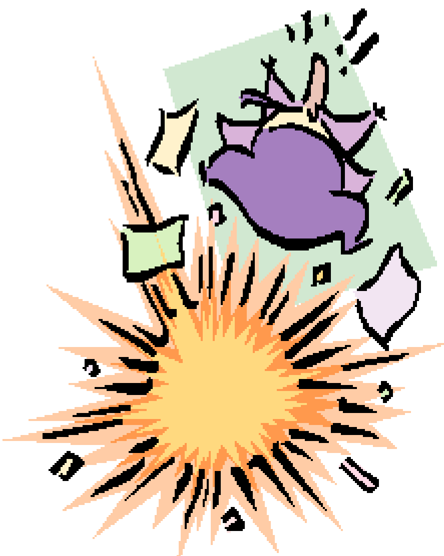
Technical Dialogue
Nuclear Weapons

What is a Nuclear Weapon?

There are two basic types of nuclear devices. One is the nuclear fission weapon, sometimes called the "atomic bomb". The other is a thermonuclear weapon, sometimes called the "hydrogen bomb". A "dirty bomb" is neither a nuclear fission nor a thermonuclear weapon but a conventional bomb with radioactive materials attached and set off by explosives. The explosives are used to disperse the radioactive material. The "dirty bomb" was the subject of a previous article in this newsletter.



Nuclear Fission Weapon: A heavy atom such as from certain isotopes of uranium or plutonium splits into smaller atoms generating neutrons. This is called fission. If enough of the heavy atoms are together such as they form a critical mass, the neutrons released by the fission process are captured by other atoms of uranium or plutonium rather that lost to the outside, and the reaction becomes self-sustaining. This happens quickly, on the order of a second or so, with a tremendous release in energy.

Thermonuclear Weapon: If deuterium or tritium (these are heavy isotopes of hydrogen) reach one million plus temperatures, they will fuse forming helium, something like what goes on in the sun. On a unit weight basis, the fusion of deuterium can release about three times as much energy as the fission of uranium or plutonium. To initiate the reaction, a fission-type bomb is set off resulting in the deuterium or tritium reaching the million plus temperatures. All this happens quickly, on the order of a second or so, with a tremendous release in energy.

The thermonuclear weapon produces much more thermal radiation (e.g. a larger fireball), compared with fission only. However, when the uranium or plutonium or heavier atom splits forming smaller atoms, a lot of neutron and gamma radiation is released during the first second or two from the detonation. This radiation can travel miles from the source. In addition, the smaller atoms produced are radioactive. The atom splits can occur in many different ways producing such things as cesium 137, strontium 90, and perhaps 150+ other different radioactive isotopes. Some of these isotopes will remain radioactive for years and will spread globally.

How does a Nuclear Weapon Work?

Enough heavy atoms such as from Uranium 233 or Plutonium 239 must be brought together to form a critical mass. Not just any heavy atom will do. The mass of material must generate enough high-energy neutrons to result in a detonation but be fairly stable if the mass is subcritical. Many of the man-made heavy radioactive isotopes have too short a half-life for practical use in a nuclear bomb, even though they emit neutrons and the critical mass is small. Uranium 233 fits the bill. The critical mass of a bare sphere of Uranium 233 is 17 kilograms (a little under 5 inches in diameter). The critical mass of a bare sphere of Plutonium 239 is 10.2 kilograms (a little under 4 inches in diameter). If the sphere is placed in a fully reflected arrangement, the critical mass of Uranium 233 is 6.7 kilograms instead of 17 kilograms. The critical mass of a fully reflected sphere of Plutonium 239 is 4.9 kilograms. The critical mass of a fully reflected sphere of Plutonium 241 is only 0.26 kilograms.

Ordinary uranium found in nature is 99.3% uranium 238. Uranium 238 by itself does not generate enough high-energy neutrons to form a critical mass. Rather elaborate and expensive facilities are required to extract the small amounts of Uranium 233 and Uranium 235 from the uranium found in nature. However uranium 238 can undergo fission when used in a thermonuclear weapon because of the very large amount of energy released during a thermonuclear explosion.

When a nuclear bomb is armed, a conventional explosive is used to bring subcritical mass fragments together to form a critical mass. A variation of this is to use a spherically fabricated shape of a high explosive with a subcritical sphere of fissionable material in the center; when the explosive detonates, an inwardly directed implosion causes the fissionable material to be compressed such that it becomes critical. The explosive is set off remotely.

