THE EFFECTS OF NUCLEAR WEAPONS

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The vast majority of what is known about the effects of nuclear weapons in an occupied urban environment was learned at Hiroshima and Nagasaki. This information has been supplemented by that gathered at numerous nuclear weapons tests. For the purposes at hand, the effects of "nominal" weapons of 20 kilotons of TNT equivalent (KT), or less, will be given, while large "sophisticated" and thermonuclear weapons will be included only briefly. However, many people will want to supplement the materials provided today with a study of Sam Glasstone's *Effects of Nuclear Weapons.* The 1962 edition has more materials on the effects of small weapons than most others. For consideration by terrorists we assume that they do not have access to large, high yield devices but may get the materials to assemble a "home made" bomb. However, for any nuclear device, the following materials should be helpful.

Table 1 shows the distribution of fission energy for uranium-235, but for our purposes here we can assume that the numbers apply generally to other uranium isotopes and plutonium. Of course, after a very long time, all the fission energy appears as heat.

Table 1. Distribution of Fission Energy in units of MeV

Kinetic energy of fission fragments	165±5
Instantaneous gamma-ray energy	7±1
Kinetic energy of fission neutrons	5±0.5
Beta particles from fission products	7±1
Gamma rays from fission products	6±1
Neutrinos from fission products	10
Total energy per fission	200±6

Table 2 shows the comparison of fission energy, per mass, with the energy of TNT. Note that if one could have fissioned ALL of the uranium in the Hiroshima bomb, extrapolation from 56 grams/KT to over 50 kilograms would have resulted in a megaton explosion.

Table 2. Equivalents of Kiloton of TNT

Complete fission of 0.056 kg (56 g) of fissionable material
Fission of 1.45 x 10^{23} nuclei
10^{12} calories
4.2 x 10^{19} ergs
1.15 x 10^{6} kilowatt-hours
1.8 x 10^{9} British thermal units

Figure 1 is a bar graph, which shows the gross energy distribution for a typical nuclear explosion in air. This energy distribution changes for a near surface, surface, or subsurface burst which may be more likely for a terrorist attack. However, this presupposes that the terrorist does not have modern sophisticated weapons or the means to deliver them by air; this assumption may not be accurate, so some of this presentation will consider airbursts, albeit briefly due to time. For most of our time let us focus on a one KT device, detonated on the surface in an urban area. Depending on the makeup of the area, the major effects (casualties) will result from blast effects, either direct, including production of flying debris from direct blast, or indirect due to collapsing structures. Burns due to direct radiant energy would be expected to be limited to short distances due to structural shielding, but a resulting conflagration could produce a high burn trauma population.

