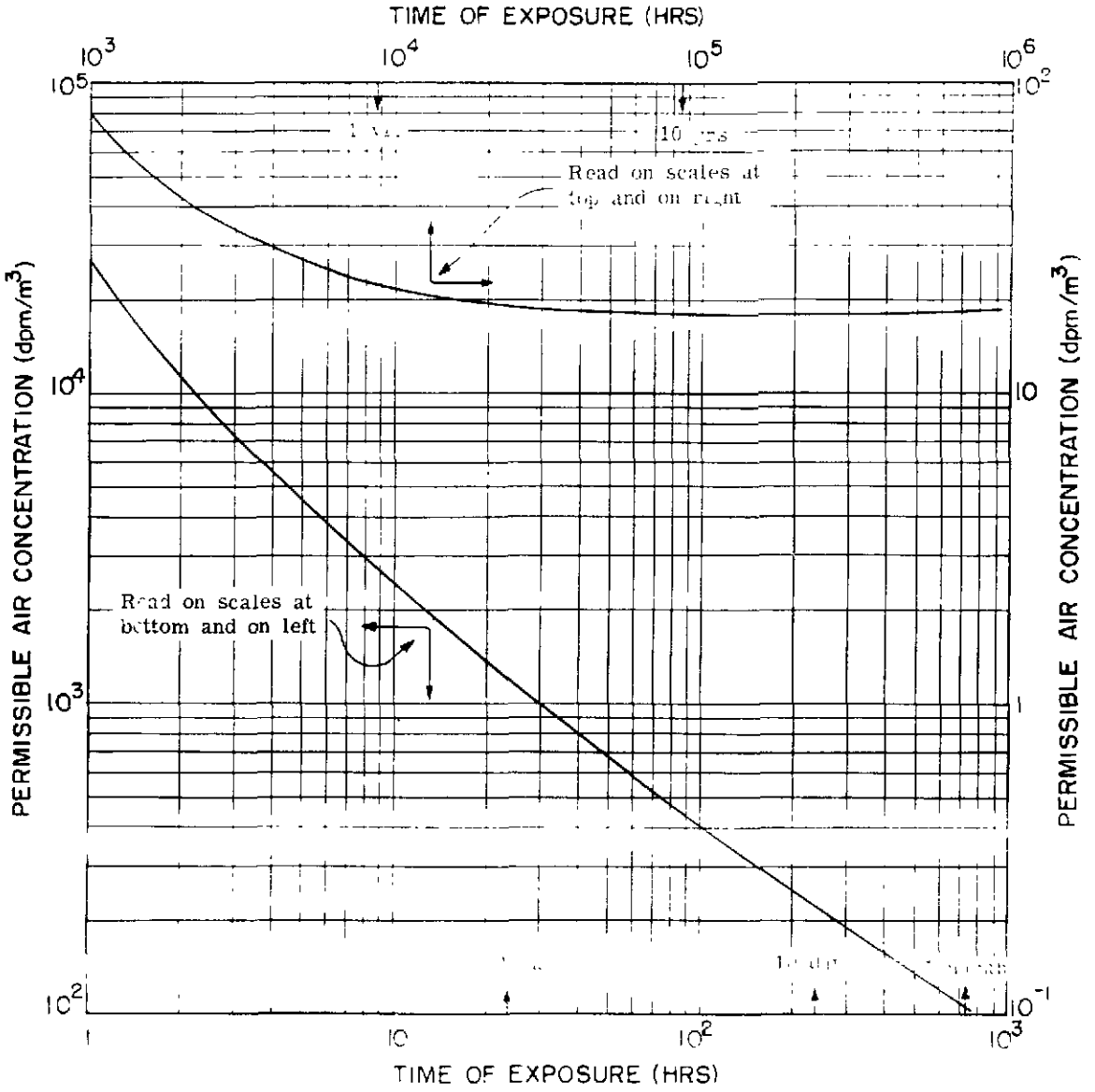

Fig. 3 Maximum permissible air concentration as a function of continuous exposure using the lung as the critical organ

