Chapter 2

Fallout from Nuclear Weapons

Contents: *This chapter provides an overview of fallout production mechanisms and a brief review of the history of worldwide nuclear weapons tests.*

2.1 Fallout Production Mechanisms

The explosion of a nuclear weapon releases energy by two processes – fission and fusion. Fission releases energy by splitting uranium or plutonium atoms into two or more smaller atoms. In fusion a fission bomb forces the combination of tritium or deuterium atoms into larger atoms, producing a more powerful explosion. The explosive energy is expressed in kilotons (kt) or Megatons (Mt) of TNT equivalent. The explosion creates three types of radioactive debris (fallout): fission products, activation products, and fissionable material used in the construction of the bomb that did not fission during the explosion process.

2.1.1 Fission Products

The fission of 52 grams of plutonium will split 10^{23} plutonium atoms and release one kiloton of energy. Every fission creates an average of two radioactive fission fragments and the radionuclide identity of each of these fission fragments varies. The fission process that takes place when a nuclear weapon is detonated creates a mix of over 900 different fission products (England and Rider 1994). The mix of fission products is very well known, as are the half-lives of all the radioactive fission products. If the energy from fission (fission yield) of an explosion is known, known fission product yields (England and Rider 1994) can be used to calculate the quantity of each fission product at a specified time after the burst.

Of the fission products created, 77 are stable and have no public health implications. Only 165 radioactive fission products have half-lives longer than one hour. Some fission products are not actually created by the initial explosion, but are created later from the decay of other fission products. If the fission yield and the time since the weapon exploded are known, the quantity of fission products present at that time can be calculated (Whicker and Schultz 1982).

In a fusion weapon, total yield and the fission yield (the fraction of energy released that is caused by fission) are both required to calculate the amount of fission products created by the weapon's detonation. The information on the fission yields remain classified today. Without it, we can only crudely estimate the amounts of fission products created in weapons tests.

2.1.2 Activation Products

The detonation of a nuclear weapon, fission or fusion, releases a massive shower of neutrons. These neutrons strike, and are absorbed by, surrounding materials – the structural materials of the bomb itself or the soil or water over which the bomb is detonated. Atoms of these materials that absorb neutrons and become radioactive are called activation products. The radionuclides that actually result from the activation process depend on the materials used to make the bomb, the surface over which the test is conducted, and the height of the explosion.

All nuclear weapons detonations create large quantities of carbon-14 (^{14}C) from neutron interactions with nitrogen in the atmosphere. A detonation also releases large quantities of tritium (^{3}H). The location of the test and the type of soil will determine what other activation products to expect.

2.1.3 Dispersal of Unfissioned Material

All nuclear weapons use some combination of uranium-235 (^{235}U), uranium-238 (^{238}U), and plutonium-239 (^{239}Pu) as the source of fission energy. Even in the most efficient modern weapons, some of the fissionable material in the bomb does not fission. A typical nuclear weapon will use both plutonium and uranium as the source of fission energy, so every nuclear weapon detonation scatters large quantities of uranium, and most of them also scatter plutonium. The quantity and type of fissionable material used in a weapon and the efficiency of the weapon are also classified, so we can only estimate the amount of plutonium and uranium scattered by weapons tests.

2.1.4 Physical Characteristics of the Radioactive Debris

A nuclear explosion creates a large fireball. Everything inside the initial fireball, earth or water, is vaporized. The fireball rises rapidly and expands as it cools. As the fireball rises, it incorporates soil or water. Eventually, the fireball loses buoyancy and stops rising. The kinetic energy of the incorporated soil or water will cause those particles to start spreading horizontally, increasing the size of the cloud created by the fireball at the top. This process gives the cloud its characteristic mushroom shape (Glasstone 1957). The top of a cloud from a large yield weapon may be as high as 140,000 feet, and the cloud may be 50 miles in diameter.

The vaporized material in the cloud condenses as it cools, creating a mix of fission and activation products and condensed material. The fission product decay chains contain gases and solids, some with very short half-lives (Glasstone 1957). Gases tend to stay in the atmosphere, while solids attach more readily to the condensate, some of which fall rapidly to the ground by sedimentation. Fireballs from large tests cool more slowly than fireballs from small tests, while the decay of the fission products always proceeds at the same rate. For this reason, the fission product mix in the fallout after a large explosion will be different from that after a small explosion. Any alteration of the fission product mix is called fractionation. Because of fractionation, actual measurement of the fission product mix made after each individual test is required to determine the exact nature of the fallout from that test.