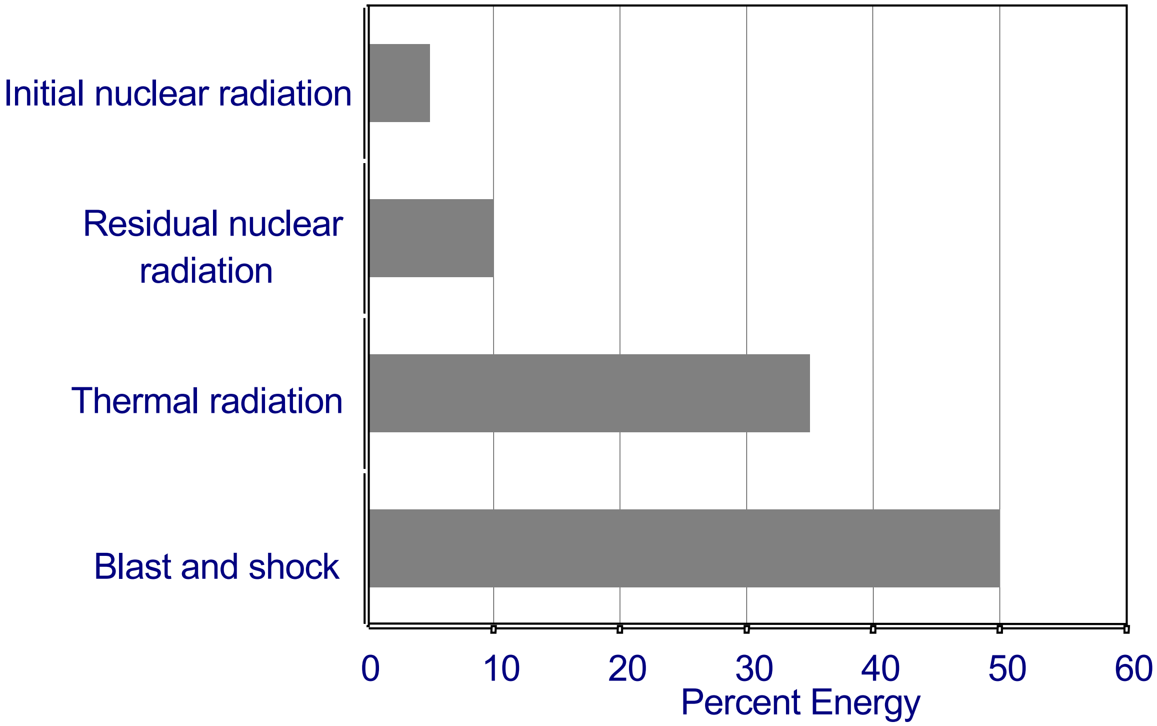

Figure 1. Distribution of Energy of an Air Burst below 100,000 ft

Let us look briefly at Hiroshima and Nagasaki to understand the effects one might encounter from a nuclear device.

Figure 2 shows how Hiroshima looked from an altitude of 30,000 feet just before August 6, 1945. **Figure 3** is a photo of Hiroshima a few days after August 6, 1945.

Figure 2 Hiroshima before

Figure 3 Hiroshima after.

Figure 4 is a photo of an identical "Littleboy" to that dropped on Hiroshima.

