

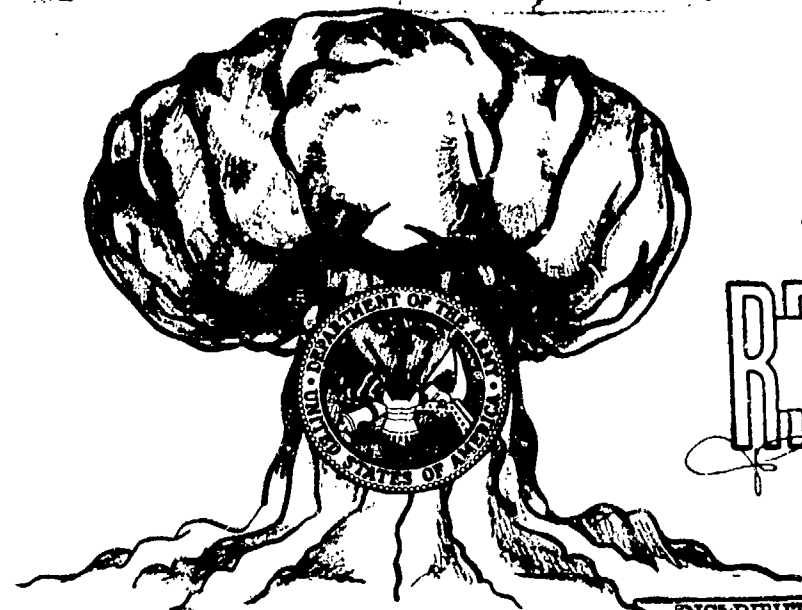
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**NUCLEAR NOTES NUMBER 5**

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**RAINOUT**

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NUMBER FIVE IN A SERIES OF INFORMATION PAPERS ON TOPICS ASSOCIATED WITH NUCLEAR WEAPONS, PRINCIPALLY DESIGNED FOR USE BY TRADOC SCHOOL INSTRUCTORS AND MAJOR COMMAND STAFF OFFICERS.

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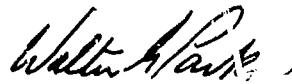
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FOREWORD

The series of papers, "Nuclear Notes," prepared by the US Army Nuclear Agency is intended to clarify and explain various aspects of nuclear weapons phenomenology and usage. These papers are prepared in as nontechnical a fashion as the subject matter permits. They are oriented toward an audience assumed to be responsible for teaching or in some way evaluating the tactics and techniques of employing nuclear weapons in a conflict situation. Their dissemination will hopefully provide to the US Army accurate, up-to-date information of critical importance to a reasoned understanding of nuclear weapons on the battlefield.

The principal author of this paper is CPT Forest O. Thompson, Jr. of the US Army Nuclear Agency. Comments and views of readers are desired and should be forwarded to: Deputy Commander, US Army Nuclear Agency, Fort Bliss, Texas 79916.



WALTER G. PARKS  
Colonel, AD  
Deputy Commander

## RAINOUT

### WHAT IS RAINOUT?

Of the many nuclear phenomena, one that has been receiving increased attention in the nuclear effects community is called "RAINOUT." Broadly speaking, rainout is the deposition on the earth's surface of radioactive particles (resulting from nuclear weapons bursts) through interactions of these particles with raindrops and rain clouds. ~~Such a phenomenon is not new. In fact,~~ for the atmospheric nuclear tests performed in the past, the possibility of rainout was recognized and then deliberately minimized by delaying the test when local precipitation existed in order to avoid any potential rainout hazard outside the test area. As a consequence, little useful rainout data were obtained from these tests. The end result was a phenomenon recognized qualitatively to be a potential hazard, but of unknown intensity and extent.

### WHY IS RAINOUT OF CONCERN?

Recently, the scientific effort in the rainout area has been increased in order to determine the extent of potential militarily significant hazards and to develop a better understanding of the phenomenon. Research indicates that in some cases, rainout can cover large areas with militarily significant residual radiation hazards. With this in mind, the military significance of rainout should be understood when employing nuclear weapons because of its far-reaching potential hazard to personnel. The following discussion describes the rainout process, its potential hazards, and its military significance in the theater of operations.

