“Research Study on Impacts of the Use of Nuclear Weapons in Various Aspects”
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Research Structure

<Radiology>	(Hematology, Radiation epidemiology)
Masao Tomonaga (Project Manager)	Director, Japanese Red Cross Nagasaki Genbaku Hospital
<Radiology>	(Hematology, Radiation Biology)
Nanao Kamada	Professor Emeritus, Hiroshima University Chairman, Hiroshima A-Bomb Survivors Relief Foundation
<Radiation Physics>	(Radiation physics)
Hiromi Hasai	Professor Emeritus, Hiroshima University
<Disaster Prevention>	(Diasaster Management Information systems)
Haruo Hayashi	Professor, Research Center for Disaster Reduction Systems, Disaster Prevention Research Institute, Kyoto University
<Economics>	(Macroeconometrics model analysis, economic forecasting, applied general equilibrium model analysis)
Kanemi Ban	Professor, Graduate School of Economics, Osaka University

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Purposes of Research

At the 2010 NPT (Nuclear Non-Proliferation Treaty) Review Conference, governments officially expressed their “deep concern at the catastrophic humanitarian consequences of any use of nuclear weapons.” Since then, active discussions took place on the humanitarian aspects of nuclear weapons, and in March 2013, the Norwegian government sponsored the First Conference on the Humanitarian Impact of Nuclear Weapons in Oslo, the first such conference in the world. In February 2014, the Mexican government hosted the Second Conference in Nayarit. The primary purpose of this research is to study the humanitarian impact of nuclear weapons through the consideration of the actual circumstances of the atomic bombs dropped on Hiroshima and Nagasaki that still continue to give various effects from diverse angles by experts in physics, medicine, disaster engineering and macroeconomics from the perspectives of Japan, the world’s only A-bombed country that experienced the enormous damage of nuclear detonation after suffering the nuclear attacks not only once but twice. As the second purpose of research, we attempt to estimate the humanitarian consequences of explosions of nuclear weapons in the modern period by examining various impacts of nuclear detonation, assuming a nuclear attack on a modern city with infrastructures much different from those of 69 years ago following remarkable progress in construction methods and information technology, etc., based on data on Hiroshima and Nagasaki as well as the Effects of Nuclear Weapons, a report published by the U.S. government in 1977.

The views and statements expressed in this research study do not necessarily represent the views and position of the Japanese government.

Summary

1. The physical and medical impact from using nuclear weapons

Japan is the only country in the world to have experienced the ravages of a nuclear attack, as it did in World War II. The cities of Hiroshima and Nagasaki were annihilated by 16 kiloton and 21 kiloton atom bombs, respectively. An estimated 140,000 people in Hiroshima and an estimated 73,000 people in Nagasaki died either instantly or within five months. This killing power came from a combination of the three elements of atom bomb energy: the blast, heat rays, and radiation. Over 90% of the total area of Hiroshima and over 70% of the total area of Nagasaki were destroyed. All urban infrastructure, including hospitals, schools, city halls, factories, and commercial buildings, collapsed. Traffic, electrical, communication, and broadcasting equipment was either completely or partially destroyed. There were therefore almost no meaningful rescue operations performed by rescue personnel. Only the barest of medical assistance was provided due to the death of so many doctors, nurses, and pharmacists. The small number of survivors somehow managed to make it by train to hospitals in neighboring areas. However, many of these people died in quick succession due to severe external injuries or acute radiation sickness.

This study estimates the number of dead, wounded, and subsequent excess number of leukemia and other cancer sufferers (as cancer cases unrelated to radiation will occur with a certain frequency in the population, the excess number of cancer cases clearly attributable to radiation was calculated) in terms of human suffering, infrastructure damage, and economic ruin should a modern city (with an supposed population of 1 million) were to be hit with another 16 kiloton atom bomb like the one dropped on Hiroshima. It was assumed that the fictional city was flat like Hiroshima and that the blast occurred close to the center, 600 m above the ground. In addition to data on Hiroshima, various data from “The Effects of Nuclear Weapons” published by the U.S. government in 1977 was referenced for this research. The same estimates were made for the explosion of a 1-megaton hydrogen bomb at a height of 2400 m in the same city.

For the atom bomb, assuming a population of 480,000 within a 4.5 km radius of ground zero during the day, estimates found there would be 66,000 dead and 205,000 injured with a burst height of 600 m. Regarding the reason why there are fewer dead in the modern city compared to the 140,000 dead among the 370,000-person population of Hiroshima in 1945, it was estimated that fewer people inside buildings would die due to the remarkable advances that have been made in making buildings stronger. The number of injured is higher than in Hiroshima. Although additional deaths would occur among the injured due to radiation injuries, estimating this number is difficult. It is assumed that almost all urban infrastructure would be destroyed, rigid structures half destroyed, and all city functions crippled.

Following the aforementioned immediate damage, the aftereffects on the human body wrought by

atom bomb radiation would begin to appear after about three or four years. Leukemia cases would continue to occur for 10 to 20 years. For 30 to 60 years (the bomb survivor's lifetime), cases of those developing some form of cancer would continue. From among the 155,000 affected by radiation within a 2.8 km radius, there would be 220 excess cases of leukemia and 12,000 excess cases of some form of cancer. There is also rising concern regarding the genetic consequences for the children (offspring of survivors) of bomb victims (there is no scientific data in this regard for either Hiroshima or Nagasaki).

In the case of a 1-megaton hydrogen bomb, everyone in the fictional city of 1 million as well as 400,000 people in surrounding areas would be hit directly, resulting in 370,000 dead and 460,000 wounded (although there is a high possibility that many of the injured would later die, this study does not provide such estimates). The radius is only 3 km in this case as the high burst height would result in less radiation reaching the ground. The shock wave and heat rays would destroy or reduce to ashes everything within an 18 km radius. Consequently, only 36,000 people would receive radiation exposure, far fewer than in the case of an atom bomb. Excessive cases of leukemia and cancer (70 and 650, respectively) are also lower than with atom bombs.

As can be seen, compared to Hiroshima and Nagasaki in 1945, there would be a far greater extent of human lives lost and urban infrastructure damaged were by the smallest modern-day versions of an atom or hydrogen bomb to be dropped on a city of today.

Such nuclear weapons make no distinction between civilians and soldiers, and bring destruction to both children and the elderly alike. Those who barely survived the bomb itself live for the rest of their lives in fear of developing leukemia or cancer. This study thus finds that nuclear weapons are weapons with serious physical and medical consequences, whether in the short, medium, or long term.

2. Impact on social infrastructure of the use of nuclear weapons (estimated damage to the infrastructure of a modern city)

This paper conceptualized and considered as follows, the damage that a nuclear attack would cause to a city. A city is assumed to be a place where a great number of diverse people live in a densely packed community that is composed of three constituent elements: social infrastructure, housing, and human activity. It is thought that a nuclear attack would produce short-term as well as medium- to long-term effects through the combination of four types of damage caused by the blast wave, heat rays, radiation, and electromagnetic waves. Short-term effects were envisioned as physical destruction caused by the blast wave, fires caused by the heat rays, and the impairment of power transmission facilities and electronic devices caused by the electromagnetic waves. Medium- to long-term effects were considered to be the effects on the human body caused by residual radiation and the limitation of human activity to avoid those effects. Among these, this paper develops an outline of the short-term effects to social infrastructure that would spread out concentrically from ground zero as a result of the blast wave and heat rays.

The social infrastructure considered in this paper is defined as the 15 areas of roads; harbors; aviation; railroads; public rental housing; sewerage systems; waste treatment; water supply; municipal parks; educational facilities; agriculture, forestry and fisheries; postal services; and industrial water supply, which are defined as social capital by the Cabinet Office, as well as electrical power and communications. Damage estimates were made for these areas in six scenarios in terms of atomic bomb size and type of burst: 20-kt, 100-kt, and 1-megaton atomic bomb with either an air burst or surface burst during the daytime on a sunny day.

In estimating the damage to social infrastructure, past research was referenced to arrange the relationship among the power of the atomic bombs, overpressure, and distance from ground zero at which different degrees of damage occur (threshold) for the constituent elements, which are: various building structures, non-structural elements of buildings (e.g. exterior cladding, windows), highway bridges, automotive vehicles, above-ground storage tanks, railroad bridges, railroad vehicles, sewerage facilities, water supply systems, electrical power facilities, and communications facilities (fixed telephone lines). Then, a qualitative description of the aspects of damage to social infrastructure caused by the blast wave and heat rays was given for the above-mentioned six scenarios at distances from ground zero of less than 1 km, 1 to 5 km, and 5 to 10 km.

Out of all the results, a description of the aspects of damage to social infrastructure caused by a 100-kt air burst (at a height of 3,000 feet) would be as follows:

(1) Description of damage within a 1-km radius of ground zero

Many highway bridges have collapsed or are severely damaged and are impassable; however, girder bridges with a 25-meter span have only moderate or lighter damage. Nearly all cars, buses, and other automobiles are inoperable.

Many warehouse buildings with reinforced concrete walls seen at harbors and heavy steel-frame industrial buildings have collapsed or are severely damaged. Many storage tanks with a diameter of 30 meters or less are severely damaged.

The structures of many buildings at airport facilities have collapsed or are severely damaged and non-structural elements such as glass windows and outer walls are also severely damaged.

As for railroad facilities, most railroad bridges and vehicles have collapsed or are severely damaged and many routes have stopped running. The structures of many station buildings with steel frames or reinforced concrete frames have collapsed or are severely damaged and non-structural elements such as glass windows and outer walls are also severely damaged.

Medium- and low-rise public buildings such as public rental housing and educational facilities with reinforced concrete frames are severely damaged and non-structural elements are also severely damaged.

Water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping have been catastrophically damaged and have stopped functioning.

(2) Description of damage within a 1- to 5-km radius of ground zero

Highway bridges are a mixture of collapsed or severely damaged structures and structures with moderate, light or no damage. Vehicles with moderate, light or no damage tend to increase the farther away they are from ground zero.

In harbor areas close to ground zero, warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings have collapsed or are severely damaged. Many storage tanks with a diameter of 30 meters or less are also severely damaged.

At airport facilities, some buildings have collapsed or are severely damaged but the structural damage of medium- and low-rise buildings with steel frames or reinforced concrete frames is light or non-existent. Non-structural elements such as glass windows and outer walls are severely damaged.

While some railroad bridges closer to ground zero have collapsed or are severely damaged, many have moderate, light, or no damage. Although some railroad vehicles are moderately damaged, many have light or no damage. Many station buildings with steel frames or reinforced concrete frames have light or no damage; however, non-structural elements such as glass windows and outer walls are severely damaged.

Medium- and low-rise public buildings such as public rental housing and educational facilities with reinforced concrete frames have light or no damage; however, non-structural elements are severely damaged.

As for lifeline facilities, water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping closer to ground zero have been catastrophically damaged and have stopped functioning but are operable in areas farther away from ground zero.

(3) Description of damage within a 5- to 10-km radius of ground zero

Most highway bridges have light or no damage and vehicles are operable.

Warehouse buildings with reinforced concrete walls in harbor areas and heavy steel-frame industrial buildings have light or no damage. Empty storage tanks with a diameter of 30 meters or less are severely damaged, but others are nearly undamaged.

Buildings at airport facilities have light or no damage; however, non-structural elements such as glass windows and outer walls are severely damaged. Most railroad bridges and vehicles have light or no damage. Many station buildings with steel frames or reinforced concrete frames have light or no damage; however, non-structural elements such as glass windows and outer walls are severely damaged.

Medium- and low-rise public buildings such as public rental housing and educational facilities with reinforced concrete frames have light or no damage; however, non-structural elements are severely damaged.

Lifeline facilities such as water supply, sewerage systems, industrial water supply, electrical power, and telephones are useable as normal.

3. Economic Impacts of the Use of Nuclear Weapons (Estimation of the Damage to the Regional and Global Economies)

It is obvious from the catastrophic damage to Hiroshima and Nagasaki where atomic bombs were dropped, that the human and material damage by the use of nuclear weapons would be enormous. What is important to note is that the impacts on the economy and society are not limited to the severity of the human and material damage at the time of the atomic bombing, but the bombs will continue to give effects over a period of several decades after the dropping. When looking at human-caused disasters by the use of nuclear weapons or the impacts on the economy and society of natural disasters, such as earthquakes, tsunami and hurricanes, the useful indicator is population trends. In the case of Hiroshima, its population is estimated to have been able to return to the demographic trends of 1925-1940 before the dropping of the atomic bomb only in 1975, taking as long as 30 years to do so. The period required was by far longer than any natural disasters observed so far.

The primary factor behind the long period required of the return to the population trends is the severity of the human and material destruction force of the atomic bombing, with the destruction of social and industrial infrastructures acting as a major hindrance to the post-bombing economic reconstruction. Furthermore, as the second factor, concerns over radioactive contamination are believed to have presented a major obstacle to reconstruction efforts. Though radioactive contamination in both Hiroshima and Nagasaki was relatively minor except for some areas as the atomic explosions took place at high altitudes, the impacts were still serious. Radioactive contamination would be a grave problem if an atomic bomb is detonated on the ground in an act of terrorism, for example. Because of radioactive contamination caused by an accident at the Fukushima Dai-ichi (first) nuclear power station triggered by the Great East Japan Earthquake in 2011, many residents in areas designated for evacuation still find it difficult to return to their homes, and the cost of decontamination for the facilitation of their return home is running very high.