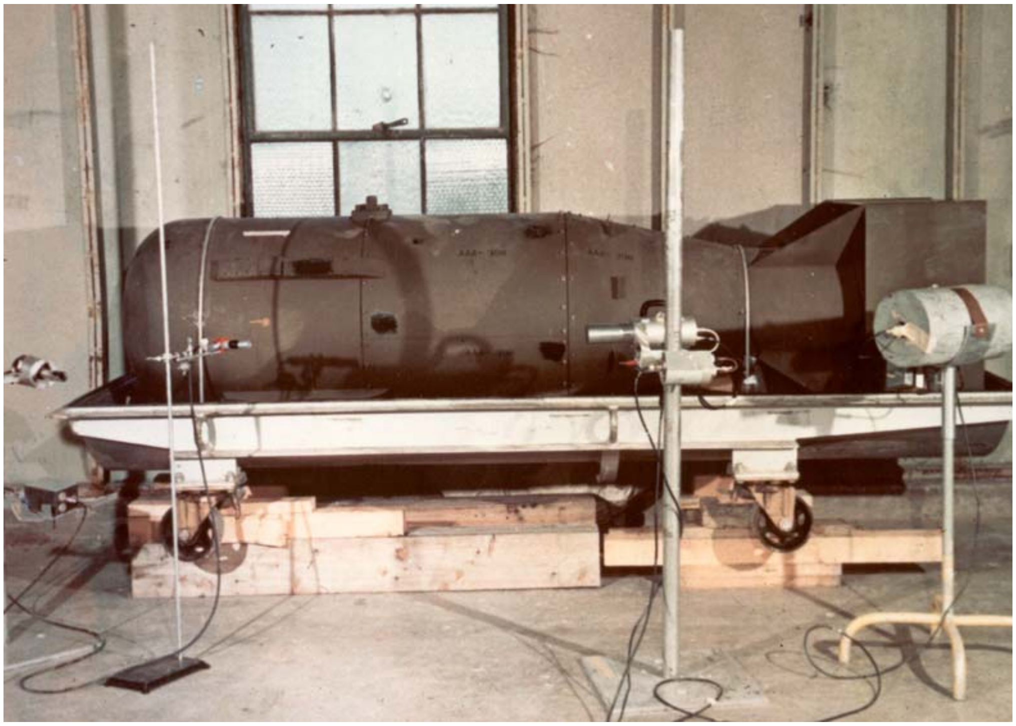

Figure 4 Littleboy

Figure 5 is a photo of "Fatman", identical to the bomb fired over Nagasaki on August 9, 1945. The effects were just as catastrophic except for some amelioration due to terrain effects.

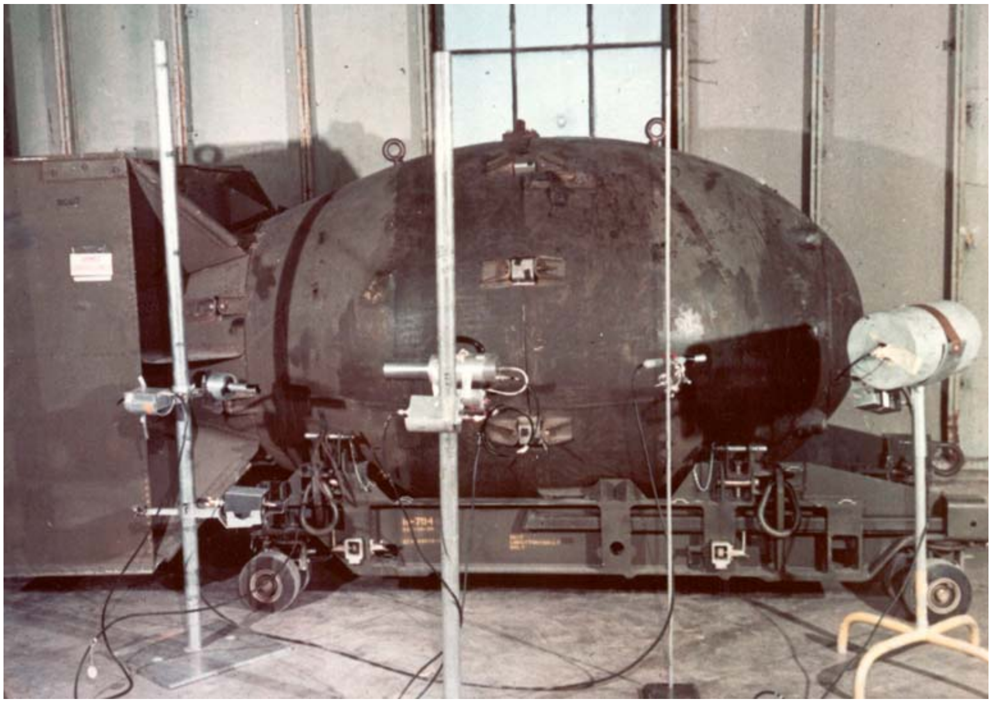

Figure 5 Fatman

Clearly, such effects on any population created by bombs of even one-tenth of the yield of the weapons fired over Japan, or less, must be avoided if we can possibly prevent such an event. Some knowledge of the effects of such weapons is essential because terrorist acquisition of nuclear devices is possible, however remote.

Repeating, the significant effects of nuclear detonations are, blast, thermal, and ionizing radiation. Emergency medical personnel are familiar with the effects of explosions that generate blast effects and thermal burns are encountered in many everyday emergencies. These effects require little discussion here except for some understanding of scaling nuclear yield and height of burst, and shielding due to terrain or other features. Glasstone provides excellent coverage of these effects and the circular slide-rule included inside the back cover allows one to analyze the effects for an extremely wide range of conditions. It is the less understood (by the public) phenomenon of radiation that is of most concern to the public and most likely to generate early panic. Much of the following discussion is aimed at the research on radiation doses and effects that might be expected from a nuclear explosion. There are two reasons for this; 1) public perception and 2) to demonstrate the range of research accomplished to get the level of understanding that we have, while keeping in mind that parallel studies were underway for blast and thermal effects. Actually, because measurement of the direct radiation from a nuclear detonation (*prompt radiation*) was not possible until the 1950's, research on blast and thermal effects got nearly a 10-year head start on prompt radiation studies. If detonated in an urban environment, considered most likely, the radiation environment differs markedly from that expected in the uncluttered weapons test environment, but the understanding of the effects must begin with these tests. Again, the effects of detonations of more than a few kilotons will be considered only briefly.

