1 Physical damage from the atomic bombings

Summary

The atomic bomb dropped on Hiroshima utilized uranium-235 (U-235) and released energy equivalent to 16 kilotons (kt) of TNT. The atomic bomb used on Nagasaki employed plutonium-239 (Pu-239), detonating with a force equivalent to 21 kt of TNT. The energy distribution comprised 50% from blast force, 35% from thermal rays, and 15% from radiation.

At the instant of explosion, extremely high temperatures of several million degrees Centigrade and intense pressure of several 100,000 atmospheres resulted in the formation of a fireball. After 0.3 seconds had passed, surface temperatures at the leading edge of the fireball rose to around 7,000 °C, with surface temperatures at the hypocenters reaching between 3,000 and 4,000 °C. A shock wave developing from the edge of the fireball turned into a blast, pushing the atmosphere at supersonic speeds. This blast had traveled 1 km from the hypocenter two seconds after the explosion and 2 km from the hypocenter 4.5 seconds after the explosion. Exposure to A-bomb radiation is categorized into “initial radiation exposure” from the instant of the explosion and the rising fireball, and “residual radiation,” the latter including induced radioactivity from neutron irradiation that had developed in soil and the like near the hypocenters and fallout radioactivity depositing on the ground’s surface in the form of, for example, ‘black rain.’

1 Detonations

At 8:15 am on August 6, 1945, an atomic bomb exploded over Hiroshima at a height of 600 m above Shima Hospital, located 160 m southeast of the Atomic Bomb Dome (the former Hiroshima Prefectural Industrial Promotion Hall). At 11:02 am on August 9, an atomic bomb detonated over Nagasaki at a height of 503 m above tennis courts located at 171 Matsuyama-machi, Urakami, in the northern part of the city.

2 Energy

The atomic bomb dropped on Hiroshima (‘Little Boy’) utilized U-235 and released energy equivalent to 16 kilotons (kt) of TNT. The atomic bomb used on Nagasaki (‘Fat Man’) employed Pu-239, detonating with a force equivalent to 21 kt of TNT. Different from conventional bombs, these bombs were characterized by not only their blast force but also powerful thermal rays and radiation. The distribution of these energies comprised 50% from blast force, 35% from thermal rays, and 15% from radiation (Fig. 1).

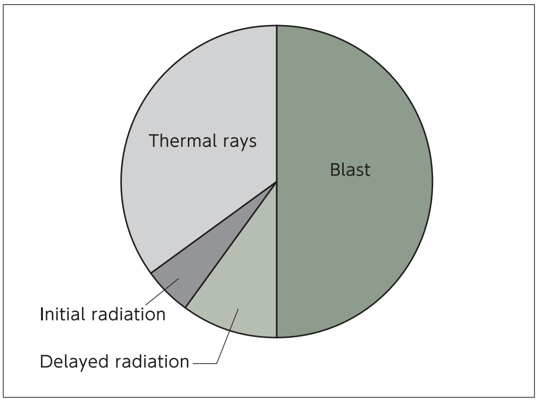

Fig. 1 A-bomb energy distribution
(Glasstone S, Dolan PJ. The Effects of Nuclear Weapons, Third Edition, 1977, U.S. Government Printing Office, Washington DC)

A Blast

At the instant of explosion, intense pressure of several 100,000 atmospheres resulted in the formation of a fireball. A shock wave developing from the edge of the fireball turned into a blast, pushing the atmosphere at supersonic speeds. This blast had traveled 1 km from the hypocenter two seconds after the explosion and 2 km from the hypocenter 4.5 seconds after the explosion, reaching a distance of around 11 km 30 seconds after the explosion. A strong outward wind followed the shock wave, with speeds reaching 280 m/s in the area around the hypocenter and 28 m/s at a point 3.2 km away. When the outwardly moving wind abated, a more moderate wind moved inward from the outside, resulting in a rising air current and the formation of a mushroom cloud column at the hypocenter. Within 2 km of the hypocenter, wooden structures were devastated by the shock wave and blast. Within 0.5 km, even many reinforced concrete buildings were destroyed.