### WHAT IS A MILITARILY SIGNIFICANT RADIATION HAZARD?

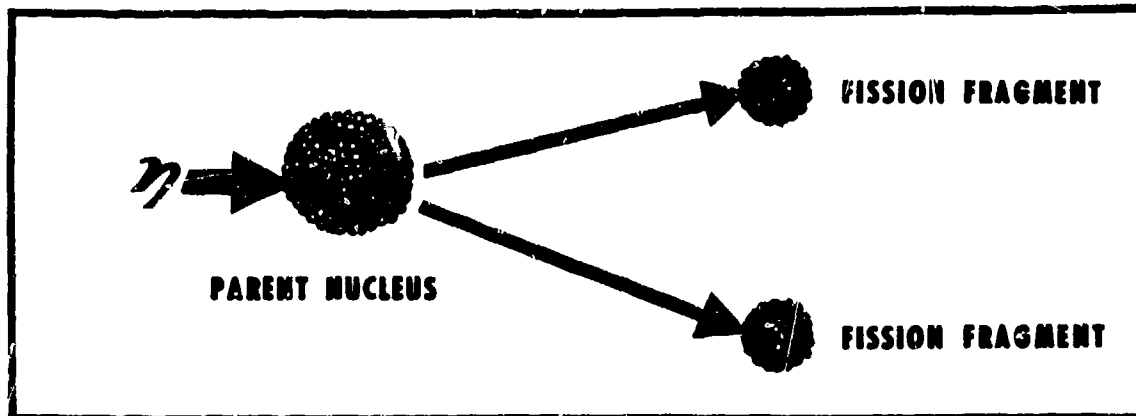
A militarily significant radiation hazard is a hazard of radioactive contamination capable of inflicting radiation doses on personnel which may result in a reduction of their combat effectiveness (i.e., doses in excess of 50 rad). For rainout, this hazard results from residual radiation. In general, residual radiation is that radiation resulting from a nuclear burst that is emitted at times later than one minute after the burst.\* The sources of this residual radiation are the primary fission products and the induced radiation of radioactive debris.

Residual radiation is produced by both fission and fusion (thermonuclear) bursts. Fission fragments are produced when a fissionable atom such as uranium-235 absorbs a neutron and splits into two or more smaller nuclei (see Figure 1). These smaller radioactive nuclei will then emit beta particles (high-energy electrons) and gamma rays over periods of hours, days, and even years. The intensity of the radiation emitted by such nuclei decreases with time. Induced radiation comes about when many debris materials absorb neutrons emitted by fission and fusion reactions and become radioactive. These debris materials consist of weapon debris and ground debris. The weapon debris is the remainder of the weapon materials after the detonation, excluding fission fragments. The ground debris may consist of soil, rock, vegetation, metals, and other materials. This induced-radioactive debris will then emit beta particles and gamma rays for long periods of time, and with an intensity which decreases with time. To simplify the discussion which follows, only pure-fission weapon bursts will be illustrated as examples, although the rainout process is equally efficient for fusion weapon bursts.

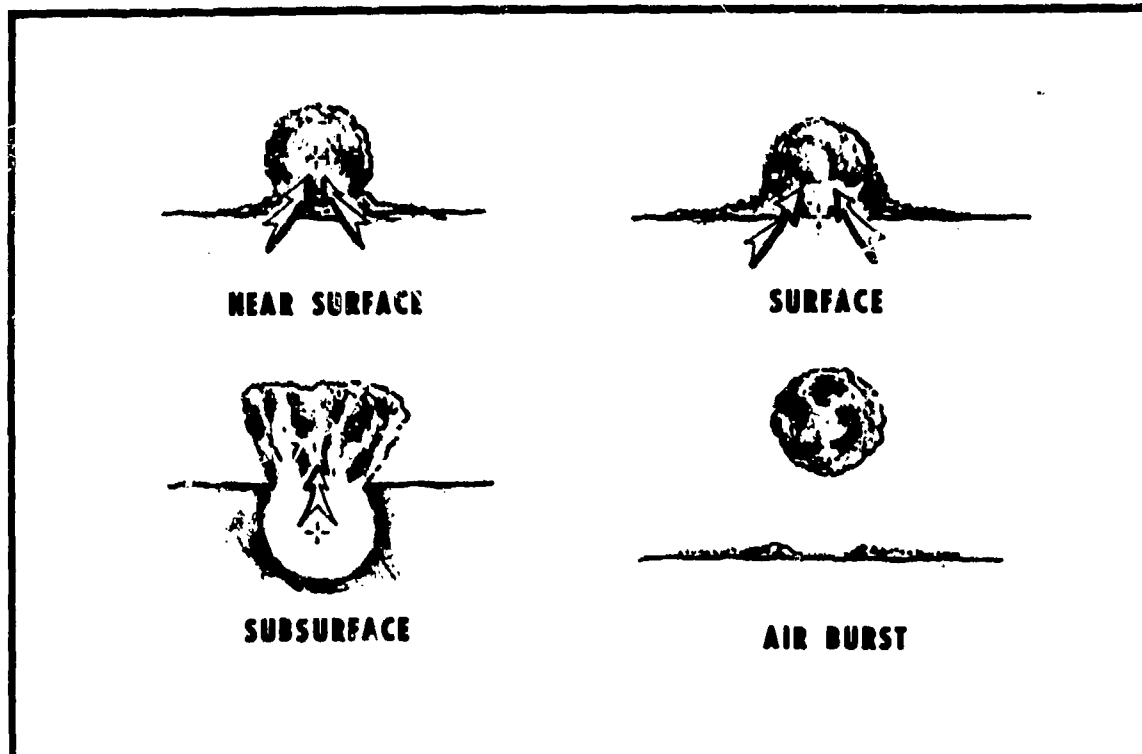
### HOW ARE THE RADIOACTIVE PARTICLES FORMED?