G. S. Hurst and co-workers, at the Oak Ridge National Laboratory (ORNL) in the early 1950's, made the major breakthrough in the measurement of prompt radiation from nuclear weapons. Special film badges and chemical dosimeters were being used with some success for the prompt gamma radiation, but Hurst's "threshold detector" system (TDS) provided for the measurement of prompt neutrons, both fast and thermal. The TDS measured the neutron fluence in five energy bands as shown in **Table 3**.

Table 3. Threshold detector energy bands, detectors, and measurement products

Detector	Neutron Energy
Au (*gamma activation*)	Thermal
^{239}Pu (*fission products*)	> 5 keV
^{237}Np (*fission products*)	> 0.75 MeV
^{238}U (*fission products*)	> 1.5 MeV
^{32}S(*n,p*)^{32}P (*beta*)	> 2.5 MeV

Figure 6 shows how different moderating materials affect the spectrum measured in this way. The HPRR was a solid metal cylinder (enriched uranium plus 10 % molybdenum) with no added moderator.

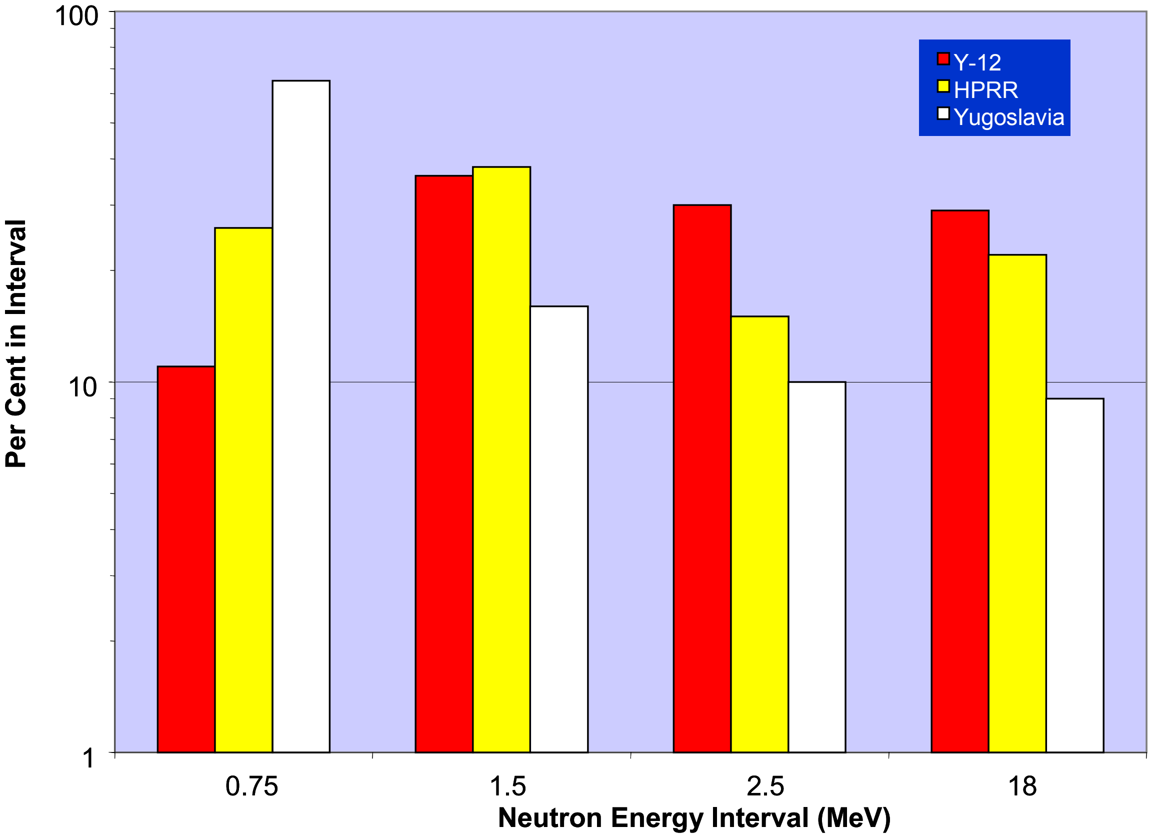

Figure 6. Energy spectra as measured by the threshold detector. (Unequal intervals)

Figure 7 shows the fluence from an airburst in the various energy increments and the related dose. After the initial scattering build-up the lines are parallel, demonstrating the spectral equilibrium. This proved to be important because of what was learned very early in weapons testing, i.e., after an initial scattering build-up, (about 250 meters in air), the spectrum comes to equilibrium and doesn’t change within the range at which significant doses are encountered. The individual elements of the graph are the fluence (or dose) times the square of the distance from the explosion, plotted as a function of distance from the detonation. Thus, once the shielding factors for the neutrons have been determined, they are insensitive to the distance from the explosion, relative to the neutron spectrum.

The major change in shielding with distance is due to the change in the angular distribution of the neutrons with distance. Consider a plane oriented such that it is perpendicular to a line from the point of interest to the detonation. If a collimated detector is pointed at an angle to this line to the detonation, the **polar angle**, the fluence varies with this angle as shown in **Figure 8.** This distribution is sharply pointed toward the near zero polar angles at distances of less than about the first 1/e change in intensity. The angular distribution then broadens to that shown at 1000 yards from an explosion in air above ground (greater that the fireball radius), and continues to broaden somewhat at greater distances. The important thing to note is that a person shielded behind a thick wall would still receive a significant dose at distances to more than 1000 yards due to radiation coming in from the angles greater than 90 degrees polar angle. The gamma radiation behaves similarly except that it is more peaked toward the small polar angles. It is still an important factor at distances of several relaxation lengths or e-folding distances.