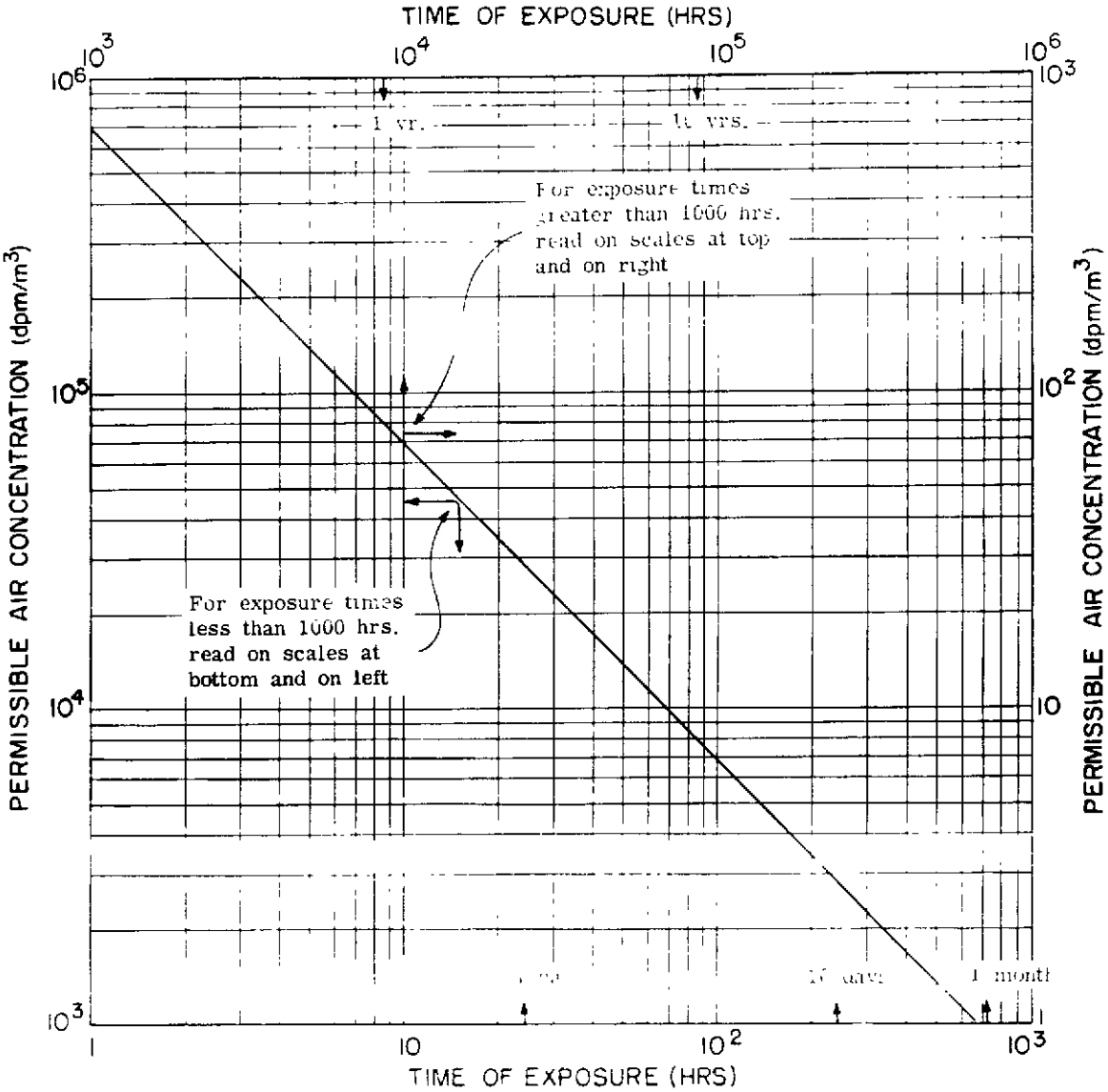

Fig. 4 Maximum permissible air concentration as a function of time of continuous exposure based on maximum permissible level of 0.5 μg for the total body