For a near-surface, surface, or subsurface fission burst, ground debris is swept up into the nuclear fireball as illustrated by the arrows in Figure 2. As the fireball cools, the radioactive fission fragments and some of the induced-radioactive debris become entrained in the weapon and soil debris to form particles that fall to the ground and form a pattern called "fallout." This fallout pattern begins forming around ground zero and extends to large distances downwind (see Figure 3). Due to the different fall rates for the various sized particles, the large heavy particles fall back to the surface immediately around ground zero and the lighter particles reach the surface at later times and farther downwind.

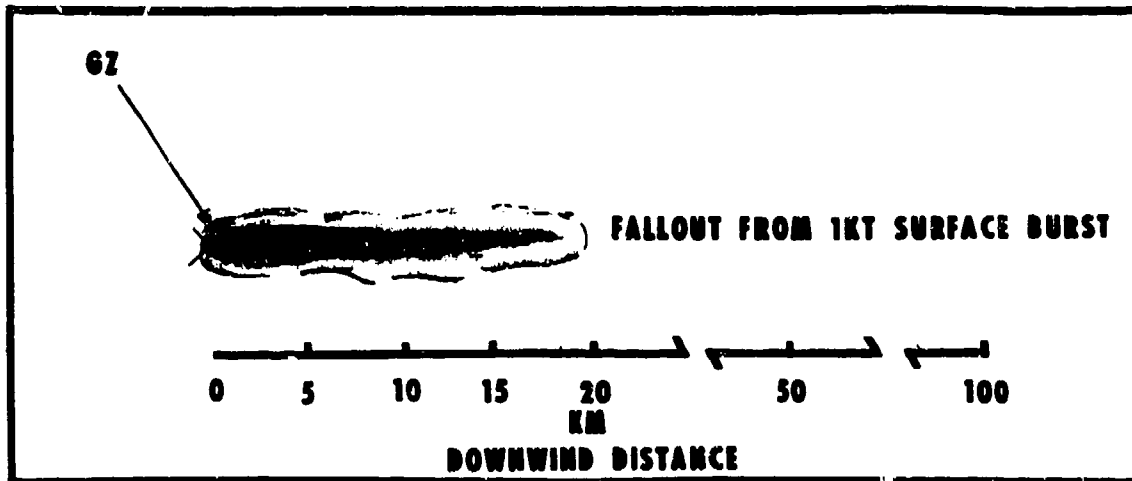
\*For a more detailed discussion of residual radiation, the reader is referred to FM 3-12 and DA Pam 39-3.