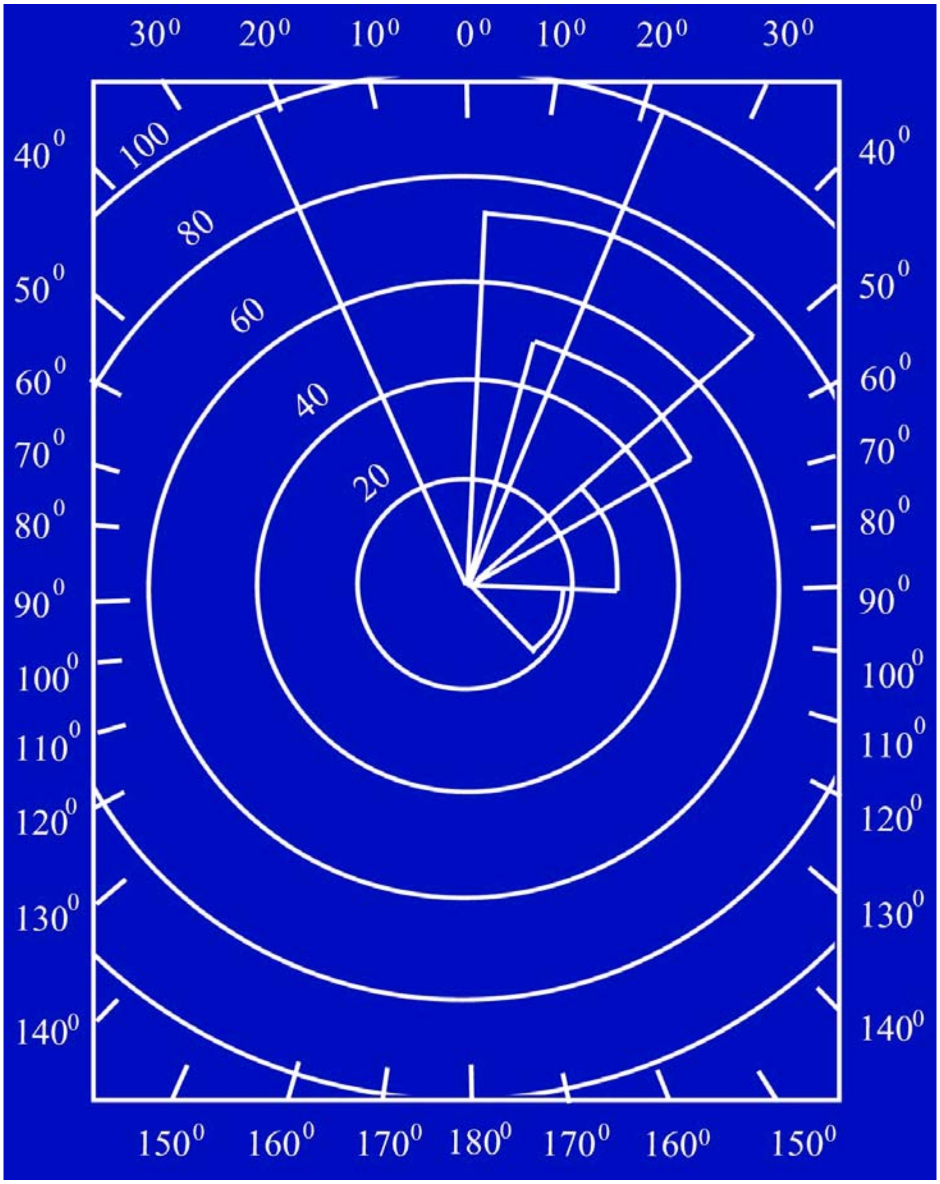

Figure 8. Percent of neutron dose with fluence

This brief description of some of the aspects of nuclear weapons radiation is indicative of the vast body of information available. However, some attention is needed here for **residual** radiation. Within the closest 500 yards to the detonation of a one KT device, there will be radioactive bomb debris and activation products. Within the first hour after the detonation the exposure rate will exceed 50 R/Hr. Both the fission products and the activation products will decrease rapidly, but may exceed five R/Hr for at least 12 hours. Emergency personnel should be scheduled for short entries during the first day, the permitted exposures depending on the urgency of the need for their entry. It is assumed here that such emergency entry personnel would be allowed up to the traditional 25 Rem. These levels can be scaled approximately linearly with yield until the yield reaches 20 Kt or more at which point there will be little need to enter areas greater than about10 R/Hr. due to near total distruction and loss of life within one thousand yards of ground zero. Based on the experience in Japan, there may well be many survivors in the basements and sub-basements of large building who may be able to get out of the buildings and walk away. Consideration of much bigger bombs leads to a whole different set of factors. Fired at near the center of a metropolitan area, megaton bombs would essentially destroy an area encompassed by a ten-mile radius. Blast damage would be significant to 20 miles and thermal flash burns even farther. In addition, fallout in the downwind direction would be in the tens of R/Hr for at least a hundred miles. Evacuation and /or shielding of personnel and animals would be required. To a rough approximation the old factor of a times ten reduction for a times seven increase in time could be used to estimate the decrease in exposure rate with time. For this type of explosion we need to review all the old **Cold War** Civil Defense documents; these are extensive and cover all aspects of a nuclear war as studied in the 50's, 60's, and 70's. Even the use of KI might be advised.

