SOME ASPECTS OF FALLOUT

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ABSTRACT

The phenomenon of fallout due to nuclear explosions is discussed. Fallout is divided into three main types : (1) Local (2) Tropospheric and (3) Stratospheric. The occurrence and character of these three types in the case of explosions taking place at different levels are explained. The probable effects and safety measures are indicated.

Introduction

Apart from blast and heat effects from nuclear explosion, there is another effect which is due to nuclear radiation. This radiation may be considered as made up of two parts—prompt and residual. Prompt radiation is that which lasts approximately for a minute from the instant of the explosion. It is with the residual radiation that fallout is associated and since the fallout in the case of high yield weapons is worldwide, it has become a matter of concern to the world population. Although nuclear test explosions have been taking place since 1945, the problem of radioactive fallout came into forefront on March 1, 1954, when a 15 megaton nuclear bomb was detonated at the Bikini Coral Islands and its fallout contaminated a cigarshaped area extending approximately 220 miles downwind, 20 miles upwind and varying in width upto 40 miles. The earlier explosions belonged mainly to the Kilotons' class.

Nuclear Detonation

It is typical of nuclear tests taking place on or near the ground that the fission products are released to atmosphere. To describe the phenomenon of fallout we must, of course, begin with nuclear detonation. In a nuclear detonation a large amount of energy is liberated in very small period of time and in a small region of space due to nuclear reactions taking place in the bomb. Following the detonation a large amount of soil and debris from the ground are sucked into the ascending fireball. Vapourised fission products, bomb fragments and neutron induced radioactive elements condense on small particulate materials, dirt, stones, debris, etc. These contaminated particles when they descend to settle on the earth constitute the "fallout". The deposition of fallout dust, consisting of particles of various sizes, takes place roughly according to 'Stoke's Law'. And as we have no sense of perception for radioactivity, this fallout will have some physical appearance as equivalent to dust cloud.

However, the significant difference is that each particle is a source of radio-activity and gives out ionizing radiations. Because the fallout is worldwide, it will contaminate places very far from the explosion site. As atmospheric conditions are responsible for deposition of the fallout particles, these are considered briefly here.

Atmosphere

Regarding fallout we are only concerned with the two lower regions of the atmosphere, *ie* troposphere and stratosphere, because even in the case of high energy yield bombs, the atomic cloud cannot ascend beyond the stratosphere.

Factors affecting fallout

The nature and distribution of the fallout from nuclear explosions vary according to size and type of the bomb used and the height at which it is exploded. The nature of the ground surface on or over which the bomb is exploded also plays an important part. In brief, the following factors may be considered as determining the extent and location of fallout—

(*a*) Altitude of the bomb burst.
(*b*) Power and design of the bomb.
(*c*) Size of the fallout particles.
(*d*) Wind velocity at different heights upto stratosphere.
(*e*) Snow and rain.
(*f*) The nature of ground surface.

Kinds of fallout

Fallout is divided into three classes : First, *local* or *close-in*, which is deposited within the first 24 hours after the detonation ; Second, *intermediate* or *tropospheric*, which is deposited largely within the first 30 to 60 days ; and finally, *delayed* or *stratospheric*, which can take many years to be deposited.

(1) *Local Fallout*—When a nuclear bomb is exploded on or near the ground, pulverized material is tossed up high in the air in the form of a cloud. The large particles of the cloud, under the influence of gravity, descend to the earth in a few hours. This constitutes the local fallout. The fraction of the total which falls out locally depends very much on the conditions of firing. The two important factors on which local fallout depends are the degree of contact of the fireball with the surface and the nature of the surface.

The fallout near the explosion site will be richer in larger particles as they will settle quicker than smaller particles. The pattern of local fallout is governed by the wind direction at different points upto the tropopause at that time, because the particles are transported by the winds. If the winds blow in approximately the same direction at all altitudes, the pattern is long and narrow, *ie*, cigar-shaped. If there is an appreciable change in wind direction with altitude, then the pattern will be a drawn out one.

(2) *Tropospheric Fallout*—Tropospheric fallout is due to that portion of the cloud which during its ascent into the stratosphere is slowed down at the inversion layer (tropopause). The important factor influencing the deposition of tropospheric fallout is precipitation-scavenging due to rain and snow-occurring in this region. Normally tropospheric fallout occurs within about 60 days after the detonation and consists of particles with exceedingly small settling speed. It is kn wn that prevailing winds generally bl w in east-west direction. Thus, transport in north-south direction is much slower than in east-west direction. This results in a fallout band round the earth, which lies almost entirely near the latitude of the explosion site, *ie*, tropospheric fallout is confined to a wide belt round the earth extending about 5° of latitude on either side of the explosion site. This type of fallout depends mainly on the bomb yield and firing conditions. For example, the percentage contribution by Kiloton type of bombs is much more towards this type of fallout than by Megaton bombs.