Economic damage from the use of nuclear weapons would have effects on a global scale, not restricted to areas where nuclear weapons were used. As experienced immediately after the Great East Japan Earthquake, the fracturing of the supply chains would result in the suspension of production activities on a global scale. If a nuclear weapon is used in Japan, it can be expected to have an extensive impact on China and Southeast Asian countries because there is a solid division of labor and collaboration systems for “manufacturing” in place among Japan, China and Southeast Asian countries.

Finally, the most serious of economic impacts in the modern society is the threat to the financial system. When North Korea conducted a nuclear test, South Korea's stock market was jolted. Even when any nuclear weapon was not actually used, the mere possibility of such use could throw financial markets into chaos. In the contemporary economy, the network of the financial systems, based on credit instead of goods and services, is spread around the world. In one of the recent cases, as a result of subprime loans to low-income households in the United States becoming nonperforming debt, banks in Europe went bankrupt and the financial collapse of investment firm Lehman Brothers put the global financial system on the verge of a crisis, throwing the world economy into chaos. The use of nuclear weapons presents the risk of not only causing human and material damage to targeted countries/areas but also disrupting the supply systems for goods and services on a global scale and resulting in a devastating impact on the financial system.

Chapter 1. Physical and Medical Effects of the Atomic Bomb on Hiroshima and Nagasaki

(Masao Tomonaga / Nanao Kamada / Hiromi Hasai)

1. Method for Estimating the Effects of Nuclear Blasts

Knowing the damage to people by the explosion of nuclear weapons requires first understanding the physical power of nuclear weapons, and analyzing the medical impact from this on people living in the target cities, as well as the degree to which urban infrastructure is damaged and the resulting economic impact. However, quantifying nuclear weapon damage is an extremely difficult endeavor. This is because, as weapons used in attacks during war or terrorist acts, nuclear weapons exist in a variety of forms to allow the users of these weapons (national and non-national groups) to achieve the desired level of damage. For example, the decision to use an atomic bomb or hydrogen bomb, as well as the degree of energy released from their nuclear blasts, is made based on the size of the city targeted for attack. To maximize the desired effect, decisions are then made concerning whether to have the blast occur on land or in the air, and if in the air, at what height. The waking hours of the target city's people is also taken into consideration to maximize the effect of the nuclear attack.

1.1 The atomic bombs dropped on Hiroshima and Nagasaki

As we do not possess any nuclear weapons and cannot conduct any experiments, we can only speculate as to the true damage of the two atomic bombs dropped on Hiroshima and Nagasaki. This study thus clarifies the actual damage visited on Hiroshima and Nagasaki, and then hypothesizes the damage that would be caused by a nuclear attack on a modern city. Especially in terms of damage to the human body, there has never been a more destructive force than the nuclear attacks that occurred not once but twice on actual cities. This makes these events the best reference available for hypothesizing such an attack, even though they took place in a war that happened many years ago.

In 1945, at the end of World War II, atomic bombs dropped by American military forces exploded over the cities of Hiroshima and Nagasaki on August 6 and 9, respectively. Under the massive mushroom cloud that resulted, the estimated 270,000 residents of Hiroshima and 240,000 residents of Nagasaki became instant victims. Some 140,000 in Hiroshima and 73,000 in Nagasaki were either instantly killed or died within five months of the detonation from the blast wind or from heat rays, radiation, or other physical phenomena[6]. As far as death rates, nearly 100% of the people within a 500 m distance of ground zero died, 90% within a 750 m radius died, 70% within a 1,000 m radius died, 50% within 1,250 m radius died, and 30% within a 1,500 meter radius died[20]. These figures have all been scientifically verified through exhaustive research. It bears mentioning that the attacks were indiscriminate, with civilians—including children—making up a large percentage of those who died.

1.2 The report on nuclear power issued by the U.S. government in 1977

In quantifying the degree of disaster wrought by nuclear blasts, relying on data concerning the power of the two atom bombs dropped on Hiroshima and Nagasaki is the only method available. Other than referencing reports from the U.S. government that present the results of numerous nuclear tests, there is no way to estimate the damage caused by various nuclear weapons, which the Japanese cannot possess. This study therefore estimates damage based on data for Hiroshima and Nagasaki and from *The Effects of Nuclear Weapons* report issued by the U.S. government.

The following is from the 1977 edition of this report:

“We should emphasize, as has been done in the earlier editions, that numerical values given in this book are not—and cannot be—exact. They must inevitably include a substantial margin of error. Apart from the difficulties in making measurements of weapons effects, the results are often dependent upon circumstances which could not be predicted in the event of a nuclear attack. Furthermore, two weapons of different design may have the same explosive energy yield, but the effects could be markedly different. Where such possibilities exist, attention is called in the text to the limitations of the data presented; these limitations should not be overlooked.”

Thus, there are many uncertain elements involved in hypothetical scenarios.

1.3 Hypothetical scenario involving a nuclear blast in a modern city

In order to understand the effects of a nuclear blast in modern times, 69 years after the events in Hiroshima and Nagasaki, it is necessary to imagine damage being done to a modern city representative of a place that would be targeted for attack. The hypothetical scenario here assumes blasts from two different kinds of nuclear weapons. One is an atomic bomb that relies on atomic fission and which, being the 16-kiloton (KT) atomic bomb dropped on Hiroshima for which the true extent of damage is already known, corresponds to the 20-kiloton bomb covered in the U.S. government report. The other is a 1 MT hydrogen bomb (the smallest such bomb), a nuclear weapon that relies on atomic fusion.

The fictional modern city chosen for this study has a relatively large population of 1 million people, and is in a flat area on a river delta. This is to make the data for the bombing in Hiroshima, which has similar terrain, easier to use for this study. This allows for damage to be looked at from a number of different perspectives, as with the situation in Hiroshima. Data for Nagasaki was not employed here as its distinctive terrain (being surrounded by mountains) makes it difficult to use. The differences between 1945 Hiroshima and the fictional modern city are major when it comes to the buildings and living conditions, especially with respect to information communication. The fictional city's population density was made to be very similar to that of Hiroshima's city center in 1945, but with people distributed evenly. For the data needed to make estimates, data from a report in 2007[2] from the Special Subcommittee on Estimating Damage in the Event of a Nuclear Attack established by the City of Hiroshima was used extensively.

1.4 Discrepancies between Hiroshima/Nagasaki and the fictional modern city

Of particular focus in this study were the major differences between the living conditions (lifestyles, modes of transportation, medical treatment, etc.) of 1945 Hiroshima and those of the fictional modern city. This study's estimates found that, compared to the Japanese-style buildings made of wood that were prevalent in 1945 Hiroshima, the dramatically sturdier buildings in the fictional modern city provides shielding that decreases human injury from shock waves, heat rays, and radiation. However, the tall height of these buildings and their long, large stairways makes rapid evacuation from these buildings difficult (as was seen in the 2001 terrorist attacks in Manhattan). With not enough time to evacuate, the impact of fire is heightened. In addition, evacuation is further impeded by streets being dramatically more full of cars, maximizing the impact of fire. Furthermore, a number of different materials are used in modern buildings, and various equipment and appliances are used inside them. While one could speculate that this equipment could turn into lethal weapons if hit by a shock wave, such effects are difficult to estimate.

The decision to have the 1 MT hydrogen bomb exploded at a height of 2400 m rests on data from the U.S. government report stating that energy release is greatest at this height. Hydrogen bombs are set apart from atomic bombs in that, because they explode further above the ground, the effects of radiation are diminished by the wind while the effects of the shockwaves and heat rays are much more severe. In either case, harm from the nuclear blast is immediate and the number of people that die while engulfed in flames is beyond imagining. As there is no time to evacuate residents, nuclear attacks that come without warning are indiscriminate agents of destruction that inevitably kill civilians not involved in the fighting.

2. Nuclear Weapon Characteristics

Nuclear explosions are designed to very quickly release a massive amount of energy in a limited space. Because nuclear weapons generate energy through nuclear reactions (nuclear fission and nuclear fusion), they are capable of yields that are many thousands or tens of thousands of times greater than standard TNT. The extremely high temperature and pressure converts the bomb's materials into hot, compressed gases. These gases rapidly expand and cause a pressure wave in the surrounding medium. These pressure waves are called shock waves and create strong winds. The superheated energy creates a fireball and releases heat rays that create fires and burn people. A large amount of radiation is also generated due to how the energy is created, namely atomic fission. First, highly-permeable radiation known as initial radiation reaches the ground in a short time. The materials remaining after the explosion emit residual radiation, which affects the human body.

2.1 Characteristics of the Hiroshima and Nagasaki atomic bombs

The following describes the composition of the atomic bombs used.

(1) Bomb dropped on Hiroshima (uranium bomb) “LITTLE BOY”

Length: 3 m, diameter: 0.7 m, weight: 4 T

Fuel: 64 kg of enriched uranium (89% enriched: 50 kg, 50% enriched: 14 kg)

Bullet: length: 16 cm, cylindrical stack diameter: 10 cm, 25.6 kg

Target: length: 16 cm, cylinder outside diameter: 14.6 cm, inside diameter: 10 cm, 38.4 kg

Neutron source (Po-Be) 4 attached to the target's tip

Bullet speed: 300 m/s, criticality occurred before everything for the two fuels combined

Bomb exploded 600 m above ground 43 seconds after being dropped. Consumption: about 850-900 g. Yield: 16 KT

(2) Bomb dropped on Nagasaki (plutonium bomb) FAT MAN

Length: 3.2 m, diameter: 1.5 m, weight: 4.5 T, plutonium fuel: 10 kg,

Exploded 605m above ground. Consumption: about 1 kg. Yield: 21 KT

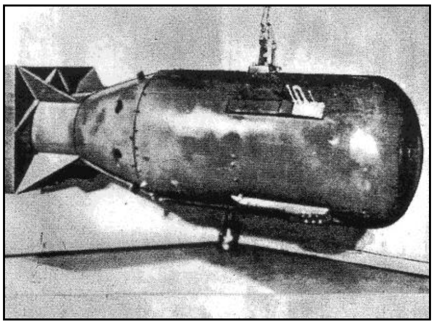

Fig. 1 LITTLE BOY

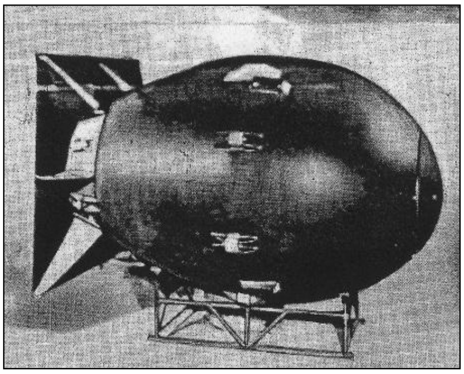

Fig. 2 FAT MAN

2.2 Types of physical energy released from atomic bombs

(1) Initial radiation

Neutrons and gamma rays reach the ground during chain reactions and cause radiation injuries in people. The neutrons that reached the ground react with materials and create new radioactive sources (induced radioactivity).

(2) Bomb blast (shock wave)

The high heat and pressure turns the nuclear bomb into gases, which quickly expand. The resulting shock wave into the surrounding air destroys buildings and directly affects the human body.

(3) The flash and heat rays

The explosion superheats the bomb causing a fireball and heat rays that burn human tissue. They also burn combustibles, creating fires. This is accompanied by a flash of light.

(4) Fires

The heat rays burn combustibles, creating fires and generating firestorms particular to urban environments.

(5) Residual radiation

①Induced radioactivity

The neutrons that reach the ground irradiate various matter and create induced radioactive materials. The radiation that results can thus affect even those who enter the city after the detonation

②Fission fragments (fallout)

The fission fragments and other bomb materials released during nuclear fission become gases and rise up in the air. They eventually fall, continually releasing radiation.

(6) Electromagnetic pulses

Large quantities of electrons are released through the co-action between the gamma rays produced and the atmosphere, instantly generating strong electromagnetic waves. This causes all the communications and information systems that rely on electronic equipment and that have rapidly become so prevalent in modern society, to malfunction.

3. Initial effects on the human body in Hiroshima and Nagasaki

3.1 Estimated fatalities (initial survey)

There are no definitive figures for the number of people killed by the atomic bombs. Although this can be partially attributed to people continuing to die even now from radiation injuries, a big factor is that there is no definitive data for the populations of these cities at the time. Another factor is that the great damage caused by the bombs made it difficult to ascertain everything about the victims' conditions.