B Thermal rays

At the instant of explosion, a fireball formed in the air, resulting in maximum temperatures of several million degrees Centigrade. After 0.3 seconds had passed, surface temperatures of the fireball reached around 7,000 °C, with ground temperatures at the hypocenters reaching between 3,000 and 4,000 °C. Calculations have shown that the hypocenter was exposed to thermal energy of 120 cal/cm2, and points 3.5 km from the hypocenter to 2.2 cal/cm2. Within three seconds of the explosion, 99% of the thermal rays emitted from the fireball had affected the ground below. Of the thermal rays from the fireball, infrared rays had the most significant effect on the human body. Wooden materials charred by the thermal rays were seen up to about 3 km from the hypocenter in Hiroshima and up to around 3.5 km in Nagasaki. Skin exposed to the thermal rays was burned up to 3.5 km from the hypocenter in Hiroshima and up to 4 km in Nagasaki. Persons within about 1.2 km from the hypocenters in both cities not protected by shielding died due to burns from the thermal rays, with an estimated 20-30% of all deaths due to such effects. Figures 2 and 3 show the areas around the hypocenters of Hiroshima and Nagasaki, respectively, that were incinerated by the thermal rays and within which buildings were destroyed by the blast.

C Radiation

A-bomb radiation from the midair explosions is classified into initial radiation, comprising instantaneous radiation released at the moment of the explosion as well as radiation emitted within one minute of the explosion from fission products in the rising fireball (5% of total energy), and delayed radiation emitted from fission products after one minute had elapsed following the explosions (10% of total energy). The majority of the fission products rose high into the upper atmosphere, with a portion becoming localized radioactive fallout settling on the ground together with black rain and so on. Exposure to A-bomb radiation people experienced can therefore be divided into two types: exposure to initial radiation, and exposure to residual radiation comprising radioactive fallout and induced radiation due to soils and the like near the hypocenters being made radioactive from neutron irradiation.

(1) Initial radiation

The major components of the initial radiation comprised neutrons and γ rays. There have been several estimates to date of the initial radiation doses, including those based on the Dosimetry System 1986 (DS86), which resulted from the Joint U.S.-Japan Working Group on the Reassessment of Atomic-bomb Dosimetry's 1987 revision of T65D, a provisional dosimetry system established in 1965. The Group released dose estimates calculated with the new Dosimetry System 2002, or DS02 (Table 1), in 2002.

(2) Residual radiation

Residual radiation is categorized into two types: induced radiation and radioactive fallout. The initial radiation (neutron radiation) collided with atomic nuclei of soils and building materials, causing atomic reactions, which in turn created induced radioactivity, a process that emitted γ rays and β particles. As the fireballs rose into the sky and cooled, a portion of the fissile materials and fission products contained therein fell to the ground with rain as fallout. Since rain falling at that time was dark, it is commonly referred to as black rain.

It is difficult to express in general terms the degree of damage caused by residual radioactivity, because the behavior of individuals after the bombing has to be taken into consideration. According to calculations based on DS02, external radiation dose from γ rays due to induced radioactivity would have reached 1.2 Gy in a hypothetical situation in which someone had stayed for an indefinite period in the vicinity of the hypocenter immediately after the bombing. If that person had entered the hypocenter area one day after the bombing and stayed one full day, exposure would have measured 130 mGy. Had someone entered the city one week after the bombing and stayed for one week, the dose level is estimated to have been 2 mGy. However, such calculations can differ substantially depending on ground composition and surrounding conditions.

When the impact on internal organs of radioactivity ingested into the body is considered, β particles and α particles, in addition to γ rays, are said to have had an effect. Persons who entered the city and engaged particularly in the handling of corpses and building materials directly after the bombing may have been exposed internally through inhalation of dust containing induced radioactivity. Because most of the induced radioactivity had short half-lives, however, the amount of exposure dropped rapidly with time.

Figure 4 illustrates the physical effects in Hiroshima after the explosion. Figure 4a shows the situation of the fireball and thermal rays early after the detonation; Figure 4b the early fireball, blast, and thermal rays; and Figure 4c the situation surrounding the initial radiation. Figures 4d, e, and f illustrate the mushroom cloud configurations and heights after one minute, two to three minutes, and 20-30 minutes, respectively.