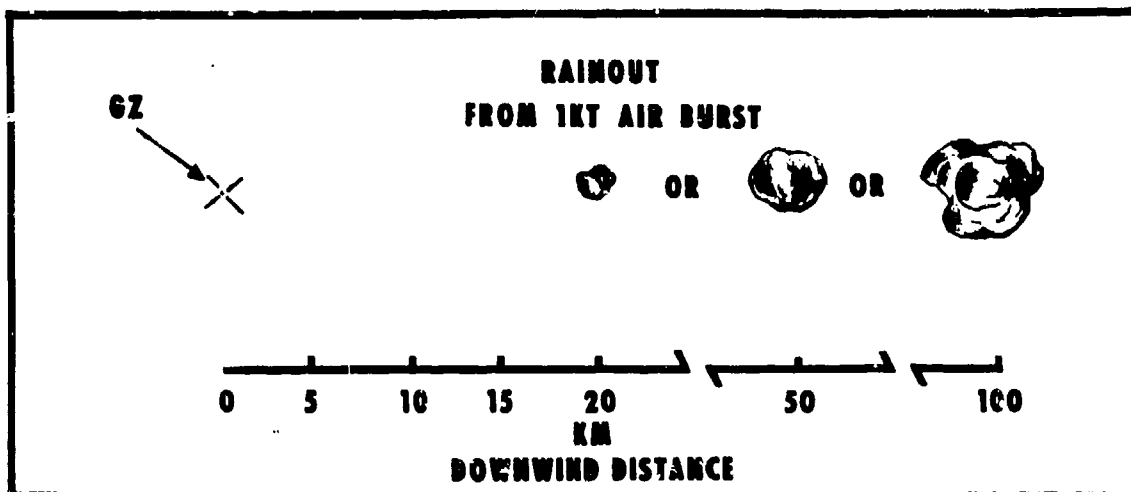
**FIGURE 1. THE PRODUCTION OF FISSION FRAGMENTS BY THE FISSIONING OF A PARENT NUCLEUS.**



**FIGURE 2. TYPES OF NUCLEAR BURSTS.**



**FIGURE 3. THE FALLOUT PATTERN USUALLY BEGINS AROUND GROUND ZERO AND EXTENDS DOWNWIND.**



**FIGURE 4. THE RAINOUT PATTERN CAN BE LARGER BUT LESS INTENSE AT GREATER DISTANCES DOWNWIND DUE TO DEBRIS CLOUD DIFFUSION.**

A nuclear weapon can be burst such that there is no interaction of the fireball with the ground (an airburst, see Figure 2). Even though the amount of residual radiation from the fission fragments is the same as that from a surface burst of the same yield, usually no militarily significant hazard from these fission fragments appears on the ground. This is because an airburst produces radioactive particles from the weapon debris and fissionable material whose diameters range from submicron to several microns (one micron equals  $10^{-6}$  meters). About 65 to 90% of the total mass of all the particles produced consists of particles having diameters between 0.1 and 1.0 micron. In the absence of rain, this small size allows most of the radioactivity to remain aloft for extended periods of time. Therefore, no militarily significant hazard from the airburst fission fragments and radioactive weapon debris appears on the ground. This neglects the materials on the surface of the earth directly beneath the burst which will emit induced radiation after being subjected to initial neutron radiation from the burst. This induced radiation normally remains on the surface in a circular pattern around ground zero.

#### HOW DOES RAINOUT OCCUR?

Rainout (see Figure 4) may occur for any type of nuclear burst that introduces residual radiation into the atmosphere: subsurface, surface, near-surface, or airburst. Two different processes may be involved in the production of this militarily significant hazard. First, when the radioactive debris cloud is mixed with a rain-producing cloud (see Figure 5), the radioactive particles can become attached to cloud moisture and be carried to the ground by rain. This process is called "rainout." Secondly, when the radioactive cloud passes under a rain-producing cloud from which rain is falling (see Figure 6), the radioactive particles can be scavenged and carried to the ground by collision with and cohesion to the raindrops. This process is called "washout." Both the rainout and the washout processes are referred to in the research community as rainout to simplify terminology since the result is the same - the deposition of radioactive particles on the ground by rain.