(1) Hiroshima

Many estimates have been made based on the data in Table 1. The numbers for the population and fatalities in 1945 that are used now and that are published by the City of Hiroshima are estimates based on the 1971 edition of the Hiroshima War Damage Journal[3] of 1971. These figures were calculated by the United Nations Appeal Data Editing Special Committee (chaired by Seiji Imabori) in November 1976 in order to provide UN Secretary General Kurt Waldheim and the visiting United Nations delegation with actual facts concerning atomic bomb damage. Due to the astounding number of victims who died in the five months following the blast, calculations include those who died up to December 31, 1945. 310,000-320,000 were directly affected by the bomb, excluding military personnel. Adding the approximately 40,000 military personnel brings this number to 350,000, of which an estimated 140,000 died. These numbers include foreign nationals, whose whereabouts were known.

The Hiroshima War Damage Journal (based on data compiled by the Hiroshima City Research Division on August 10, 1946) puts the number of affected at 320,081 (including those beyond 5 km from ground zero), the number of dead or missing at 122,338, the number of injured at 78,130, and a 62% casualty rate[4]. The number of dead as of December 31, 1945, including military personnel, that is now published is 140,000. The base data used at this time is shown in the supplementary table.

[Table 1] Main Reports of Fatalities Attributed to the Hiroshima Bombing, including Missing Persons (Not Including Military Personnel)

Report Date & Source		Dead	Missing	Total
August 20, 1945	Hiroshima prefectural governor report	32,959	9,591	42,550
August 25, 1945	Hiroshima Prefecture Health Division report	46,185	17,429	63,614
November 30, 1945	Hiroshima Prefectural Police Department report	78,150	13,983	92,133
March 8, 1946	Hiroshima City administrative report	47,185	17,425	64,610
August 10, 1946	Damage survey, Hiroshima City Surveying Division	118,661	3,677	122,338
1951	US-Japan Joint Research Team report	64,602	-	64,602
1961	Estimate by the Special Committee of the Japan Council Against Atomic and Hydrogen Bombs	119,000 or more 133,000	-	151,900 or more 165,900

[Supplementary Table] US-Japan Joint Research Team report data on Hiroshima[4]

Distance from ground zero (km)	Number (People)						Composition (%)		
	Dead	Severely injured	Slightly injured	Unknown	Uninjured	Total	Dead	Injured	Uninjured
≦0.5	19,329	478	338	593	924	21,662	92.0	3.8	4.3
0.5-1.0	42,271	3,046	1,919	1,366	4,434	53,036	82.3	9.4	8.4
1.0-1.5	37,689	7,732	9,522	1,188	9,140	65,271	59.6	26.4	14.0
1.5-2.0	13,422	7,627	11,516	227	11,698	44,490	30.7	43.0	26.3
2.0-2.5	4,513	7,830	14,149	98	26,096	52,686	8.8	41.7	49.5
2.5-3.0	1,139	2,923	6,795	32	19,907	30,796	3.8	31.6	64.6
3.0-3.5	117	474	1,934	2	10,250	12,777	0.9	18.8	80.2
3.5-4.0	100	295	1,768	3	13,513	15,679	0.7	13.2	86.2
4.0-4.5	8	64	373		4,260	4,705	0.2	9.3	90.5
4.5-5.0	31	36	156	1	6,593	6,817	0.5	2.8	96.7
5.0＜	42	19	136	167	11,798	12,162	1.7	1.3	97.0
Total	118,661	30,524	48,606	3,677	118,613	320,081	38.2	24.7	37.1

(2) Nagasaki

Similar estimates are given for Nagasaki, with a total of 270,000-280,000 people directly affected by the bomb, and 73,000 dead. The data used is shown in Table 2.

[Table 2] Main Reports of Fatalities Attributed to the Nagasaki Bombing

Report Date & Source		Dead	Missing	Total
August 31, 1945	Nagasaki Prefecture report	19,748	1,924	21,672
October 23, 1945	Nagasaki Prefecture Foreign Affairs Division report	23,753	1924	25,677
Before 1947	Report from a British delegation of inquiry	39,500	―	39,500
1949	Survey from Nagasaki City Atomic Bomb Data Preservation Committee	73,884	―	73,884
1951	US-Japan Joint Research Team report	29,570 or more 39,214	―	29,570 or more 39,214
1956	US-Japan Joint Research Team report	39,00	―	39,000

3.2 Comparison of death rates in Hiroshima and Nagasaki according to distance

Death rates according to distance were referenced to estimate the number of dead. Data is shown in Table 3[4].

[Table 3] Distance from ground zero and death rates
(US-Japan Joint Research Team report data)

Distance from ground zero (km)	Hiroshima (%)	Nagasaki (%)
Less than 0.5	96.5	88.5 (Total of 0.5 or less and 0.5 to 1.0)
0.5〜1.0	83.0	
1.0〜1.5	51.6	51.5
1.5〜2.0	21.9	28.4
2.0〜2.5	4.9	6.4
2.5〜3.0	2.7	2.1
3.0〜4.0	2.5	1.2
4.0〜5.0	1.1	0.7

It is estimated that 64,601 people and 39,500 people died in Hiroshima and Nagasaki, respectively, at this time.

3.3 Nuclear fission and chain reactions

The nuclear fission reaction ended in 1 millionth of a second (1 μs), and the mass deficiency resulting internally from the nuclear fission effected further nuclear fission and produced kinetic energy, which became extremely hot and compressed (several million degrees celsius and several hundred thousand atmospheres). From within the initial radiation, neutrons and gamma rays with high penetrating power head towards the ground as they decay due to the atmosphere.

3.4 Elapsed time from the explosion and damage to humans

In the case of Hiroshima, the atomic bomb was dropped from a height of around 9,600 m and exploded 43 seconds later at a height of 600 m. The Hiroshima atomic bomb energy distribution is reported to have consisted of 50% blast, 35% heat rays, 10% residual radiation, and 5% initial radiation. Table 4[5] shows the effects on the human body as time elapses from the explosion.

Fig. 3 Mushroom cloud
from the Hiroshima atomic bomb

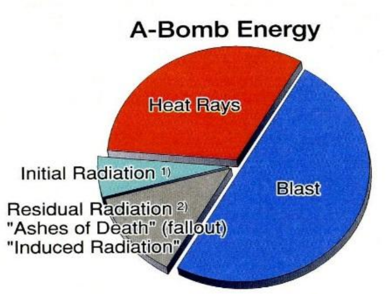

Fig. 4 Hiroshima atomic bomb
energy distribution

[Table 4] Time elapsed from the explosion (1945 Hiroshima)

Elapsed Time (Seconds)	Phenomena
0 seconds	Dropped from 9,600 m, the bomb detonates 43 seconds later 600 m above the ground.
1/1,000,000 second	Atomic fission ends. Neutrons and gamma rays are released during this time. The inside of the bomb reaches several million degrees celsius and several hundred thousand atmospheres.
1/10,000 second	A fireball with a 14 m radius and some 300,000 degrees celsius is formed.
1/100 second	The fireball's radius increases to 90 m, the surface temperature decreases to 1,700°C, and rises thereafter.
0.3 seconds	The surface temperature of the fireball rises to 7,000°C. Light is seen and the shock wave occurs.
1 second	The fireball achieves its maximum radius, 140 m, and its surface temperature drops to around 5,000°C.
3 seconds	The surface temperature of the fireball drops to 1700°C and all remaining energy is released.
Approximately 10 seconds	The city is completely destroyed. Fires break out.
3 minutes later	People see the mushroom cloud.
20 minutes later	Radioactive black rain full of dirt and dust begins to fall in certain places.

3.5 Acute radiation sickness caused by initial radiation

Table 5[5] shows relationship between initial radiation reaching the ground in Hiroshima and distance from ground zero. The neutrons and gamma rays, which are ionizing radiation generated from the nuclear fission chain reactions prior to the explosion, reach the ground and directly affect the human body[5] while also irradiating materials on the ground[6]. People receiving a lethal dose of radiation at this point died, regardless of the shock wave or heat rays. Table 6 shows the relationship between single radiation dose amounts and the human body. Cases of acute radiation sickness become apparent from among people who were neither injured externally by the shock wave nor directly affected by heat rays. There were also many people who engaged in rescue efforts vigorously as they appeared to be injury-free. Such individuals were anywhere from 1,000 to 1,500 m away from ground zero, and suffered an estimated exposure of 1,500 to 2,500 mSv. In most cases, these people began feeling lethargic 10 days after exposure, their throats began to hurt, their hair began to fall out (fig. 5), and their white blood cell count dropped to between 500 to 1,000 / µL within a week thereafter. Numerous purple spots caused by subcutaneous hemorrhage appear, and the victims die somewhere between three and six weeks later. Around the fifth week, signs of blood forming cells' recovery are seen within bone marrow, but most of those who died from acute radiation sickness did so before September 15[6]. Among those who made it through this period and made full recoveries due to good nutrition and proper medical care, many developed so-called radiation aftereffects such as leukemia and cancer.

[Table 5] Distance from ground zero and initial radiation dosage

Distance	Neutrons	Gamma rays	Total dosage	Dosage absorbed by human body	Wooden structures
(m)	(mGy)	(mGy)	(mGy)	(mSv)	(mSv)
100	32,000	115,000	147,000	435,000	302,000
200	25,100	95,600	120,000	346,600	239,000
300	17,500	73,000	90,500	248,000	169,000
400	11,100	52,600	63,800	163,700	110,000
500	6,480	35,700	42,180	100,500	66,000
600	3,610	23,600	27,210	59,700	38,000
700	1,950	15,500	17,450	35,000	22,000
800	996	10,000	10,996	19,960	12,000
900	517	6,470	6,987	11,640	7,000
1,000	260	4,220	4,480	6,820	4,000
1,100	129	2,750	2,879	4,040	2,100
1,200	67	1,810	1,877	2,475	1,300
1,300	34	1,190	1,224	1,527	700
1,400	17	789	806	960	500
1,500	9	527	536	617	300
1,600	5	353	358	403	200
1,700	2	237	239	262	100
2,000	0.4	76	77	80	31
2,300	0.1	25	25	26	10
2,500	0.00	13	13	13	

Note regarding wooden structures: As most of the buildings at this time were made of wood, the figures here were calculated based on statistics concerning wooden building shielding.

Accurately calculating individual risk would require accounting for individual shielding conditions.

[Table 6] Single radiation doses and effects on the human body

Radiation dose	Effects on the body
250 mSv or below	No bodily symptoms
500 mSv	Temporary leukopenia
1,000 mSv	Nausea and vomiting
1,500 mSv	50% of people develop 放射性宿酔 (a hangover condition)
2,000 mSv	5% of people die
4,000 mSv	50% of people die within 30 days (half lethal dose)
7,000 mSv	100% of people die

(From the Nagasaki University website)

Fig. 5 epilation

Fig. 6 Exposed 1.0 km from ground zero, low platelet count resulted in Purpura; died two hours later (21-year-old soldier)

3.6 Damage from the fireball

(1) Damage from the fireball

The high temperature and pressure turns the bomb into gases, creating a fireball. The fireball expands rapidly, and a shock wave forms at its edge. People die from collapsing buildings. Table 7 shows the relationships among distance from ground zero, arrival time of the shock wave, pressurization, and wind speed.

[Table 7] Shock wave pressurization and arrival time, and wind speed upon arrival

Distance (m)	Overpressure (kPa)	Arrival time (seconds)	Wind speed (m/s)
100	185.85	0.82	277.7
500	109.63	1.23	189.3
1000	69.56	2.15	132.3
1500	38.74	3.32	80.6
2000	24.51	4.60	53.5
2500	17.16	5.95	38.4
3000	12.88	7.34	29.3
3500	10.15	8.74	23.4
4000	8.29	10.16	19.2
4500	6.95	11.59	16.2

(Bibliographic reference 4) Wind speeds are estimates (bibliographic reference 1)

Table 8 shows the direct effects of the shock wave on the human body. Figures 7 through 10 show the extent of destruction to buildings and the distance from ground zero inside the city.

[Table 8] Effective peak overpressure's effects on the human body
(estimated from animal experiments)

Category		Psi	KPa	Notes
Lung damage	Threshold	12	83	
	Severe	25	173	
Death	Threshold	40	276	
	50%	62	428	
	100%	92	635	
Ruptured eardrums	Threshold	5	34.5	Wooden structures collapse at these levels

Note: 1 psi (pounds per square inch) = 6.8947 kPa (kilopascals) (bibliographic reference 1)

The shock wave and shock wave knocked down various buildings, also resulting in bodily injury.

Fig. 7 Steel structure 850 m from ground zero

Fig. 8 Teishin Hospital (concrete construction), 1400m from ground zero

Fig. 9 Hiroshima Station, 2,000 m from ground zero

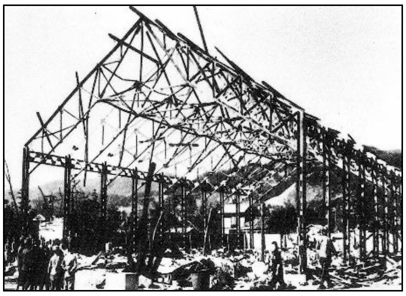

Fig. 10 Misasa Elementary School (reinforced wooden construction), 2,000 m from ground zero

(2) Effects of heat rays

As the fireball expands, the temperature drops, resulting in the gradual emission of ultraviolet rays, visible light (flashes), infrared rays (heat rays), and other long-wavelength electromagnetic waves. People can see these fireballs in the visible light region. The resulting heat rays in the infrared region can burn human tissue. Table 9 shows the effects of heat rays on human tissue.