Fig. 2 Atomic-bomb damage in Hiroshima
(1990, Atomic Bomb Survivors Relief Department, Public Health Bureau, the City of Hiroshima)

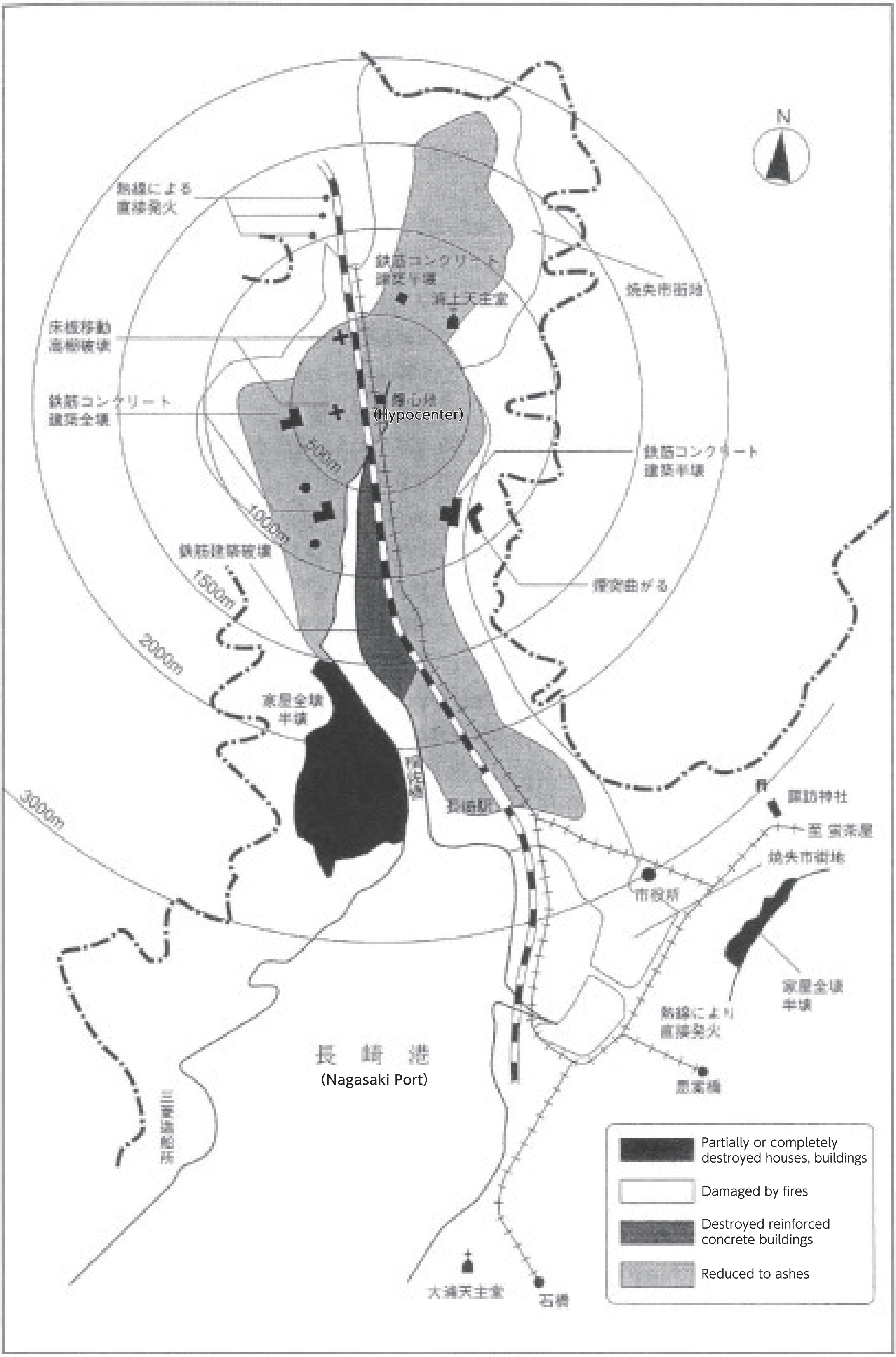

Fig. 3 Simplified map of atomic-bomb damage in Nagasaki
(1996, Atomic Bomb Survivors Affairs Department, the City of Nagasaki)