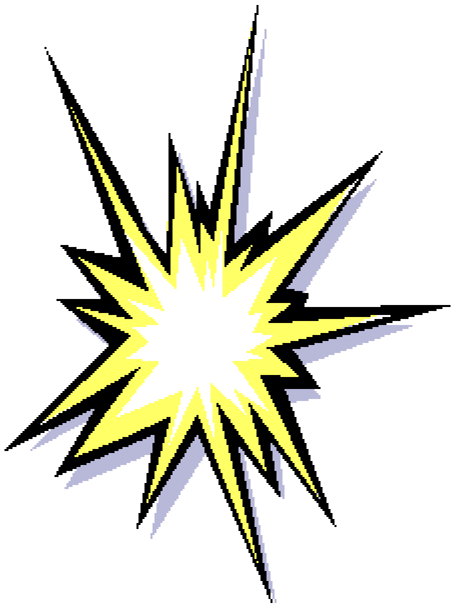
The amount of energy released depends on the arrangement. Theoretically, the complete fission of one pound of uranium or plutonium releases as much energy as 8000 tons of TNT. The fusion of all of the deuterium in a thermonuclear weapon can release up to the energy equivalent of 26,000 tons of TNT per pound of deuterium. The actual amount of uranium or plutonium (and deuterium if used) in a nuclear bomb required for a given TNT energy release is more because the process is not 100% efficient.

It is customary to rate the energy release from nuclear weapons in terms of equivalent TNT. The nuclear bombs dropped over Japan at the end of World War II each had an energy equivalent of 20 kilotons of TNT.

The energy released from a nuclear weapon is in the form of blast and shock waves, thermal radiation from the fireball, initial radiation from gamma and x-rays and high energy neutrons from the detonation, and residual nuclear radiation from the fission isotopes produced. The distribution of energy depends on the nuclear device and the height that it is detonated. If detonated on the ground, much of the energy will be absorbed by the ground so the thermal radiation and blast/shock waves some distance away will be less compared with an explosion hundreds of feet in the air. On the other hand, a ground explosion will vaporize the ground at the site (e.g. about 4000 tons of soil for a 1-megaton TNT nuclear weapon) resulting in a radioactive cloud heavily loaded with debris.

What Happens During the First Minute of a Nuclear Blast?

The fireball:



The nuclear detonation occurs as soon as the mass becomes critical. In less than a millisecond, fission occurs releasing tremendous amounts of energy. The energy is transferred to the bomb casing and surrounding air (or ground) resulting in a temperature increase perhaps exceeding 10,000,000 degrees F and pressures several million pounds per square inch. The extremely hot center radiates a large amount of thermal and x-ray radiation. This is the fireball which accompanies nuclear explosions. The fireball from a 1 megaton TNT equivalent nuclear explosion would appear to an observer 50 miles away to be more brilliant than the sun in only one millisecond after detonation. The fireball will increase rapidly in size and decrease in brilliance and temperature. The fireball from a 1-megaton explosion will be about 7200 feet across after 10 seconds. After 1 minute, a ground-level 1-megaton explosion fireball will be about 4.5 miles high.

For a 20-kiloton weapon, the fireball will reach its maximum size of about 1500 feet in diameter about 2 seconds. The fireball will be more intense for a thermonuclear explosion.

The distance from ground zero for first-degree burns to bare skin from an air burst depends on the height of the explosion, the type of nuclear device, and the TNT equivalent. For example, for an air burst of a fission weapon, the distance from ground zero might be 0.7 miles for a 1-kiloton burst and over 30 miles for a 10 megaton burst. The arrival time for the thermal maximum might be 0.03 seconds for the 0.7 mile distance (1-kiloton burst), and 3.2 seconds for the 30 mile distance (10 megaton burst).

Blast Waves and Accompanying Wind:

The expansion of the hot gases at very high pressures in the fireball causes a blast wave to form in the air which moves outward at high velocity. The destructive effect of the blast wave is characterized by the peak overpressure. The threshold for lethality from the blast effect appears to be about 3 psi overpressure, and at 10 to 20 psi total destruction occurs. In addition to the blast wave, there will be strong transient winds accompanying the passage of the blast wave which contributes to the blast damage. For overpressures of say 5 psi, the accompanying wind may be 160 miles per hour (mph). Closer to ground zero, the overpressure might be 70 psi and the accompanying wind over 1000 mph.

For a 1-kiloton fission surface bomb blast, the peak overpressure of 2 psi occurs approximately 2500 feet from ground zero within several seconds from the detonation. For a 10-megaton fission blast, the peak overpressure of 2 psi occurs at a distance of 30 miles, and the arrival time of the blast wave is about 37 seconds.