[Table 9] Effects of heat rays on human tissue

Distance (m)	cal/cm^2	Damage
100	114.35	
500	68.77	
1000	30.26	
1500	15.42	Almost anything catches on fire, human tissue suffers fatal burns
2000	9.02	Third-degree burns; death at 25% BSA
2500	5.81	Second-degree burns; death at 30% BSA
3000	4.00	Wood and black clothing scorches
3500	2.90	First-degree burns; skin turns red

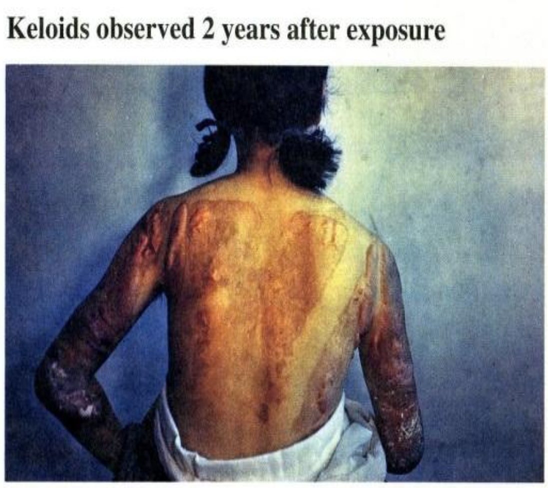

Fig. 11 Keloids seen two years after exposure

Fig. 12 Burn-induced, instantly-forming keloids (scars)

(3) Effects from fire

Intense heat rays ignite combustible materials and fires break out 10 seconds later. Firestorms unique to urban environments maximize damage. Trapped under fallen buildings, some people cannot escape being burned to death.

(4) Damage from residual radiation

There are two kinds of residual radiation: induced radiation, which consists of activated neutrons that reach the ground, and radioactive fallout, which consists of radioactive materials resulting from atomic bomb components gassified upon explosion.

① Induced radiation

Neutrons that reached the ground conduct nuclear reactions with various materials and create radionuclides. The resulting radioactive substances emit beta and gamma rays. The amount of nuclides generated depends on the amount of neutrons that reach the ground. Although radiation decays over time, even people not exposed to initial radiation can be exposed later by going into areas near ground zero.

The amount of induced radiation is determined based on the relationship between materials on the ground and neutron dose. The relationship between distance from ground zero and total induced radiation dose in the case of Hiroshima is shown in Figure 13. Remaining for 100 hours within 1 km of ground zero following the blast exposes one to several sieverts of radiation. Induced radiation decays to 1/100 the value after 30 minutes, 1/1000 after one day, and 1/1,000,000 after a week (Figure 14)

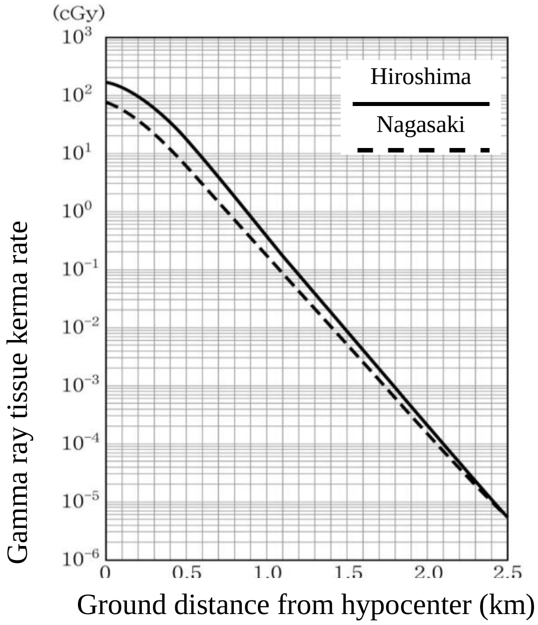

Fig. 13 Distance from ground zero
and induced radiation

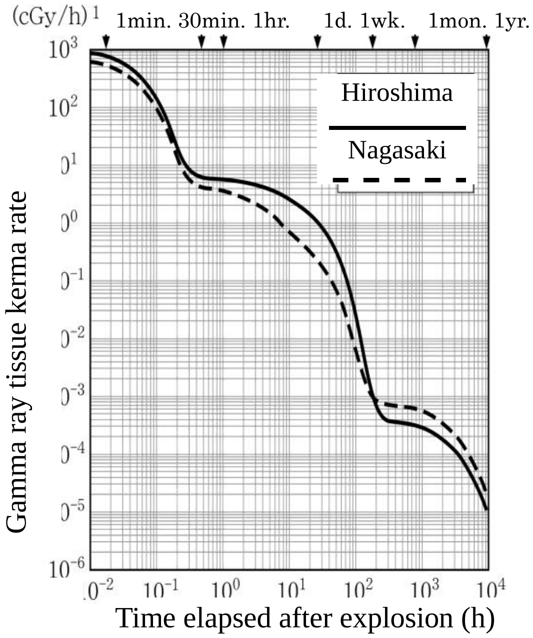

Fig.14 Temporal decay
for induced radiation

② Fallout

A wide range of fission products (the entire bomb) generated from atomic fission reactions were rolled up into the mushroom cloud. These rained down along with sticky rain (black rain) that had the consistency of fuel oil and that was comprised of soot, dirt, and dust generated from the fires. It is difficult to accurately estimate the extent and volume of this rain. The presence of isotopes such as uranium 235 and plutonium 239 that did not undergo fission also result in the emission of alpha rays. Alpha rays that get inside the body exacerbate the damage done. There are also isotopes with half-lives that are longer than those of induced radiation (plutonium 239 has a half-life of 25,000 years).

4. Long-Term Effects on the Human Body in Hiroshima and Nagasaki

4.1 Total number of atomic bomb survivors

A total of about 250,000 people across the cities of Hiroshima and Nagasaki have overcome a multitude of effects from exposure. Although recovery in both cities began several weeks after the bomb hit, the pace was sluggish. This was mainly due to a devastating lack of economic resources and manpower following Japan's defeat on August 15. There were extreme shortages of food and other daily necessities. These survivors became known as bomb survivors. After three years of efforts, some measure of recovery was seen, but the bomb survivors found themselves confronted with surging rates of leukemia, which was the first sign of ill health wrought by radiation exposure, referred to as atomic bomb aftereffects (Figure 15)[7].

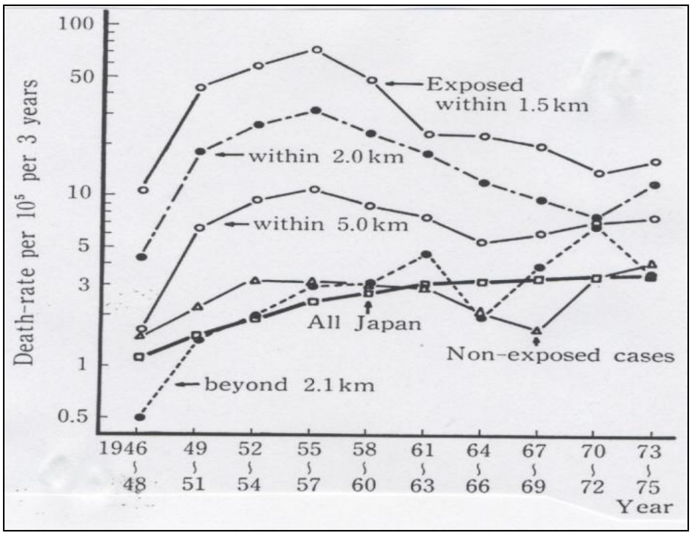

Fig.15 Rise in rates of early-stage leukemia (according to distance) (Okita)

4.2 Leukemia

Around 1948, doctors in Hiroshima and Nagasaki began noticing rising rates of leukemia in mostly children. These rates increased dramatically, reaching a peak around 1955[7]. Rises were also noted for adults, with both acute leukemia (both myeloid leukemia and lymphocytic leukemia) and chronic leukemia (myeloid leukemia only; lymphocytic leukemia did not increase) showing increases. Rates were especially high among survivors who were within 1.5 km of the blast (Figure 15).

When it became possible to estimate exposure dose for individual people around 1965, the connection between leukemia rates and radiation dose became significantly clearer[8] (Figure 16).

This relationship was immediately shared with the rest of the world, and the effects of atomic bomb radiation on the human body became publicly known. Research into leukemia rates has continued in the 69 years since the bombs dropped and, based on a comprehensive analysis of this research, it is becoming accepted that people suffer from excess leukemia incidence rates when exposed to doses of 100 mSv or above, the level that exists about 2 km from ground zero. This dose response curve differs from that for myelodysplastic syndrome (MDS) mentioned below and represents, uncommonly, a downward projecting curve.

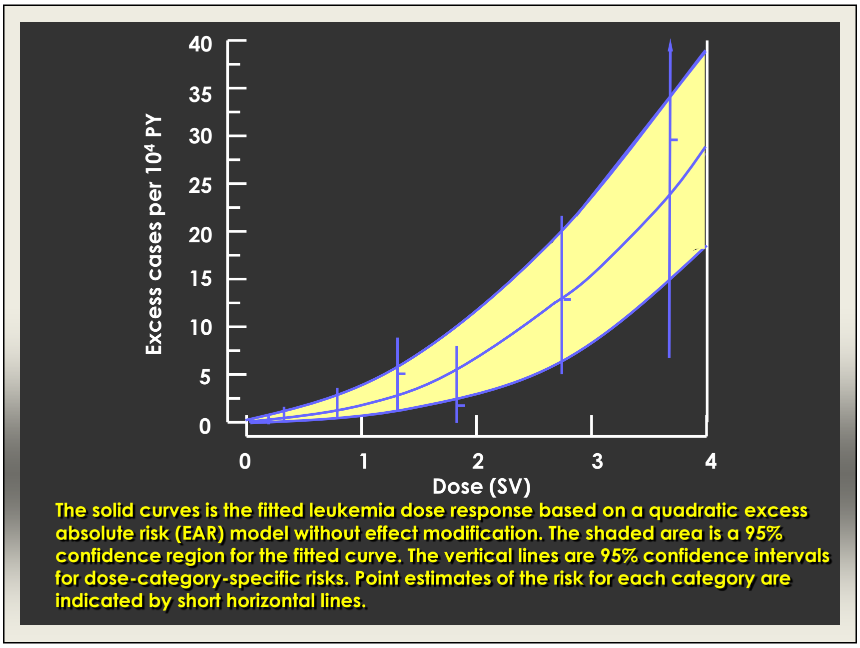

Fig. 16 Relationship between excess cases of leukemia and exposure dose (exponential function)

Factors that greatly influenced the leukemia rates were the distance from ground zero at the time of the blast, the degree of shielding (whether they were on the street, inside a wooden building, inside a concrete building, inside a bomb shelter, etc.), and the age they were at the time of the attack. Overall, the leukemia rate was 4 to 5 times higher than the annual rate for the average population. Limited to only children, rates were several dozen times higher. Epidemiological research into leukemia has continued for more than half a century, and there continues to be risk of leukemia even now. Looking at numbers over time, there are two phases at which risk is rising: the leukemia rate peak at the end of the15-year initial phase, and the leukemia rate peak in the latter phase centered on myelodysplastic syndrome (MDS), a leukemia-related condition for which incidents rate increases are becoming apparent.

4.3 Myelodysplastic syndrome (MDS)

The recently-published results of a study on MDS in Nagasaki shows that Leukemia-related conditions are continuing to increase even after the first 50 years since the bombings. Surprisingly, the increase in risk is on par with that at the time leukemia rates peaked in the initial phase, indicating the effects of atomic bomb radiation are still being observed even a half century later[9]. MDS is a condition that occurs more frequently the older a person gets, and incidence rates are on the rise in every developed country due to their aging populations in recent years. This trend is very apparent among atomic bomb survivors: it has been observed that victims who were close to ground zero at the time of the bombing have an MDS incidence rate that is 3 to 4 times that of elderly Nagasaki residents who were not victims of the bombing.