2.1.5 Deposition of Radioactive Debris

Large particles of fallout tend to settle locally, while small particles and gases may travel around the world. Rainfall washes out fallout in the troposphere (approximately the first 10 km of the atmosphere), causing localized high concentrations many miles from the test site. Large atmospheric explosions will inject radioactive material into the stratosphere (the layer of the atmosphere immediately above the troposphere) where it will remain for years. Even today, small quantities of fallout created during the atmospheric testing period are still being deposited on the surface of the earth. Deposited material is typically measured in Becquerels (Bq), a measure of radioactive decay corresponding to one disintegration per second, and is reported per square meter (i.e., Bq m^{-2}).

2.2 Brief Review of Nuclear Weapons Tests

2.2.1 Atmospheric Tests

The first test of a nuclear weapon was in the atmosphere on 16 July 1945, in southeastern New Mexico. Following this test, nuclear bombs were dropped on Hiroshima and Nagasaki, Japan, in August 1945. These bombs leveled both cities and ended World War II in the Pacific. Subsequent testing of nuclear weapons in the atmosphere continued until 1980, with periods of intensive testing in the years 1952-1954, 1957-1958 and 1961-1962. A limited nuclear test ban treaty (Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space and Under the Water) was signed in August 1963, and much less frequent testing in the atmosphere occurred subsequently. Over 500 atmospheric nuclear explosions have occurred at a number of locations. Five countries have acknowledged atmospheric nuclear weapons tests: the United States, the former Union of Soviet Socialist Republics (U.S.S.R.), the United Kingdom, France, and China. Test weapons were placed on barges in the ocean, suspended from balloons, placed on wood or steel towers, exploded in outer space, placed on the ground surface, dropped from airplanes, and used to create large craters in the earth, as described in Section 2.2.3.

2.2.2 Underground Tests

In addition to the atmospheric tests, about 1,400 nuclear test explosions have been carried out beneath the earth’s surface, including some by India and Pakistan. After 1963, when the limited nuclear test ban treaty banning atmospheric tests was negotiated, underground testing became more frequent. A well-contained underground nuclear explosion delivers extremely low doses to any group of people. Even though there have been occasions when radioactive materials leaked from underground tests, the environmental and health impacts of these explosions are much lower than those from the atmospheric tests.

2.2.3 Cratering Tests

In addition to the atmospheric and underground tests, the United States conducted a series of cratering tests to assess the feasibility of using nuclear weapons as excavation tools. Glasstone (1957) provides details of crater size and tons of earth removed as a function of yield and depth. The fallout from these tests tends to be much more of a local phenomenon than is the case for atmospheric tests.

2.3 List of Nuclear Weapons Tests

There are several published databases and printed books listing all nuclear weapons tests in the world. There are some significant differences in the number of tests and yields of the test between these sources. There are several reasons for these differences:

- Sources are not always consistent in what they count as a test. Sometimes conventional explosives were used to blow up a warhead, testing its safety from inadvertent detonation or transportation accidents. Called safety experiments, those tests scattered plutonium locally, but created no fission or activation products.

- Sometimes warheads were used in physics experiments that may or may not have created fission products. These experiments, called by different names, may or may not be included in a country's list of reported nuclear weapons tests.

- Some sources consider all nuclear weapons tests conducted on the same day in the same place as one test. Others count weapons at the same time only if they are in different holes at the test site. A series of tests may be conducted on the same day in the same location at different times. (DOE 1992; 1994)

- Some sources used seismic data, so they may list as a test a conventional explosion at a nuclear test site (Lawson 1998; Australia 2000).

- Locations introduce another source of confusion. Some documents list different test sites for tests (Mikhailov 1999; Kirchman and Warner 2000). Test sites in the former U.S.S. R. are listed in some publications by test site name (Lawson 1998) while others may list the administrative district (Mikhailov 1999). Some list only the general latitude and longitude (PIDC) while others give the specific locations (Mikhailov 1999; DOE 1992; Lawson 1998).