#### WHEN AND WHERE WILL RAINOUT OCCUR?

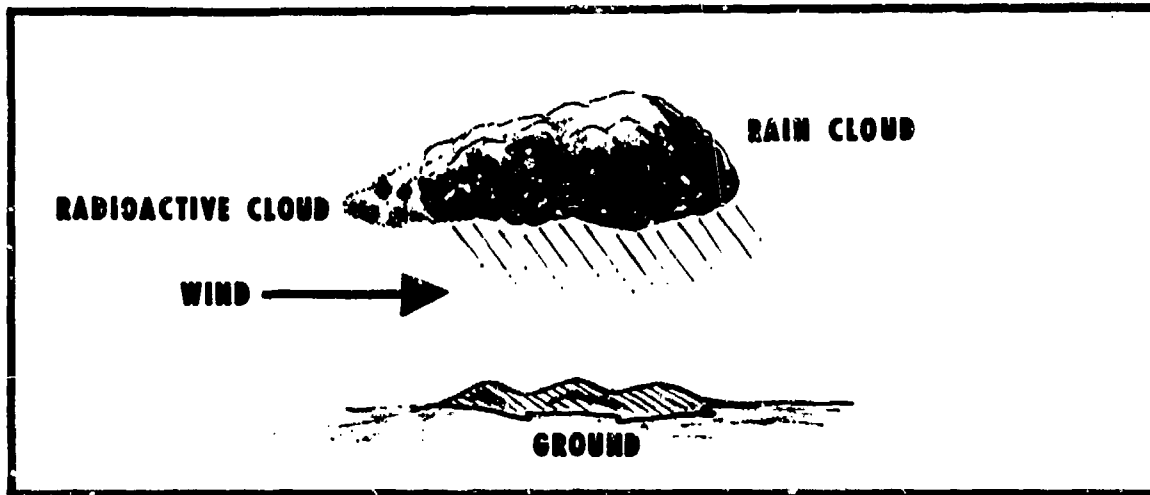
For a surface-interacting burst where radioactive debris is released into the atmosphere, there will always be fallout (see Figure 3). In order to have rainout, however, not only must rain occur, but it must occur near, or after interaction with, the radioactive debris cloud within a few hours after the nuclear burst. Although considerable research has recently been carried out on rainout hazards, the physics of particle formation, of particle distribution within the debris cloud, and of particle scavenging by rain are still not completely understood. In addition, uncertainties exist in the ability to predict where rain will occur.

In comparison to the prompt hazard area around ground zero caused by blast, thermal and prompt radiation effects, the militarily significant rainout hazard area may be larger, but will not necessarily cover the same area as the prompt hazard. A militarily significant rainout hazard area, if one occurs, might conceivably be many tens of kilometers downwind (see Figure 4). The rate of rain-fall must usually be moderate to heavy in order to have a militarily significant rainout hazard, because mist and light rain normally do not act efficiently in scavenging radioactive particles (or any other type of airborne particles) from the atmosphere.

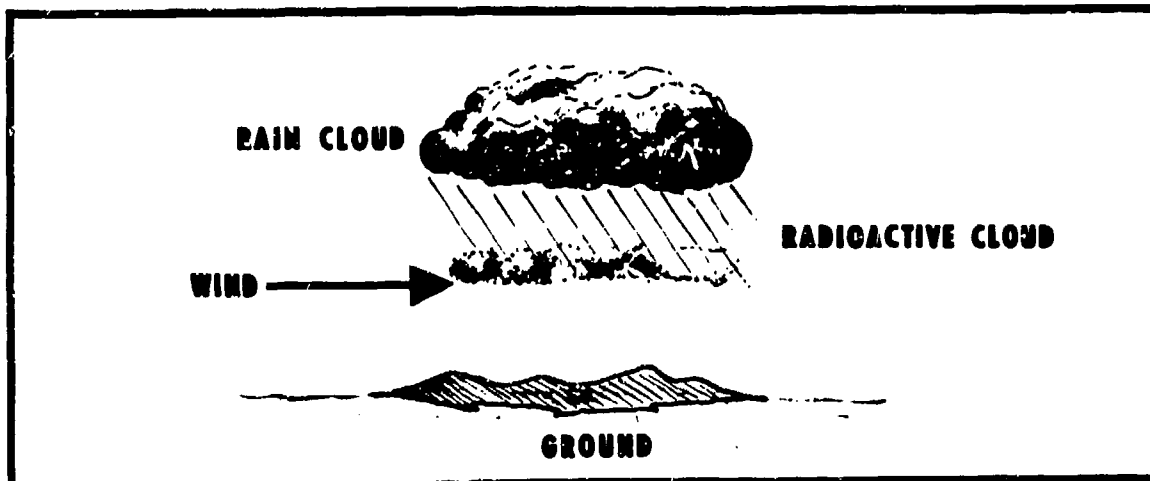
#### WHAT MECHANISMS ARE RESPONSIBLE FOR RAINOUT?