Nuclear explosion tests were completed at the Nevada Test Site in 1953 and 1955, where the effect of the blast on buildings constructed at varying distances from ground zero was evaluated. At 1.7 psi overpressure, unreinforced brick and wood frame houses escaped structural damage but most of the windows were broken. At 1.7 psi overpressure, two of nine trailer-coach moble homes were tipped over, and most windows were broken. A small house or shed with combustibles (trash) by the shed caught fire, a shed without combustibles was charred but did not catch fire. At 4 psi overpressure, a two-story strengthened wood-frame house was still standing but the roof and fireplace was collapsed, and the side facing the blast was heavily charred from the thermal radiation. A small wood house or shed with combustibles (trash) by the shed caught fire, a wood shed without combustibles was charred but did not catch fire. At 5 psi overpressure, both unreinforced brick and wood-frame houses were completely demolished, but a reinforced precast concrete house was still standing. Damage to transportation-type aircraft parked on the ground depended upon how the aircraft was oriented to the nuclear burst, but generally the aircraft was damaged beyond economical repair at overpressures of 4 to 6 psi.

Initial Nuclear Radiation:

The initial nuclear radiation consists of gamma rays and neutrons produced during the first minute of the nuclear explosion. Essentially all of the neutrons reach their target within the first second of the detonation. A person dropping to the ground at the instance of a nuclear flash would not be able to decrease his neutron exposure because everything happens too fast, but he/she might reduce his/her gamma radiation exposure by say 67% at 1000 yards from a 20-kiloton air explosion.

The radiation is intense enough that it would be fatal to exposed humans within 2 miles of a 1-megaton blast, even discounting the fireball and blast effects.

The interior of buildings offer some protection. A person surrounded on all sides by 12 inches of concrete would experience 1/10 the gamma radiation level as a person not shielded. About 18 inches of damp ground has the same gamma ray reduction value as 12 inches of concrete. For neutrons, the 1/10 reduction thickness is about 24 inches of damp ground. The air scatters gamma rays and neutrons, meaning, that protection must be provided in all directions and not just the direction of the detonation.

From the nuclear tests conducted during the 1950's, it is possible to estimate the initial radiation dose as a function of distance from the nuclear blast for various energy yields in TNT equivalents. The altitude of the blast also plays a role.

About 50% of people receiving a 450 rem radiation dose will die within 60 days. The threshold for lethality appears to be about 200 rem. This does not include possible later cancer developed by people exposed to a lower dose.

<u>What Happens After the First Minute of a Nuclear Blast?</u>

After the first minute, the major danger is from secondary fires and residual radiation. Collapse of buildings is another hazard. Residual radiation is probably the major concern.

The residual radiation comes from the fission products and from radioactive active species produced from neutron interactions. The fission products consist of a very complex mixture of perhaps 200 different isotopes which decay mostly by emitting beta particles and are accompanied by gamma radiation. Another source of residual radiation is the uranium and plutonium which escapes the fission process and undergoes alpha decay with some gamma emission. About 2 ounces of fission products are formed for each kiloton (TNT equivalent) of energy yield.

The radiation dose as a function of distance from ground zero depends how the radioactive isotopes are distributed; they can be absorbed into or onto the ground or carried by the wind to some distance from the site. However, if the dose rate (Roentgens per hour) is known at a location at particular time since detonation, the dose rate can be estimated for a later time. The mixture of isotopes from a fission-type detonation are such that the dose rate falls off according to $t^{-1.2}$, for example, if the dose rate at a particular location is 1000 Roentgens/hour at one hour after the detonation, after 1000 hours, the dose rate is 0.24 Roentgens/hour. About 55% of the "infinity residial radiation dose" (e.g. the radiation dose if the person remained there for many years) is received between the first minute and hour since detonation. About 80% of the infinity dosage is received between the first minute and 24 hours since detonation. This kind of information is of use to responders who may venture into an area devastated by a nuclear explosion, or when people in shelters might come out. This rule of thumb does not include rainout or fallout of radiation particulates carried by the wind.