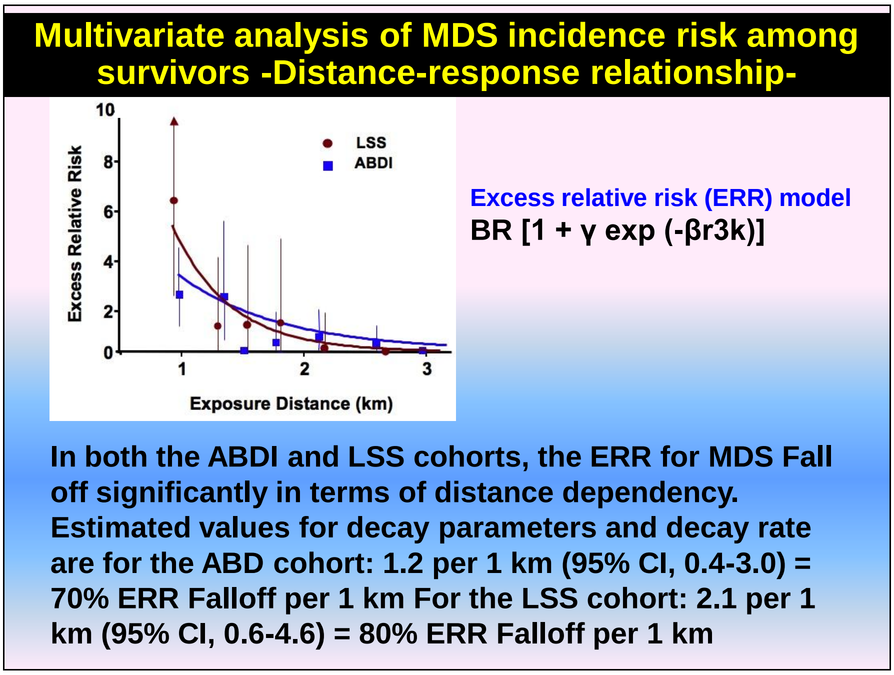

Fig. 17 Excess rates of myelodysplastic syndrome (MDS)
according to distance from ground zero

We have learned more about the dose-response relationship in recent years, and an idea gaining acceptance is that, as with leukemia, individuals exposed to more than 100 mSv increase their risk of developing MDS, with the dose-response relationship increasing in a linear fashion up to between 2 and 4 Sv levels. This curve is distinguished from that of leukemia with downward concave pattern. Moreover, just as MDS is considered a condition related to leukemia, about half of those who develop MDS go on to develop myelocytic leukemia, many of whom die due to their treatment resistance. It is now a prime focus of aftereffects research to determine why the heightened risk of leukemia continues even now, 69 years after the bombings. The same goes for solid cancer, described below, and such research is an extremely important issue when it comes to thinking about the mechanisms behind radiation-induced cancer.

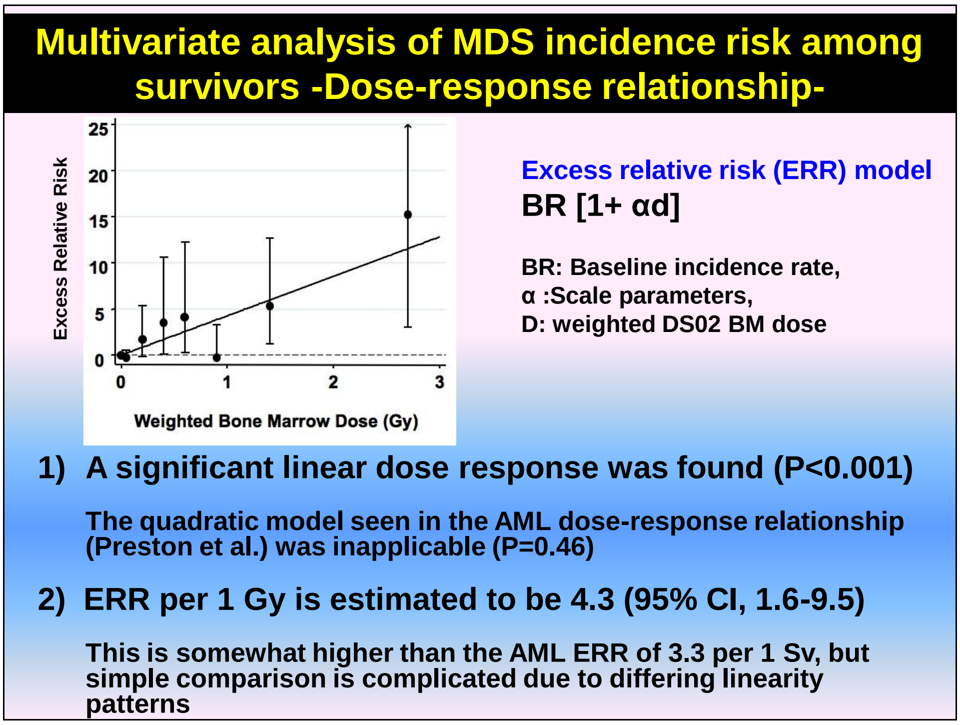

Fig. 18 Relationship between dose and excess rate of myelodysplastic syndrome (MDS)

4.4 Solid cancer

As shown in figures 15 and 21, excess risk of developing leukemia began gradually dropping in the latter half of the 1960s. In contrast, numbers began rising for solid cancers affecting various internal organs. The types of cancer so far discovered have been shown to affect almost all organs[9]. This includes cancers of the lungs, stomach, intestines, breasts, thyroid, bladder, prostate, and skin.

Excess death rates due to solid cancers will continue to increase until 2020, meaning they will continue for the next 5 to 10 years. As with MDS, elderly bomb survivors suffer from higher rates. In general, cancer rates in people begin increasing after about age 55. As of 2013, the average age of Hiroshima and Nagasaki bomb survivors was 78 years. This means that victims who were 10 or younger at the time of the bombings make up the majority.

There is a clear relationship between exposure dose and excess rate of cancer and, as with leukemia, it is being found that excessive rates of solid cancers appear when the exposure dose is 100 mSv or above. When high-dose levels (2-4 Sv) are reached, the rise in the excess rate of cancer increases in a linear fashion, indicating dose dependency[9]. Currently, about 1 million people have been exposed to radiation as a result of the Fukushima Daiichi Nuclear Power Station accident. Nobody has been exposed to more than 100 mSv, and the risk of them developing cancer is estimated to be extremely low. However, not all the facts are yet known about the risks of those exposed to 100 mSv or less, and people's concerns about the issue are significant. In the same way, bomb survivors exposed to low doses (Less than 100 mSv) also continue to worry.

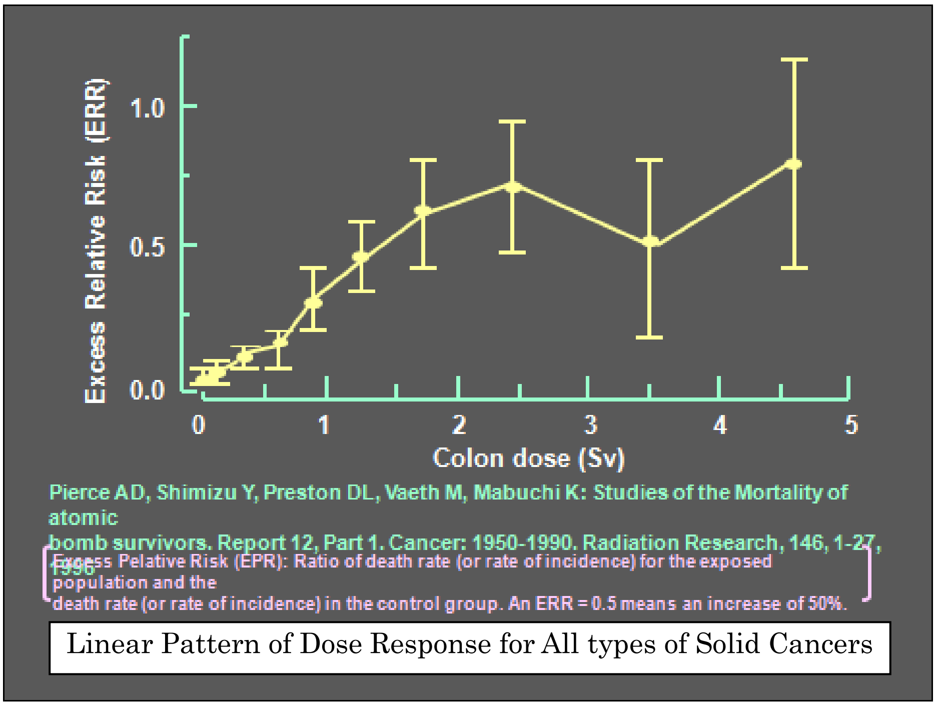

Fig. 19 Exposure dose and excess risk of cancer

4.5 Multiple primary cancers

In issue becoming more prevalent in recent years is the excess rate among bomb survivors of multiple primary cancers developing in separate organs simultaneously or at different points in time. For both men and women who were close to the blasts, risk is increasing at about 3 times that for victims who were distant from the blasts[11]. About 700 bomb survivors a year are admitted to the Nagasaki Atomic Bomb Hospital with solid cancer or leukemia. Somewhere between 5% and 8% of these have developed a second or third cancer. Some people have even had 4 or 5 cancers. These facts, along with the fact that increases are being seen in incidences of the aforementioned MDS as well as cases of solid cancer and multiple primary cancer, are causing new worries among the bomb survivor community.

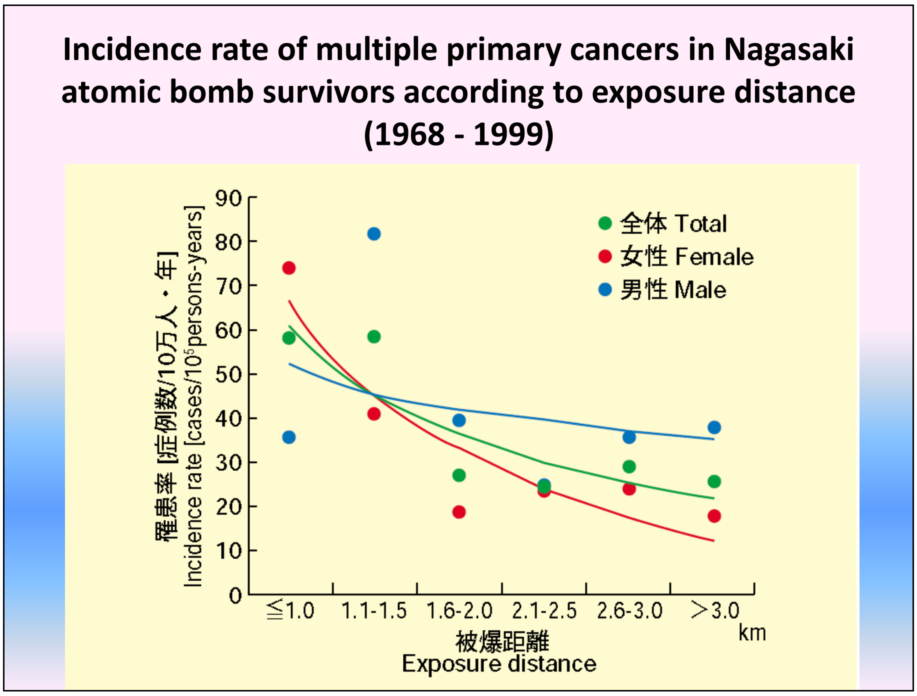

Fig. 20 Upward trend for multiple primary cancer cases

4.6 Estimate of the number of excess cases of leukemia and cancer (1950-2000)

For the 50 years from 1950 to 2000, the Radiation Effects Research Foundation (RERF) has tracked more than 100,000 bomb survivors for which personal exposure has been estimated (the LSS cohort), and has researched the incidence rates of leukemia and cancers among them for this period. This data allows for calculating the total number of malignant tumors that have developed among bomb survivors over this time period. However, incidences of malignant tumors would also be found in any group of tens of thousands of people in the general population if tracked over the long term; for example, one out of every two men and one out of every three women in Japan today develops a malignant tumor.

Therefore, in order to calculate the total number of malignant tumors that actually developed as a result of exposure to atomic bomb radiation, it is possible to estimate the actual radiation-induced cancer rate (contribution ratio) from the relationship between dose received and excess cases of leukemia and cancer (the dose response). Results are shown in Table 10[12]. This contribution ratio can be used to estimate the number of excess leukemia and cancer cases that would result from a modern city attacked with a nuclear bomb.

In the case of leukemia, 296 out of 86,000 survivors died of leukemia (back then, all who developed leukemia died because of poor treatment) and it is estimated that 93 and 56 cases respectively were real excess numbers among survivors for the two dose-groups (all dose range group and 2Gy< group). These case numbers and radiation-dose response pattern provided radiation-attributable rates of 46% and 88% for the two dose-groups, respectively. Regarding cancers among 105,427 survivors, 853 and 74 cases were estimated as real excess cases for the two dose groups, all-dose range group and 2Gy< group, respectively. Similarly to leukemia radiation-attributable rates for cancers were calculated as 10.7% and 61% for the two dose groups, respectively.

Cancer cases attributable to radiation can thus be calculated as the contribution ratio. While the 10% figure above for radiation-related cases may seem low, this number carries unimaginable significance for each survivor. When many bomb survivors develop leukemia or cancer, they are unable to think about having developed a malignant tumor in terms of probability based on the contribution ratio. Most of them end up attributing their condition to atomic bomb radiation, regardless of the dose they received. Even before developing a malignant tumor, these survivors resign themselves to the idea that one day they will. What is important to bomb survivors is not the actual probability (contribution ratio) of developing cancer, it is the fact that being exposed to atomic bomb radiation increases those chances at all.