Several mechanisms have been identified which provide the means for rain clouds to interact with radioactive debris. For rainout to occur, either one-stage or two-stage processes, or both, take place. The size of the water drop with which the radioactive debris interacts is the factor that determines which process is important. The two processes and the more important of the identified mechanisms which each process involves are:

1. Raindrop (one-stage process) - the water drop is large enough to fall due to gravity from the rain cloud to the ground and will interact with debris by:
  - a. Inertial capture - the capture of suspended debris particles by collision with falling rain drops. This process is most efficient when the debris is near the base of the rain cloud where the density of falling rain drops is greatest.
  - b. Brownian motion - the random motion of submicron particles suspended in an atmosphere, resulting from molecular vibration causing the particles to move and collide with the surrounding molecules. The particles (in this case, submicron radioactive debris particles) consequently have substantially more collisions with water drops than if inertial capture only was involved.



**FIGURE 5. RAINOUT: THE RADIOACTIVE DEBRIS CLOUD MIXES WITH THE RAIN CLOUD AND RAIN FALLS TO THE SURFACE OF THE EARTH.**



**FIGURE 6. WASHOUT: RAIN FALLS THROUGH THE RADIOACTIVE DEBRIS CLOUD TO THE SURFACE OF THE EARTH.**



2. Cloud drop or droplet (two-stage process) - the water droplet in the cloud is not large enough for gravity to overcome the internal forces of the cloud that are acting on the droplet. The droplets interact with radioactive debris and then must be collected by a falling raindrop in order to fall to the ground. Thus, this is a two-stage process. The mechanisms which are involved in this process are:

- a. Brownian motion - same as 1b above.
- b. Electrical attachment - the attachment of debris particles to cloud droplets caused by the presence and interaction of electrical charges on both.
- c. Turbulent attachment - the attachment of the radioactive debris due to the collision of the debris with water droplets caused by the turbulence associated with eddies in the atmosphere in and around rain clouds. Cloud turbulence will affect a large volume of the atmosphere outside the cloud and will incorporate suspended particles from this external region into the cloud, thereby concentrating the particles.
- d. Nucleation - the debris particles acting as condensation sites for cloud moisture. The size and physical state of the debris particles determine if the particles can serve as condensation nuclei. The process of nucleation has the greatest probability of occurring in the region of the greatest moisture content -- generally in the base of the cloud.
- e. Diffusiophoresis and thermophoresis - the influences on the motion of the debris particles resulting from nonuniformities in the atmosphere. Diffusiophoresis is the movement of particles in the direction of the flow of water molecules, which is caused by the heat flow in the atmosphere. Thermophoresis is the movement of particles in the direction of the flow of heat. These processes are of concern since heat and water vapor flows are usually associated with the evaporation and/or condensation growth of water droplets.

#### WHAT YIELDS ARE OF INTEREST FOR POTENTIAL RAINOUT HAZARDS?

The yield of a nuclear weapon is significant because different yields will produce radioactive debris clouds of different sizes and which stabilize at different heights. For example, the bottom of the stabilized cloud for a 2 KT nuclear burst will be at approximately 2.5 kilometers and its top will reach approximately 5 kilometers. For many parts of the world, to include Western Europe, these are the altitudes in which a great deal of rain cloud activity occurs. Stabilized cloud heights will normally be lower for yields smaller than 2 KT and higher for yields larger than 2 KT. Thus, it is the low end of the yield spectrum (i.e., less than approximately 10 KT) which poses the greatest potential hazard for rainout. This is because debris clouds interact most efficiently with rain clouds at or below the base of the rain cloud.

#### WHAT IS THE POTENTIAL HAZARD OF RAINOUT?

Rainout is a potential militarily significant hazard from the standpoints of friendly troop safety and collateral damage. Troop safety and avoidance of collateral damage are always considered in the planning for and employment of friendly nuclear weapons. Command directives specify the degree of risk for friendly troop safety and guidelines for avoiding collateral damage. In this sense, potential and/or existing rain storm centers should be evaluated for possible interaction with nuclear debris clouds since rainout could affect friendly troop performance of their mission and even cause large numbers of casualties. From a collateral damage standpoint, the rainout hazard to friendly civilians from an airburst of a nuclear weapon could conceivably be worse in some instances than the fallout hazard from a surface burst of the same yield.