(3) *Stratospheric Fallout*—Radioactive debris is thrown into stratosphere by Megaton bomb tests. Due to horizontal winds in the stratosphere the radioactive debris spreads out and mixes nearly uniformly throughout the stratospheric air in course of time. After circling the globe for years, this bomb residue diffuses slowly into the troposphere where the material is brought to the earth as a result of rain and snow. It is not yet finally established how and where the stratosphere radioactive particles re-enter the troposphere. The part played by the seasonal variations in the height of the tropopause, constituting a type of pumping action, and the atmospheric motions affecting transport phenomena in the stratosphere are likely important considerations in understanding the diffusion phenomena. Probably stratospheric air in which extremely fine radioactive particles are present enters the troposphere in the middle latitudes (50—60 deg N & S), and then travels towards equatorial belt and there ascends again into stratosphere and thus completes the circulation. It is this pattern which probably supports the observed fact that stratospheric fallout is maximum in the middle latitudes of North and South Hemispheres and minimum in equatorial region. Again some disparity has also been observed in the intensity of radioactive fallout in the North and South Hemispheres, the reason for which can be assigned to the number of test explosions conducted in North Hemisphere.

The rate of descent of the tiny radioactive particles from stratosphere is very small. Previously the residence time was taken to be 10 years, but according to Dr. Willard F. Libby of Atomic Energy Commission, U.S.A., stratospheric fallout takes about 6 years to deposit. From the data collected by the Atomic Energy Commission, U.S.A., it has been observed that stratospheric fallout occurred at maximum rates in two specific bands of latitudes in both hemispheres. The most important factor on which stratospheric fallout depends is the firing conditions of megaton bombs. The contribution to the stratospheric fallout in the cases of megaton air bursts is about 95 percent of the total whereas the figure is about 20 percent in the case of ground burst.

The types of fallout and qualitative indication of the relative distribution between them of the total fallout material under typical conditions of detonation are given in the following table:—

Table 1: Fallout from nuclear explosions

	Local	*Annular (Trospospheric)*	*Global (Stratospheric)*
Region of earth's surface over which fallout occurs	Local area-vicinity of explosion site	Wide belt round the earth extending to several degrees of latitude on either side of the latitude of explosion site	All over the earth: Maximum in middle latitudes and minimum in equatorial belt
Duration of fallout	A few hours to a few days	A few weeks to a few months	About 6 years
Relative distribution of fallout:			
I. Kilotons explosion—			
(*a*) Air burst	Small	Large	Negligible
(*b*) Ground burst	Large	Small	Negligible
II. Megatons explosion—			
(*a*) Air burst	Small	Small	Large
(*b*) Ground burst	Very Large	Small	Large

Prediction of Local Fallout

To predict the area of local fallout a method which may be used under emergency conditions is given below—

In this method the basic information about mean wind velocity in miles per hour in a series of 5,000 feet thick layers of the atmosphere from the earth's surface is required. Let O be the ground zero and the height to which atomic cloud ascended be 30,000 ft. This height is divided in 6 layers of 5000 ft each. The vector OA represents the mean vector of motion in presence of wind in that layer. Vector AB of second layer and so on. Join OF. OF is the locus on the ground level of the particles falling from the height 30,000 ft. Similarly OE is the locus of particles falling from 25,000 ft. and so on. The region OABCDEFO may be regarded as providing indication of the general direction of the fallout with respect to ground zero. If the wind vectors are expressed in miles/hour, OF is the distance travelled by the particles descending from 30,000 ft. in 6 hours. The area OAB—FO is for particles having diameter more than 75 microns. Such particles fall at the rate of 5000 ft/hour (or more). Smaller particles fall more slowly and will be found outside the area shown in the figure. The general shape of the fallout area will remain same although it covers large area. It gives only a rough idea as most of the factors on which fallout depends will not be known under emergency conditions.

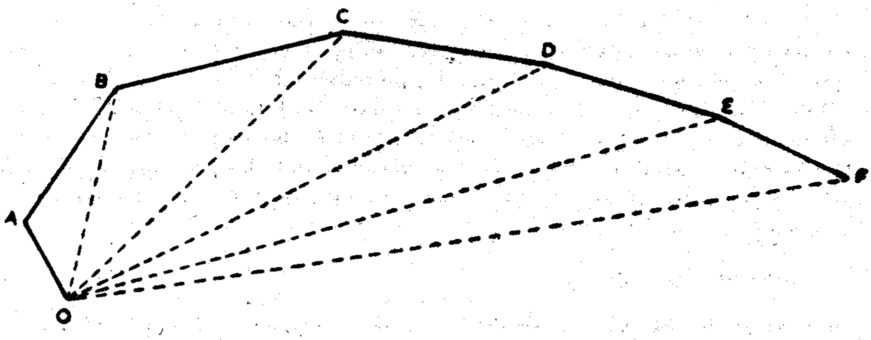

Fig 1. The area of a local fallout

Radiation Dosimetry

Fission of Uranium–235 or Plutonium–239 produces a whole complex of radioisotopes. These radionuclides have half lives ranging from a fraction of a second to several years. If the rate of decay of the fission pr ducts is so large that little radioactivity is left by the time the particles reach the ground, the effect on life is considerably lessened and fallout is not so dangerous. The radioisotopes decay according to an exponential law, each with its own characteristic half-life. When the decay rates of the different elements are added together. the decay of the mixture is given approximately by the power law

$$A_t = A_1 . t^{-1 \cdot 2}$$

Where A^t is the activity at time 't' and A_1 the activity at unit time from the instant of detonation. The value of A_1 differs for different units. The activity of the fission products is reduced by a factor of 10 when the time increases by a factor of 7. Thus taking the activity at one hour after detonation to be equal to unity we have approximately—

Table 2. Decay of radio-isotopes activity with respect to time.