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

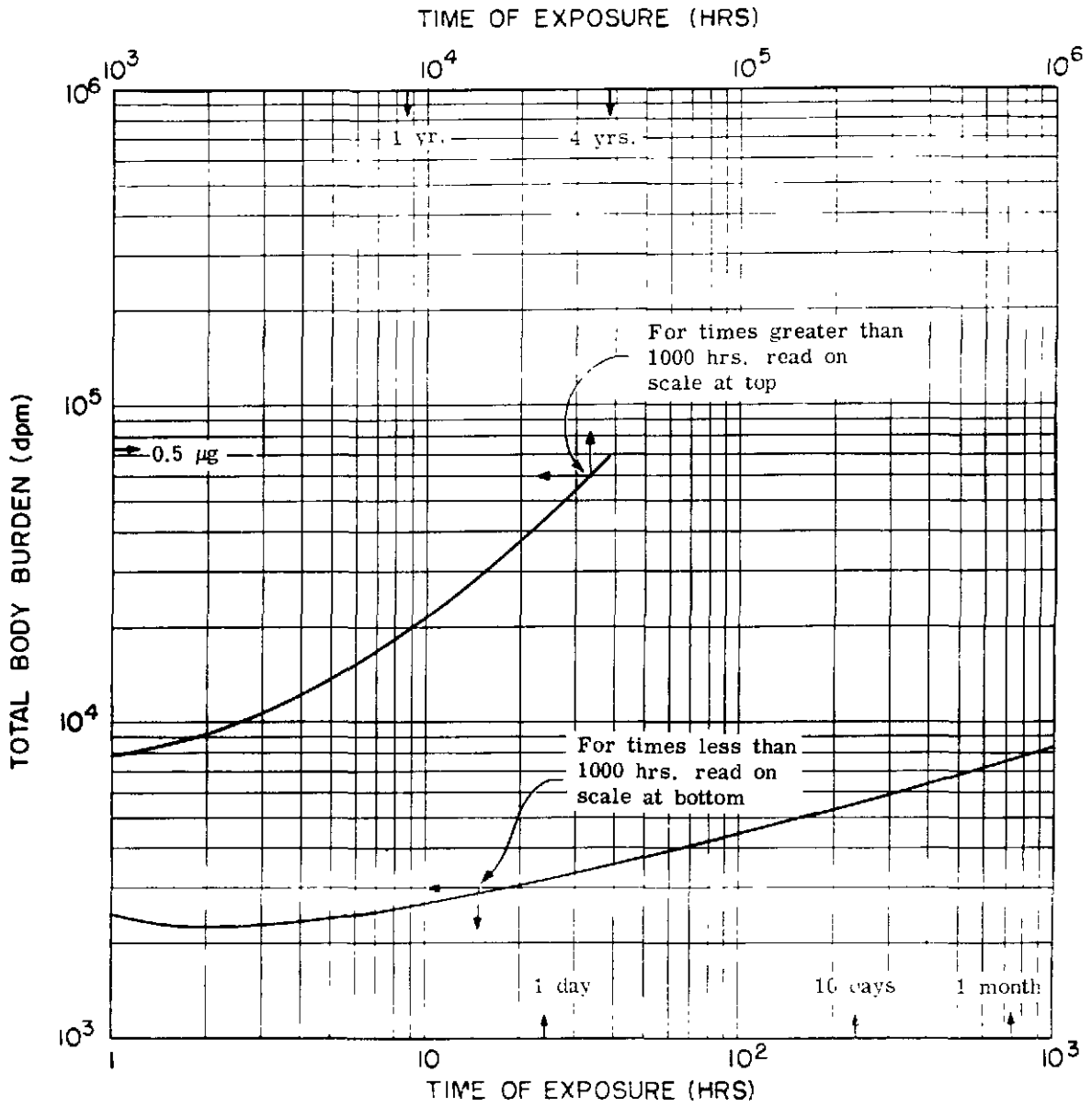

Fig. 6 Change in total body burden as a function of time of continuous exposure using maximum permissible amount in the lung as the limiting factor for air concentration

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.

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

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.

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

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

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

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.