Rainout resulting from enemy nuclear detonations can also be a hazard to friendly troops and civilians. After an enemy nuclear burst occurs, friendly troops and civilians in the downwind direction from the burst can be warned. The friendly troops should follow established radiation monitoring and reporting procedures for radioactivity in their areas, in addition to seeking shelter.

#### WHAT ARE SOME FACTORS WHICH AFFECT THE LIKELIHOOD OF RAINOUT?

Reiterating some of the main points above, several factors must combine to produce the necessary atmospheric and physical conditions for rainout to occur. Some of these are:

1. Occurrence of rain: Rain clouds must be available to interact with the debris cloud.
2. Wind speed and direction: The nuclear debris cloud must interact with the rain clouds. For this to happen, atmospheric conditions (wind speed, wind shear, wind direction) must allow the mutual movement of the two cloud centers so that they interact.
3. Yield: The yield of the nuclear burst will, in general, determine the height of the stabilized debris cloud. If the yield is too large (above approximately 60 KT), the stabilized cloud is not likely to interact with any rain clouds because it will rise high above them. However, an exception to this would be a burst occurring beneath an existing rain cloud from which rain is falling at the time, and then the debris cloud rising through it.
4. Height of burst: If the fireball interacts with the surface of the earth, the average size of the radioactive particles will be large enough so that most (50 to 60%) of the particles will fall to the surface in a relatively short period of time (several hours). The remainder of the radioactive particles from the burst will remain suspended in the atmosphere for long periods of time. For no interaction of the fireball with the surface (an airburst), no fallout hazard will exist and the radioactive particles will remain suspended for very long periods of time. This suspended radioactive debris will then be available for interaction with rain-producing clouds and can be carried to the surface as rainout.

#### WHAT IS THE OPERATIONAL SIGNIFICANCE OF RAINOUT?

The operational significance of rainout on the nuclear battlefield can be summarized as follows:

1. Militarily significant rainout hazards may occur from any type of nuclear burst (subsurface, surface, near-surface, or airburst) that releases radioactive debris particles into the atmosphere. However, the yields which are most likely to produce the greatest hazards are those less than 10 KT. Yields greater than 60 KT are not expected to produce rainout hazards except as discussed above. Those yields in the range of 10-60 KT may produce rainout hazards. These hazards are expected to be much less than those from yields less than 10 KT because there will usually be much less interaction between these debris clouds and rain-producing clouds.
2. The probability that rainout will occur is low for a single burst because of its dependence on weather conditions, yield, and height of burst. However, the probability increases as the number of bursts increases over a short time span on the battlefield because of the increase in the radioactive debris in the atmosphere. Under the present employment concepts, many nuclear bursts could occur in a very short period of time (up to a few hours), increasing the amount of radioactive debris in the atmosphere manyfold.
3. The rainout pattern may be small but exhibit very high radiation levels, particularly if it occurs in the vicinity of ground zero at the time of burst. As the debris cloud moves downwind, it will diffuse in the atmosphere. If rainout occurs far downwind, the area of the militarily significant rainout may be larger than that at ground zero, but the radiation levels may be much less.
4. The location of the rainout pattern is essentially unpredictable at the time of the nuclear burst because of the uncertainties associated with weather prediction.
5. Rainout can be a militarily significant hazard to both friendly and enemy troops and may affect their tactical operations and movements. Established procedures for monitoring and reporting residual radiation should be followed.

#### WHAT SHOULD BE DONE ABOUT RAINOUT?

Based on the current knowledge of rainout, the following courses of action are available for minimizing its impact on the nuclear battlefield:

1. The commander should be aware of the potential existence of rainout whenever a nuclear burst occurs, and for a period of time afterward.

2. When the military situation allows, the employment of nuclear weapons by friendly units should be planned for times and locations when atmospheric conditions will be unlikely to produce interaction of rain clouds with radioactive debris clouds, provided that the mission can still be accomplished.

3. The possibility of rainout reinforces the need for strict adherence to current operational procedures for the nuclear battlefield. After nuclear bursts, troops must monitor their environment with radimeters for radioactivity and take whatever protective measures possible to prevent casualties.

#### WHAT IS THE STATUS OF THE PROBLEM?

Until accurate rainout predictions can be made, courses of action available for friendly troops to minimize the hazard are limited to those described in the previous section. In the meantime, research is in progress to determine the extent of the threat by rainout, to define the parameters for its occurrence, and to reduce the inherent rainout hazard of friendly nuclear weapons.