Figure 2.1 shows the locations where nuclear weapons tests totaling greater than one megaton in yield were conducted prior to 1963 (PIDC). Table 2.1 presents a summary developed by the United Nations Scientific Committee on the Effects of Atomic Radiation of the number and yield of atmospheric nuclear weapons tests (UNSCEAR 2000). Safety tests, underground tests, and cratering tests are not included in this list. As noted earlier, the number of megatons, not the number of tests, determines how much radioactive material is created during a detonation. Table 2.1 shows that UNSCEAR estimates that the total yield of all nuclear weapons tested in the atmosphere is approximately 440 Mt. If one uses the highest estimates that have been published for the yield of individual tests, the total is approximately 604 Mt. This uncertainty will likely not be resolved until more information on nuclear weapons testing is declassified.

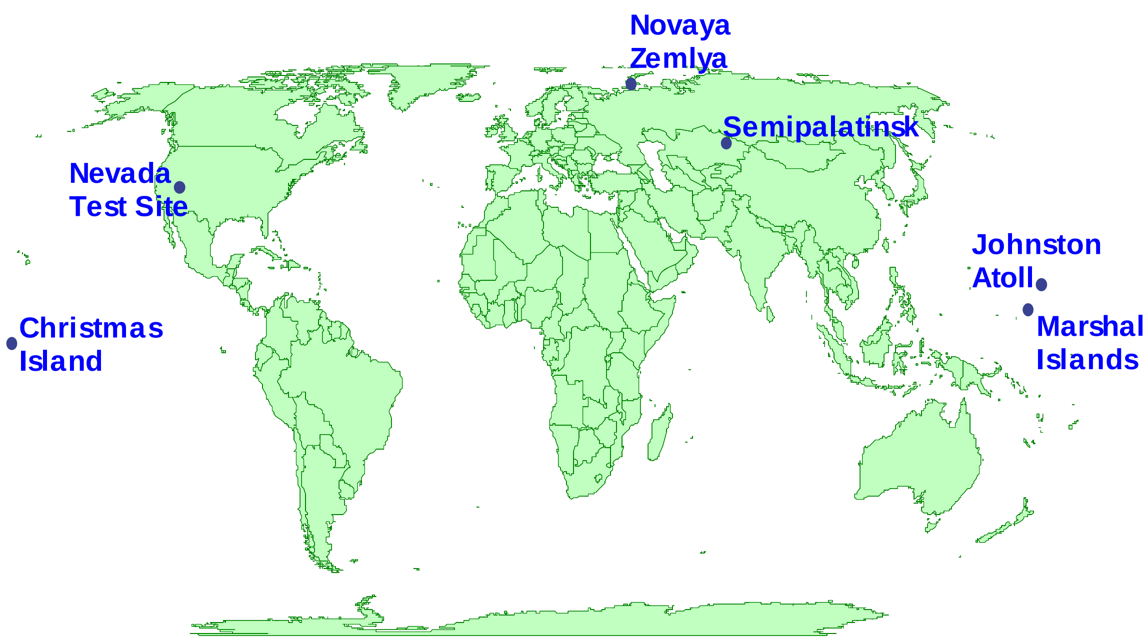

Figure 2.1. Locations of sites where tests were conducted prior to 1963 with greater than one megaton total explosive yield.

Table 2.1. A summary of atmospheric nuclear tests by major site and country (UNSCEAR 2000)

Country	Test Site (see Figure 2.1)	Number of Tests Conducted	Yield (megatons)
China	All	22	21
France	All	45	10
United Kingdom	Christmas Island	6	7
	Others	15	1
United States	Nevada	86	1
	Marshall Islands	69	109
	Christmas Island	24	23
	Johnston Atoll	12	21
	Others	6	0.1
Former U.S.S.R.	Novaya Zemlya	91	239
	Semipalatinsk	116	7
	Others	12	1
Totals		543	440

2.4 Conclusions

The detonation of a nuclear weapon in the atmosphere releases three types of radioactive debris into the environment. Depending on the size and type of weapon detonated, some of this fallout may travel great distances before depositing on the earth and exposing people to radiation. The next two chapters evaluate the dose and risk to the American people as a result of exposure to fallout from nuclear weapons testing. Appendix D discusses the need to preserve documents that would be useful to resolve some of the issues raised in this Chapter, as well as other questions related to historic fallout exposures, should additional fallout-related work ever be mandated.

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