Long-term consequences of atomic bomb radiation in Hiroshima and Nagasaki Survivors

Population-based study on leukemia and cancer statistics
Hiroshima/Nagasaki combined

	Fixed population of survivors	No. of death in 50 years	expected No. of death	Excess cases	Percent Radiation-Related
Leukemia					
all doses	86,611	296	203	93	46%
2Gy<	2,709	64	8	56	88%
Cancers					
all doses	105,427	17,448	16,500	853	10.7%
2Gy<	2,211	185	111	74	61%

Table 10 Number of excess cases of leukemia and solid cancer among bomb survivors

4.7 Why does elevated risk persist for a lifetime?

That—as explained above—it is becoming clear that elevated leukemia and solid cancer risk persists for a lifetime is extremely important knowledge in conducting research involving the effects on the health of bomb survivors. Although the true reasons behind elevated lifetime risk are unknown, it is becoming clear that as more and more gene mutation occurs in stem cells (bone marrow stem cells in the case of leukemia, and various organs' stem cells in the case of solid cancer) in various organs in leukemia and many cases of solid cancer as well, disorders develop from the build up of cancerous or leukemic cells. The prevailing theory is that the process is gradual: In bomb survivors as well, the DNA in stem cells in various organs were instantly damaged in the blasts and the various genetic mutations that result accumulate over many years, eventually producing cancerous cells. Once these cancerous cells reach a certain size, these people are told they have cancer. It could be said that the effect on health from a lifetime of elevated risk attributable to atomic bomb radiation exposure, which is believed to—in an instant—set the body's stem cells on the road to cancer, is the very worst of the long-term effects brought by the atomic bomb.

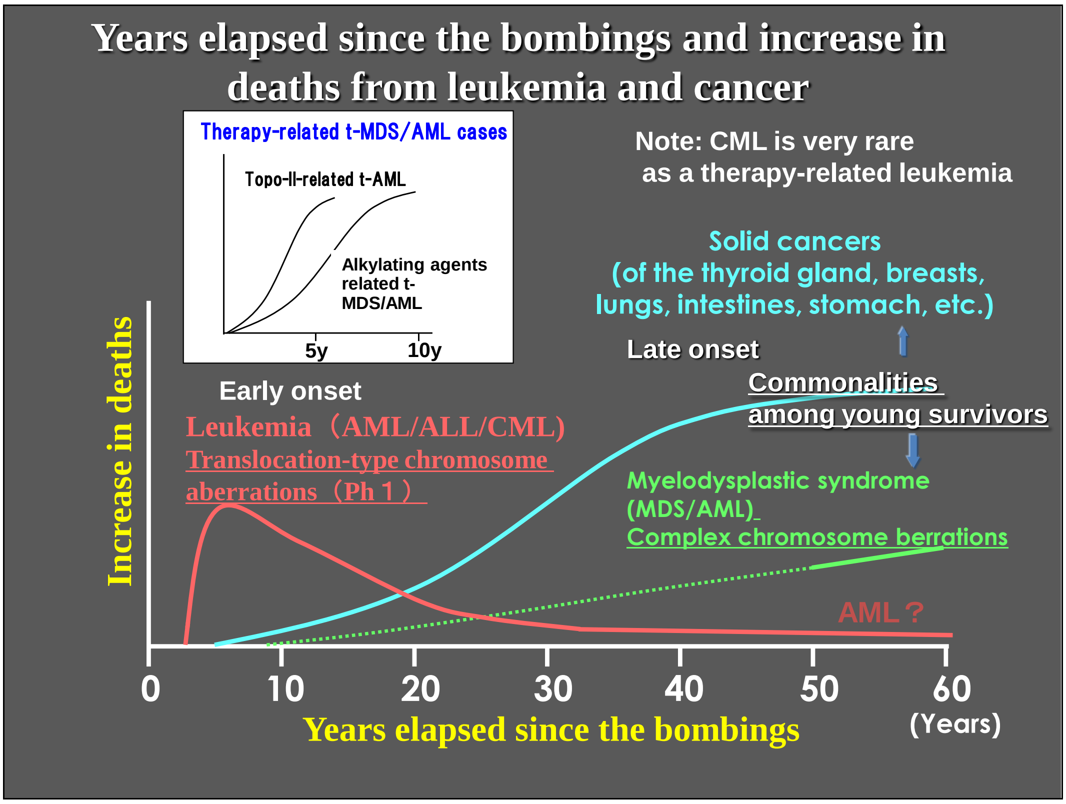

Fig. 21 Elevated lifetime risk of leukemia and cancer in bomb survivors

4.8 Health effects other than cancer

(1) Upward trend for vascular diseases (myocardial infarctions)

Epidemiological research involving atomic bomb survivors in recent years is drawing attention to a gradually increasing frequency of vascular diseases, including myocardial infarctions, developing among the aging bomb survivors[13]. Compared to radiation-induced cancer, much is still unknown about how radiation exposure results in mainly arteriosclerosis and other vascular diseases. Based on the fact that such diseases involve elevated CRP values, which are an indicator of chronic inflammation, a theory that attributes the cause to chronic inflammation of blood vessel cells (endothelial cells) is gaining ground.

(2) Psychological and social effects of elevated lifetime risk from atomic bomb radiation exposure
With 50 years having passed since the bombings, a large-scale mental health study was conducted in 1995 in Nagasaki that focused on the worsening problem of atomic bomb survivors' mental health as they aged. The study targeted social groups as designated by the WHO and measured the mental health of survivors at the time based on a 12-item general questionnaire completed by individual bomb survivors themselves. Figure 22 shows that having 10 points or higher indicates a considerable worsening of mental health, and that there is a clear relationship between worsened mental health and distance from ground zero. The study analyzed things such as whether or not the survivors suffered acute radiation during the detonation, lost family, or suffered aftereffects, and a higher score indicates a higher incidence rate of these conditions. Those with poor mental health often have nightmares or flashbacks about the bomb when August comes around, or live in a general state of depression. This suggests that, even more than half a century after the fact, the bombing remains a tragic memory and continues to cause suffering among the survivors.

The specific psychological trauma suffered by bomb survivors is as follows: 1. Regret and guilt. These survivors regret not being able to help others, despite the situation being one in which they could not help. They feel guilt at having saved themselves and abandoned students, relatives, and others asking for help. 2. Interminable anxiety. They hear about a relative or friend dying from a bomb-related sickness or injury and worry that the same fate awaits them, or they get married and worry about their children being affected. 3. Flight response. They build mental barrier to protect them from ever experiencing the hell they once experienced. This manifests itself in a persisting abnormal fear and rejection of lightning, strong light, and loud noises. 4. Reverence for the dead. Bomb survivors see bomb victims as having died in their place and have a respect for the dead. They feel that their heavy mourning is the least they can do to relieve their guilt, and is an outpouring of the gratitude they feel towards those who died.

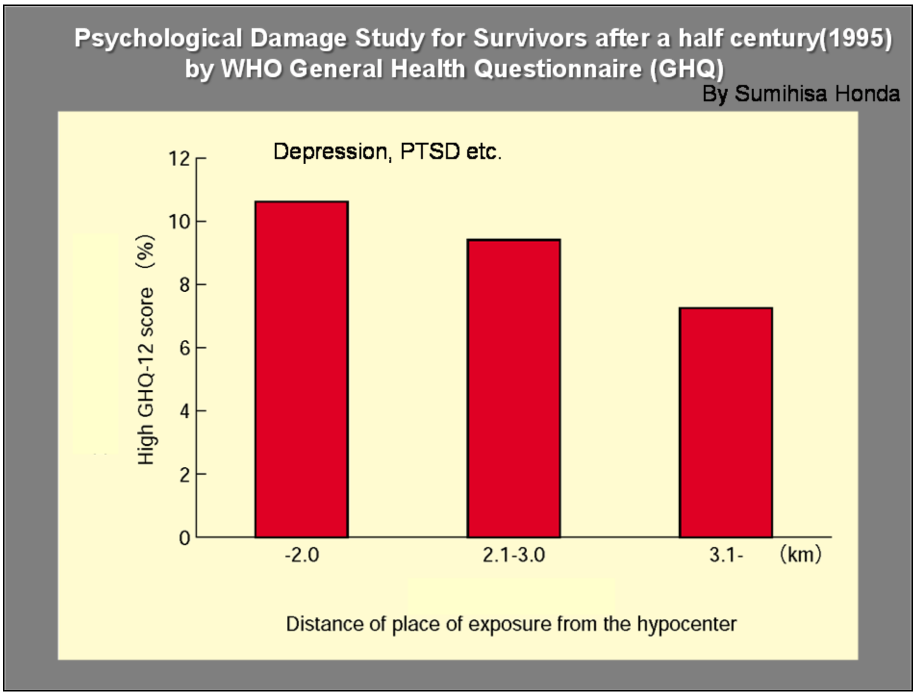

Fig. 22 Survey of the psychological effects suffered by bomb survivors

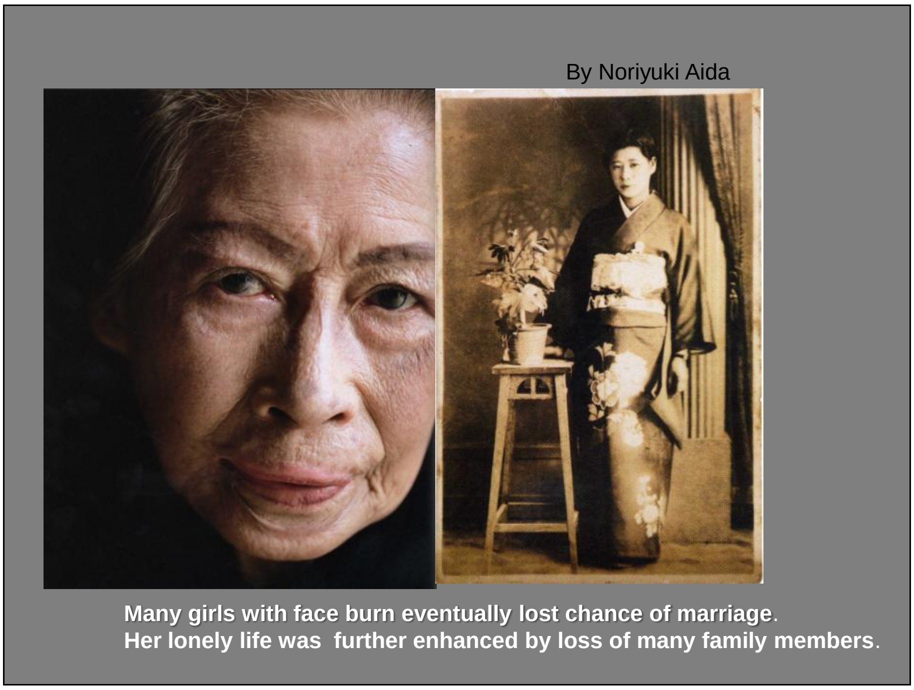

Fig. 23 Keloid scars across the entire face resulting from the Nagasaki bombing

4.9 Effects on social life

Bomb survivor’s social lives have also been affected. There have been more than a few cases where those who experienced the aforementioned horrors of the bomb met with some form of discrimination in society as atomic bomb survivors. The most pronounced example of this is the discrimination that young female victims of the bombings faced when seeking marriage. Because of the possibility of these women's children being affected, some hesitated to disclose being a bombing survivor.

4.10 Children of atomic bomb survivors (offspring of survivors)

It has long been feared that DNA in the sperm and eggs of offspring of survivors' parents, who were exposed to atomic bomb radiation, was damaged, passing this damage on to them and elevating their risk of developing deformities, cancer, or a range of adult-onset diseases. This phenomenon became clear through experiments involving exposing rats and mice to radiation, and is based on experimental evidence. In addition to the studies that have been conducted by the RERF (Radiation Effects Research Foundation), there are a number of other studies (shown in Table 11) that have looked at the children of bombing victims for whom exposure dose has been estimated. None of these studies has provided any definitive evidence of genetic damage[15].

As the average age of these offspring of survivors targeted by the studies are still relatively young (moving into their 50s and 60s), it will be very important to see if there is any genetic damage at work in the development of cancers, high blood pressure, myocardial infarctions, diabetes, and other so-called multifactorial diseases. It is too soon to draw any conclusions.

Should any effects be discovered, they will likely be in the children of parents who were close to ground zero. If genetic damage is observed in humans as it has been observed in animal experiments, we will now see that the effects of atomic bombs carry over to the next generation, making for a very serious situation. Because their many fears have yet to be assuaged, psychological effects are already being seen among offspring of survivors.

Summary of study concerning genetic effects in Hiroshima and Nagasaki survivors

Study areas	Target population (people)	Genetic effects
Abnormal pregnancies (deformities, stillbirths, death immediately after birth)	71,280	None
Male/female ratio	47,624	None
Chromosome aberrations (lymphocytes)	16,298	None
Malignant tumor frequency	72,000	Not detected
Death rate	68,000	Not detected
Gene mutation (Proteins)	30,000	None
DNA research	1,000 (families)	Pending

As second-generation survivors are reaching the adult-onset age for multifactorial diseases, large-scale prospective studies are being conducted by the Radiation Effects Research Foundation.