A little detailed consideration of the blast effect of the more likely one KT ground burst is needed. The Civil Effects Branch of the old Atomic Energy Commission (AEC), conducted extensive studies over several weapons tests in the 1950's. Most of the studies of effects on structures, vehicles, and a vast assortment of other targets were for above ground tests of nuclear devices in the one to 50 kiloton range. Most of what we know about surface bursts is extrapolated from airbursts. There were, however, extensive studies of underground and underwater bursts so that structural damage can be calculated rather well for such explosions. For most effects some assumptions must be made for surface bursts, but due to the many factors that are specific to an unspecified targeted area, the uncertainties due to some general assumptions are not likely to be of great importance. Let us now look at "cratering", an effect that has been studied directly at several surface detonations. **Figure 9** shows the characteristic dimensions of the crater for a surface explosion. Note that there are two sets of depths and radii (or diameters) shown, the first being the actual size of the hole in the ground and the second the actual fractured zone. A surface burst is one at five feet or less above ground. For this situation, the horizontal and vertical dimensions of the crater increase approximately as the cube root of the yield in kilotons. A one KT explosion will produce, in dry soil, a hole about 130 feet in diameter with a throw-out "berm" extending an additional 60 feet. The crater depth would be about 30 feet in dry soil, and the dimensions would generally be somewhat less for rock-laden surfaces. For water saturated soils the dimensions would the appreciably greater though the final depth would be decreased with time due to the slumping of the wet materials. As the height of the detonation increases above ground, "the dimensions of the crater vary in a rather complicated manner, because of the changes of the mechanism of crater formation" (Glasstone p 277).

$$Volume\ of\ crater = \frac{\pi D_a^2 H_a}{8}$$

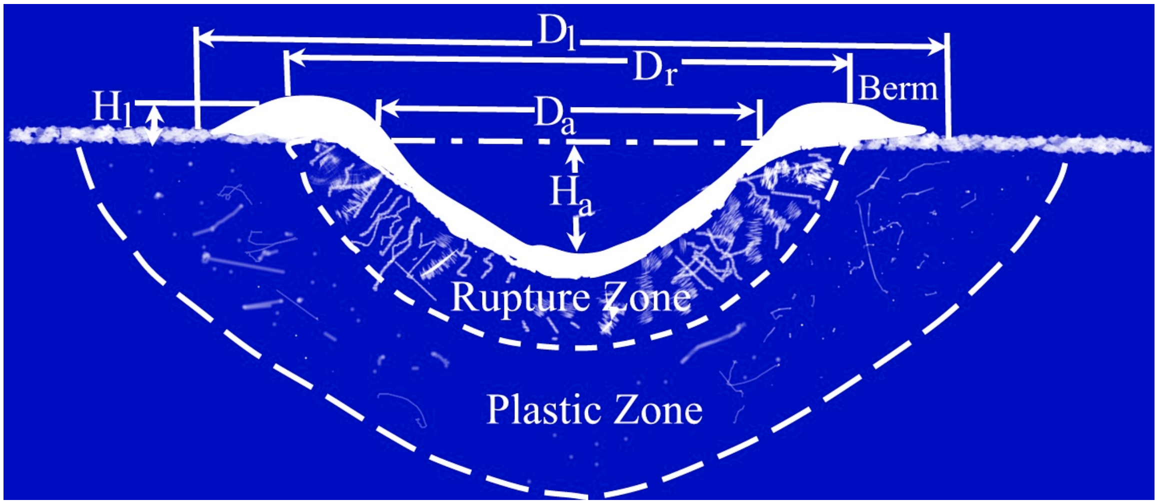

Figure 9. Cratering effects of a surface burst.

References

Glasstone, Samuel, Ed. *The Effects of Nuclear Weapons*, Revised Edition, Published by the U.S. Atomic Energy Commission, April 1962

Hurst, G. S., J. A. Harter, P. N. Hensley, W. A. Mills, M. Slater, and P. W. Reinhardt, Techniques of measuring neutron spectra with threshold detectors—tissue dose determination, *The Review of Scientific Instruments,* Vol. 27, No. 2, 153-156, 1956.