From tests at the Nevada Test Site and the Eniwotok Proving Grounds, estimates were made of fallout patterns for a 1 megaton nuclear ground-level explosion at a wind speed of 15 mph, assuming 50% fission. For example, at 20 miles downwind from ground zero and one hour after the detonation, the dose rate is about 10 roentgens/hour and rising rapidly. The dose rate would peak at about 1000 roentgens/hour , and then decay to 300 roentgens/hour at 6 hours, and 80 roentgens/hour at 18 hours. The total dosage is about 3000 roentgens after 6 hours and 4800 roentgens after 18 hours. At 100 miles downwind, the fallout cloud will begin at slightly less than 6 hours and will be essentially complete after 9 hours; the total dosage after 18 hours at 100 miles is predicted to be 80 roentgens.

The radiation dose "rem" is an acronym for "Roentgens equivalent man". There are some correction factors to convert "Roenthens" to "rem" but for the purpose of discussion (at least for gamma rays) they may be considered as equal to 1. For neutrons, the correction factor is greater than one, (e.g. 100 Roenthens neutron exposure produces more than 100 rems radiation dose, perhaps 1000 rems radiation dose).

In a rainy situation, practically all of the radioactive fallout might occur within the rain location, especially in the case of a lower yield detonation near or at the ground.

Building structures offer some protection against delayed radiation including fallout. A one-story frame house in the center of the house might offer a 2.3 protection factor for radiation. A basement of a one-story house might offer a 15 protection factor. A two story frame house basement might offer a 37 protection factor. The protection factor in subbasements of multistory buildings or in underground shelters (at least 3 feet of dirt on top) could be 1000.

Theoretically, a 1-kiloton TNT-equivalent fission explosion would produce a total gamma radiation of 550 gamma-megacuries 1 hour after the explosion. If all of the fallout particles were speadout uniformly over one-square mile of surface, assuming a photon energy of 0.95 Mev, the radiation dose at 3 feet above the surface is calculated to be approximately 3700 roentgens/hour. Gamma radiation from isotopes formed by neutron capture adds another 200 roentgens/hour giving 3900 roentgens/hour total. The BRAVO test (Bikini Atoll, 1 March 1954) indicated an integrated average value (after various corrections to measuring instrumentation) of 2400 roentgens/hour per square mile per kiloton TNT equivalent after one hour from the detonation, which compares with the 3900 roentgen/hour theoretical.

Certain isotopes from fission explosions are of particular concern because they get into the food chain. The two major ones are strontium 90 (half life 27.7 years) and cesium 137 (half life 30.5 years). Moreover these two isotopes have gaseous precursors as part of the radioactive decay chain allowing for dispersal over a large area, even worldwide. For every 1000 atoms undergoing fission, about 30 to 40 atoms of strontium 90 and 50 to 60 atoms of cesium 137 are eventually formed.

The threshold for lethality appears to be about 200 rem whole body exposure from a nuclear blast. Between 200 and 1000 rem exposure the probability of recovery is good at the low end of the scale but poor at the upper end. At 450 rem radiation exposure, 50% of the people will die within 60 days. Death at 1000 rem exposure is almost certain, the actual death may occur several weeks later even though the person may not feel discomfort initially. The lethality data do not include cancer deaths which occurred many years later. The peak incidence of leukemia among the survivors of the 1945 Japan nuclear blasts occurred in 1953.

Treatment for those exposed to radiation includes rest and use of antibiotics to minimize the incident of secondary infection.

What Can a Person Do to Protect Himself or Herself?

There were a very small number of survivors who were located near ground zero at the time of the 1945 Hiroshima and Nagasaki 20 kiloton nuclear blasts. These were people inside concrete or stone buildings shielded from most of the heat and radiation. If a nuclear attack is imminent, the lower floors and basements of buildings, especially reinforced steel and concrete buildings may be the safest place to go.

If caught out in the open and the brilliant flash of light associated with a nuclear blast occurs (much brighter than the sun at noon), the effects of gamma radiation, heat, and the blast can be reduced by dropping to the ground. It is too late to escape the deadly neutron radiation (It has already occurred during the first second). If possible, after the first minute of the nuclear blast, shelter should be sought against radioactive fallout.

After the first minute of the nuclear blast, the major dangers are from residual radiation including radioactive fallout, secondary fires, and from collapsing buildings.

References

Most of the information used in preparing this write up came from

S. Glasstone (ed.). 1962. The Effect of Nuclear Weapons. Prepared by the U.S. Department of Defense and published by the U.S. Atomic Energy Commission, Washington, D.C.. Libraries may have this government document under call number Y3.At7:2W37/962 (or another year edition).

Some additional information was obtained from

D. Stewart, 1985. Data for Radioactive Waste Management and Nuclear Applications. John Wiley and Sons, N.Y., N.Y.

There is a sketch of a nuclear weapon in the November 2002 issue of Scientific American.