Table 11 Health study on the children of bomb survivors (offspring of survivors)

4.11 Summary of the long-term effects on the human body

As has been clarified through the above medical observations, atomic bombs are weapons capable of indiscriminant slaughter. Their initial damage is done by the shock wave, heat rays, and radiation, and people are killed instantly by three fatal physical forces. This is coupled with the fact that the resulting radiation exposure affects peoples' health for the rest of their lives. Moreover, there is no doubt that the effects will continue until 2045 (100 years after the bombings), when all the survivors are dead. The psychological damage and social discrimination suffered by survivors is profound and never goes away. Fears of genetic damage also have yet to be eliminated. A comprehensive knowledge concerning the effects on atomic bomb survivors remains elusive.

Chapter 2. Hypothetical damage in the event of a nuclear explosion in a modern city

(Masao Tomonaga / Nanao Kamada / Hiromi Hasai)

1. Physics-related hypothetical scenario

In hypothetical scenarios, there is no limit to things like bomb yield, explosion height, population density, time period, buildings, etc. The actual bombs dropped on Hiroshima and Nagasaki were about 20 kt. Here we will estimate damage by taking social composition and the architectural environment into account using the Hiroshima atomic bomb as a primary reference. Damage will also be estimated for a 1 MT hydrogen bomb dropped at a height of 2,400 m. This height will maximize the range of the shock wave, which has a certain destructive force.

1.1 Extent of damage

Regarding the effects on the human body, the effects of shielding provided by wooden structures as well as that by non-wooden structures must be taken into account alongside the effects of suffering a direct hit. As recent years have seen an increase in the number of high-rise buildings, this scenario assumes that the average wooden structure has two floors and that the average non-wooden structure has five floors, and buildings are placed 25 m apart.

(1) Estimated damage to the human body from initial radiation (based on Hiroshima bombing dose levels)

Table 12 provides another look at the relationship between exposure dose and distance from ground zero in the case of Hiroshima. Table 13 was used in estimating non-wooden structure shielding.

Table 12 Distance from ground zero and initial radiation dose (shielding effects taken into account)

Distance	Neutrons (mGy)	Gamma rays (mGy)	Total dosage (mGy)	Dose absorbed by human body (mSv)	Wooden structures	Non-wooden structures
(m)					mSv	mSv
100	32,000	115,000	147,000	435,000	302,000	66,000
500	6,480	35,700	42,180	100,500	66,000	14,000
1,000	260	4,220	4,480	6,820	4000	600
1,500	9	527	536	617	300	30
2,000	0.4	76	77	80	31	
2,500	0.00	13	13	13		

(Bibliographic reference 6)

Table 13 Initial radiation shielding factor (permeability) according to shielding type

Shielding type	Neutrons		Gamma rays	
	Atomic bomb	Hydrogen bomb	Atomic bomb	Hydrogen bomb
Concrete thickness: 60 cm	0.2	0.01	0.02	" "
" " 100 cm	0.1	0.001	0.005	" "
" " 160 cm	0.02	-	0.00015	" "
Wooden structures	0.8	0.6	0.4	" "

Table 14 below shows the effect of full-body exposure to radiation during the acute phase.

Table 14 Exposure dose for those killed or injured used in estimating damage

Exposure dose	Dead	Acute disorders	Uninjured
7 Sv or higher	100%	—	—
4 Sv to less than 7 Sv	50%	50%	—
2 Sv to less than 4 Sv	5%	95%	—
1 Sv to less than 2 Sv	—	100%	—
0.1 Sv to less than 1 Sv	—	—	100%

The hypothetical ranges of effect for initial radiation (ranges of affect estimated from tables 12, 13, and 14) are shown in Table 15.

Table 15 Hypothetical ranges of radiation effect

Category		16 KT	1 MT
100% dead	Open air Wooden structures Non-wooden structures	0.9 km 0.8 km 0.6 km	0.9 km 0.2 km —
50% dead	Open air Wooden structures Non-wooden structures	1.1 km 0.9 km 0.7 km	1.3 km 0.8 km —
Affected 0.01 Sv or higher	Open air Wooden structures Non-wooden structures	2.5 km 2.3 km 1.7 km	3.0 km 3.0 km 2.1 km

(2) Hypothetical ranges of effect for shock waves

Shockwaves and shock waves knock down various buildings, adding to bodily injury. Table 16 shows ranges for distance from ground zero, shock wave arrival time, and the casualty rate.

Table 16 Range of calculation for rate of casualties attributed to shock wave and shock wave arrival time

Category		16 KT	1 MT
Casualty rate range		4.5 km	18.0 km
Time to achieve the above		11.6 seconds	46.4 seconds
Window glass breakage		7.2 km	29.0 km
Wooden houses	Serious damage Moderate damage	2.0 km 2.5 km	8.9 km 10.1 km
Steel-framed buildings	Serious damage Moderate damage	0.5 km 0.6 km	2.5 km 2.8 km
Reinforced concrete	Serious damage Moderate damage	0.6 km 0.7 km	2.8 km 3.1 km

(Bibliographic reference 1)

(3) Hypothetical damage to the human body from heat rays

Heat rays can be blocked to a certain extent by hats and clothing. But even they themselves can catch on fire if there is sufficient heat. Heat rays arrive together with light, and vision is temporarily lost in a range that far exceeds the range in which burns can occur. In the case of a 1 MT nuclear explosion, vision is lost for about 10 seconds at a range of 21 km from ground zero at a 10,000-foot elevation. Retinal burn can even occur at a distance of 53 km if one's gaze is fixed on the fireball (bibliographic reference 1). Table 17 shows the hypothetical effects of heat rays.

Table 17 Hypothetical range of effect of heat rays

Category		16 KT	1 MT
Burn depth	Third-degree Second-degree	2.2 km 2.8 km	12.3 km 15.0 km
Heat ray duration		1.4 seconds	8.7 seconds

(Bibliographic reference 1)

(4) Hypothetical damage to the human body from fires

Heat rays would cause combustibles to catch fire, buildings knocked down by the blast would touch off fires, and fires would rage across a large area. The range of the fires would be extensive: although much depends on various conditions and fire prevention measures in place, compared to 69 years ago, the urban environments of today – where cars are now commonplace on streets – are full of combustibles. Based on data for 1945, large fires would cover a 2.0 km and 7.9 km radius for a 16 KT bomb and 1 MT bomb, respectively. In Hiroshima, there was a firestorm in one section of the city that was burning. The range the fires would extend are shown in Table 18.

Table 18 Hypothetical fire range

Category	16 kt	1 mt
Large fire range	2.0 km	7.9 km

(Bibliographic reference 1)

(5) Hypothetical damage to the human body from induced radiation

Induced radiation dose is determined by the relationship between materials on the ground and neutron dose. Megaton-class bombs result in a lower number of neutrons reaching the ground, and fewer radioactive materials are generated compared to kiloton-class bombs.

(6) Hypothetical damage to the human body from radioactive fallout

The bomb that fell on Hiroshima had a high burst height and exploded at high temperature, which caused the materials remaining after the explosion to rise suddenly up into the air and disperse. Many of the substances remaining after the explosion in Nagasaki rained down on the Nishiyama region. As has been confirmed in the Koi and Takasu regions in the case of Hiroshima, later atmospheric nuclear testing resulted in nearly 10 times the amount of fallout, the measurement of which is difficult to accomplish now. Although the possibility of substances remaining after the explosion in the case of even megaton-class bombs cannot be denied, because they are rolled up higher into the sky, and the danger they pose is relatively lower.

(7) Effects of electromagnetic pulses

Although not a concern at the time, modern-day cities are full of electronic equipment. Consideration must therefore be given to the effects of electromagnetic pulses. Effects are especially widespread in the case of megaton-class bombs.

1.2 Comprehensive damage evaluation

(1) Population density

In order to consider issues such as shielding against initial radiation and heat rays, the Manual to Assist in Estimating Earthquake Damage (Cabinet Office Disaster Prevention Department) was referenced in dividing up the daytime population of the affected areas as follows: During the daytime on a weekday, 90% were indoors, 35% were at home, 60% were in wooden buildings, and those not at home were in non-wooden structures. We determined that 75% of the population outdoors would be shielded due to being behind some kind of building. As no city of 1 million people with a uniform population density could be found, the population density at the center of Hiroshima was assumed throughout. Table 19 shows the estimated population density for the daytime as calculated using a method in the Hiroshima Atomic Bomb Damage Journal.

Table 19 Estimated daytime population distribution (daytime population) in a 4.5 km radius

Total	Indoors - wooden structure	Indoors - non-wooden structure	Outdoors - shielded	Outdoors - open air
585,215	95,136	431,558	43,891	14,630
100%	16.3 %	73.7 %	7.5 %	2.5 %

(2) Range of effect for a 16 KT atomic bomb and a 1 MT hydrogen bomb

Figures 24 and 25 show the respective radiation, shock wave, and heat rays that result from a 16KT atomic bomb and a 1MT hydrogen bomb. Table 26 shows the range (radius) of damage to the city from the shock wave and heat rays at the burst height for both the atomic bomb and hydrogen bomb.