Table 1 Initial radiation doses (based on DS02)

Distance from hypocenter (m)	Distance from epicenter (m)		γ rays (Gy)	Neutrons (Gy)
0	Hiroshima	599	120	34.5
	Nagasaki	502	328	18.8
500	Hiroshima	780	35.7	6.48
	Nagasaki	709	83.0	2.97
1,000	Hiroshima	1,166	4.22	0.26
	Nagasaki	1,119	8.62	0.125
1,500	Hiroshima	1,615	0.527	0.00904
	Nagasaki	1,582	0.983	0.00511
2,000	Hiroshima	2,088	0.0764	0.00039
	Nagasaki	2,062	0.138	0.00024
2,500	Hiroshima	2,571	0.0125	0.00002
	Nagasaki	2,550	0.0228	0.00001

(Young RW, Kerr GD(eds). Reassessment of Atomic Bomb Radiation Dosimetry for Hiroshima and Nagasaki. Dosimetry System 2002, Radiation Effects Research Foundation, 2005)

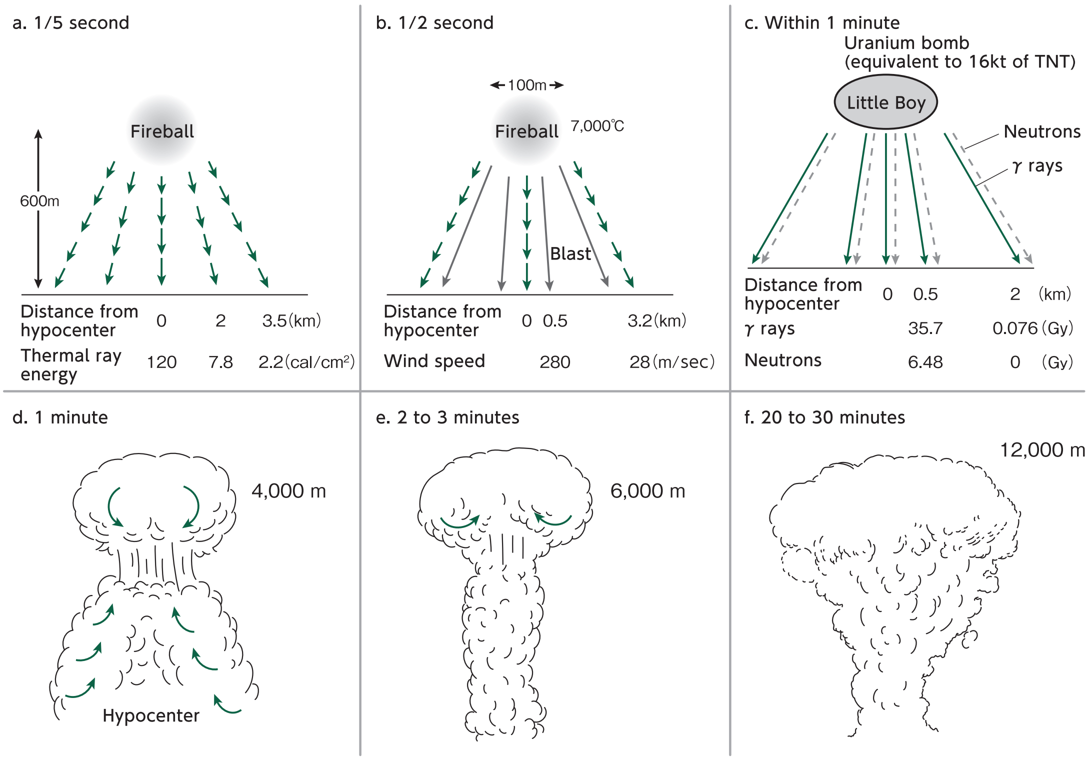

Fig. 4 Physical effects after the Hiroshima atomic bombing

(1947, Hiroshima District Meteorological Observatory; 1988, the Prefecture of Hiroshima; 1950, Hirschfelder et al.)