Time after burst	*Activity*
1 hour	1
7 hours	1/10
7 × 7 hours (2 days approx)	1/100
2 weeks	1/1000
3 months approx	1/10000

The blast and the heat effects are over immediately after the nuclear detonation, but immediate casualties are unlikely to result from nuclear radiations. One method of ascertaining the probable effects on an individual is to estimate the dose of nuclear radiation received by him. The amount of nuclear radiation received by an individual varies with the yield of the weapon, the distance from ground zero, period of exposure and the protection afforded to the individual by shelter. Consequently, the dosage rate in roentgens per unit time can be represented by

$$\text{Roentgens per unit time} = I_1 \ t^{-1\cdot 2} \qquad \text{(A)}$$

where I_1 is the dosage rate at unit time. By the process of integration of summation, it is possible to determine from (A), the total dosage in r entgens that would he absorbed by continuous exposure to the radiation from fiss:on products over a per:od of time.

Probable effects

In a war with high-yield fission weapons the most serious hazard is from local fallout. The situation is, of course, quite different with regard to peace time nuclear tests. These tests are conducted in isolated atolls and other places far away from population centres, and by taking stringent precautions, the hazard from local fallout is almost completely eliminated. We are left, however, with the radiation hazards of global and tropospheric fallouts.

In megaton explosion a large portion of the total fallout is stratospheric fallout. The fallout particles remain for about 6 years in the atmosphere. The radioisotopes having long radioactive half-lives such as Sr. 90 (half life–28 years) Cs. 137 (half life–27 years) etc. will reach the ground and can easily enter into the metabolism of human body and can act as internal sources of radiations. Strontium which is chemically like calcium tends to concentrate in human bone, where it can cause cancer and leukaemia. This is why the problem of megaton bomb test explosions, even in peace time, is of much concern to world population.

The fallout on the ground will mostly consist of β and γ radiations. Range of γ-rays in air is much greater than that of β-rays. So the appreciable part of the dose received from fallout is expected to be made of γ-rays. Apart from external exposure, injuries can also result from "radioactive poisons". This term is used for the radioactive materials which enter the body by—

(*a*) breathing in contaminated fallout dust,
(*b*) eating contaminated food or drinking contaminated water,
(*c*) contamination of wound by fallout.

When radioactive material is inhaled, the nose and cilia of the respiratory passages screen out 95 % of all particles of more than 5 micron in size which are removed by blowing the nose. Only particles in the range of 0·1 to 2 microns remain in the lungs.

Retention of particulate matter in the lungs depends on many factors such as size, shape and density of the particles, their chemical form and whether the person breathes through the mouth or not; however, in absence of more exact knowledge the following is the probable distribution—

Table 3: Distribution of "radio-active" poisons.

Distribution	*Readily soluble Compounds*	*Other Compounds*
Exhaled	25%	25%
Deposited in upper respiratory passages and subsequently swallowed.	50%	50%
Deposited in the lungs (lower respiratory passages).	25% (This is taken up into the body).	25% (Of this, half is eliminated and swallowed in the first 24 hours. The remaining 12½% is retained with biological half-life of about 120 days).

The amount of very fine radioactive particles inhaled increases with the increment of air breathed and again breathing depends upon the activity of man which can easily be seen from the following table—

Table 4: Intake of radio active particles.

State of activity	*Air breathed at 20 °C (Litres/min)*
Resting in bed	6
Sitting	7
Standing	8
Walking (2 m.p.h.)	14
Walking (4 m.p.h.)	26
Slow run	43
Maximum exertion	65—100

The above figures are for a man weighing 150 lbs. Hence under emergency conditions troops should be removed from atmosphere in such a way that their moving exertion is minimum as they will then breathe less amount of air and so less amount of radioactive particles will enter the body. After entering the body the radioactive particles tend to concentrate in different parts of body, some going to the bones, some to blood, etc. There they act as internal source of radiation, thereby damaging that organ of the body. Fallout acts as a source of external irradiation if it gets deposited over the skin or nearby ground, and as an internal poison if inhaled or ingested with contaminated food and water, thus causing internal irradiation.

Personal and equipmental decontamination is necessary after exposure to fallout. Personnel can clean themselves and their personal equipment by brushing off the particles or by washing; other equipments will have to be decontaminated by other suitable methods. Decontamination should be checked by the use of the survey meter to see that contamination is kept below the harmful level.

Though specifically discussed with regard to atomic weapons in warfare the above consideration will apply well to the case of accidental burst in nuclear research laboratories and nuclear power units.

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