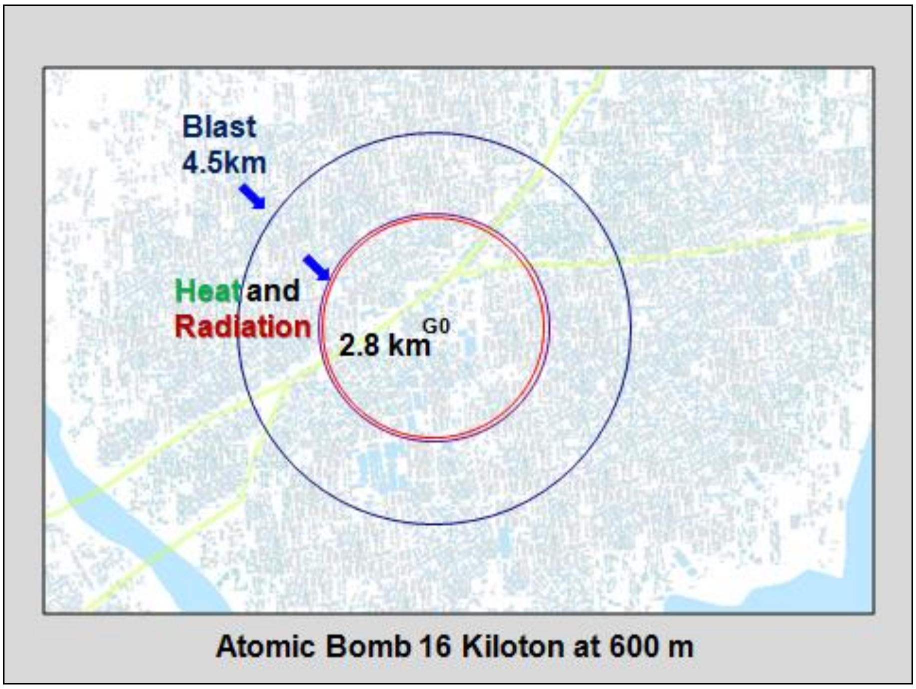

Fig. 24 Range of effect for 16 KT atomic bomb on a modern city of 1 million

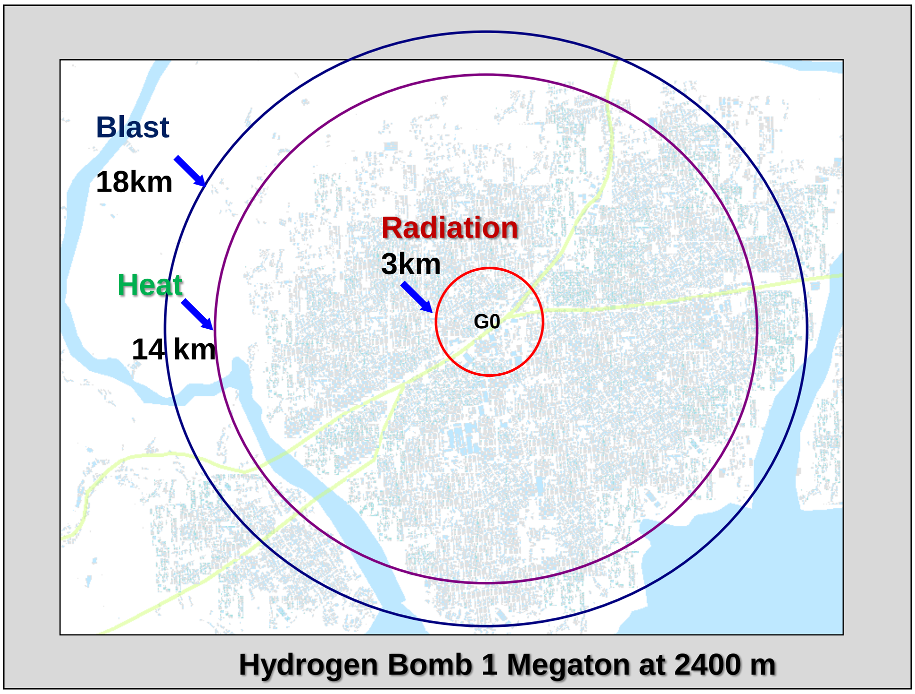

Fig. 25 Range of effect for 1 MT hydrogen bomb on a modern city of 1 million

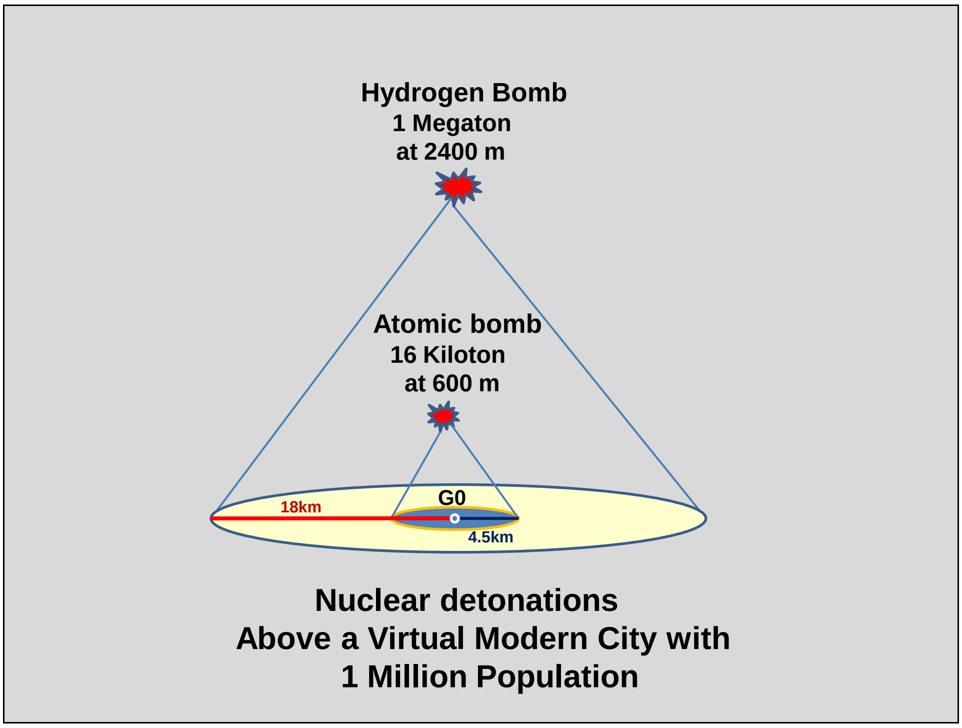

Fig. 26 Burst height and range of effect

Immediate and Late Casualty of Nuclear Detonations in a Modern Virtual City with 1,000,000 population and 400,000 in suburb

	16 kiloton atomic bomb	1 megaton hydrogen bomb
Immediate Death	66,000	370,000
Immediate Injury	205,000	460,000
Radiation-affected population	155,000 (within 2.8 km)	36,000 (within 3 km)
Excess Leukemia	220	70
Excess Cancers	12,000	650

Table 20 Number of dead, excess cases of leukemia, and excess cases of cancer for a hypothetical city of 1 million

(3) Comparing casualties

Table 20 shows the casualties (in the acute phase) from a 16 KT atomic bomb like the Hiroshima bomb and a 1 1MT atomic bomb. The casualty rate determined here reflects an assumption of high protection being provided by strong buildings such as those with reinforced concrete frames. On the other hand, it is assumed that evacuation from high-rise buildings would be more problematic.

2. Medical consequences

Due to the extreme difficulty in estimating the number of people that would die from acute radiation sickness or as a result of external injuries from among the number of wounded shown above, no such estimates were made for this study. Especially in the case of the hydrogen bomb, it is highly likely that even those whose lives would be saved by the shielding provided by being inside a tall building would be burned to death in the conflagrations or firestorms that would follow. As no such event has ever occurred, there is no base data on which to perform calculations.

It goes without saying that these wounded would become bomb survivors, many of whom would continue to live out their lives, just as in the case of Hiroshima and Nagasaki. The fate of some of these would involve leukemia and cancer. Table 20 shows estimates for the number of affected for both the atomic bomb and the hydrogen bomb using the radiation contribution ratio for the Hiroshima atomic bomb.

For leukemia, it was estimated that 220 atomic bomb survivors and 70 hydrogen bomb survivors would develop this condition. It may seem odd that the number for the hydrogen bomb is significantly lower than for the atomic bomb. However, as was mentioned earlier, the higher burst height (2,400 m) of hydrogen bombs results in less radiation reaching the ground (due to decay). This produces a lower absolute number of exposed. The same is true for cancer: the affected would be 12,000 versus a much lower 650 for the atomic bomb and hydrogen bomb, respectively.

3. Summary concerning explosions in the air over a fictional modern city

As can be seen, the extent of human suffering in a city of 1 million from a single atomic bomb or hydrogen bomb goes far beyond what a single nation can endure. When they come without warning, as was the case in Hiroshima and Nagasaki, these weapons of indiscriminate destruction kill without respect to age or gender, civilian or soldier, causing more damage than even natural disasters. The resulting casualty rates are beyond what a country can handle. Even the injured who survive become bomb survivors and—as with Hiroshima and Nagasaki—live in fear of their heightened risk of developing leukemia and cancer.

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(Chapter 1 and Chapter 2)

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Chapter 3. Estimation of Damage to Social Infrastructure

(Haruo Hayashi)

1. Introduction

This paper estimates the damage to 15 areas: roads; harbors; aviation; railroads; public rental housing; sewerage systems; waste treatment; water supply; municipal parks; educational facilities; agriculture, forestry and fisheries; postal services; and industrial water supply, which are defined as social infrastructure (social capital) by the Cabinet Office, as well as electrical power and communications.

The damage estimates were made for six scenarios in terms of atomic bomb power and height of burst: a 20-kiloton, 100-kiloton, and 1,000-kiloton atomic bomb with either an air burst or surface burst during the daytime on a sunny day. For air bursts, the results of past research were referenced to set the burst height so as to maximize the extent of the overpressure's constant pressure lines. The effects examined were the damage caused by the overpressure (sudden rise in pressure) and heat rays produced by an atomic bomb.

2. Social infrastructure that makes up a city

The Cabinet Office defines social infrastructure (social capital) as the 17 areas of roads; harbors; aviation; railroads; public rental housing; sewerage systems; waste treatment; water supply; municipal parks; educational facilities; water conservation; soil conservation; coasts; agriculture, forestry and fisheries; postal services; national forests; and industrial water supply, indicated in Table 2.1, and has estimated the stock value.[1] There are other definitions of social infrastructure. This study examines 13 of these areas shown in Table 2.1 plus electrical power and communications, for a total of 15 areas. They were arranged in relation to the constituent parts of social infrastructure for which aspects of damage caused by an atomic bomb have been described in past research.

Table 2.1 Social infrastructure examined in this study and its constituent parts

No.	Type of infrastructure	Scope of this study
1	Roads	Highway bridges and vehicles
2	Harbors	Buildings and outdoor tanks
3	Aviation	Buildings
4	Railroads (Japan Railway Construction, Transport and Technology Agency, and subways, etc.)	Railroad bridges and railroad vehicles (subways not included)
5	Public rental housing	Buildings
6	Sewerage system	Buildings, treatment plants, and piping
7	Waste treatment	Buildings
8	Water supply	Buildings, purification plants, underground piping
9	Municipal parks	Buildings
10	Educational facilities (school facilities, academic facilities, social education facilities, social athletic facilities, and cultural facilities)	Buildings
11	Water conservation	―
12	Soil conservation	―
13	Coasts	―
14	Agriculture, forestry and fisheries	Buildings
15	Postal services	Buildings
16	National forests	―
17	Industrial water supply	Buildings, purification plants, and underground piping
18	Electrical power	Buildings, utility poles, electric lines, and pole-mounted transformers
19	Telephone	Buildings and telephone lines

3. Conditions of the atomic bombs considered

3.1 Power and burst height of the atomic bombs considered

In the study of the aspects of damage to social infrastructure, the combinations given in Table 3.1 for the power and burst height of an atomic bomb were considered. The burst was assumed to occur in the daytime on a sunny day.

Table 3.1 Examination condition of atomic bomb power and burst height

Atomic bomb power	Burst height	
	Air burst	Surface burst
20 kilotons	Burst at 1,400 feet Daytime, sunny	Burst on surface Daytime, sunny
100 kilotons	Burst at 3,000 feet Daytime, sunny	Burst on surface Daytime, sunny
1,000 kilotons	Burst at 6,500 feet Daytime, sunny	Burst on surface Daytime, sunny

3.2 Atomic bomb effects considered

The atomic bomb effects considered were the damage caused by overpressure (sudden rise in pressure) and heat rays. The effects of radiation were not taken into account.

Referring to references 3 to 5 for models of overpressure caused by an explosion, the distance from ground zero where the overpressure originates was arranged by burst height and overpressure for the three atomic bombs. The results are shown in Tables 3.1 and 3.2.

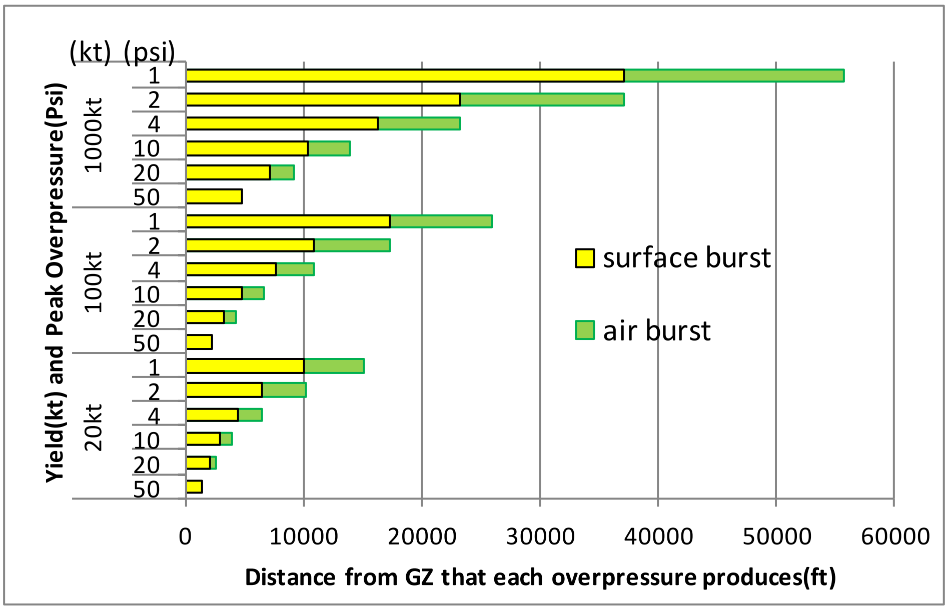

Figure 3.1 Relationship between overpressure and distance from ground zero for each bomb power[3),4)]

According to these results, the scope at which causalities start to appear at 1 psi,[2] would be 15,100 feet (about 4.6 km) with an air burst of a 20-kt atomic bomb and 10,000 feet (about 3 km) with a surface burst. Likewise, the scope would be 25,900 feet (about 7.9 km) with an air burst of a 100-kt atomic bomb and 17,200 feet (about 5.2 km) with a surface burst. In the case of a 1,000-kt atomic bomb, the scope would be 55,700 feet (about 17 km) with an air burst and 37,100 feet (about 11 km) with a surface burst.

Referring to reference 3 for a model of heat rays from an explosion, the distance from ground zero where the radiant exposure originates was arranged by burst height and radiant exposure for the three atomic bombs. The results are shown in Table 3.3. According to the results, the radiant exposure at which second degree burns (blister formation) start to appear (4.5cal/cm^2) would extend to 9,500 feet (about 2.9 km) with a 20-kt atomic bomb. Likewise, the radiant exposure would extend to 44,900 feet (about13.7km) with a 1,000-kt atomic bomb, to 17,200 feet (about 5.2 km) with a surface burst, and to 55,700 feet (about 17 km) with an air burst of a 1,000-kt atomic bomb.

Table 3.2 Peak overpressure as a function of ground distance for the three atomic bombs[3),4)]

Power of atomic bomb (kt)	Peak overpressure (psi)	Ground distance(ft) from GZ of air burst	Ground distance(ft) from GZ of surface burst
20kt	50	0	1,300
	20	2,500	1,900
	10	3,800	2,800
	4	6,300	4,400
	2	10,100	6,300
	1	15,100	10,000
100kt	50	0	2,200
	20	4,200	3,200
	10	6,500	4,700
	4	10,800	7,500
	2	17,200	10,800
	1	25,900	17,200
1000kt	50	0	4,600
	20	9,100	7,000
	10	13,900	10,200
	4	23,200	16,200
	2	37,100	23,200
	1	55,700	37,100

Table 3.3 Heat rays as a function of ground distance for the three atomic bombs[3),4)]

Power of atomic bomb (kt)	Heat rays(cal/cm^2)	Slant ranges (ft) from GZ of air bursts at altitudes up to 15,000 ft for a 12 mile visibility
20kt	50	3200
	26	4500
	12	6300
	6	7900
	5	9500
	3	13200
100kt	50	6300
	26	9500
	12	13200
	6	15800
	5	18500
	3	23800
1000kt	50	18500
	26	26400
	12	34300
	6	37000
	5	44900
	3	63400

4. Effects of blast waves and heat rays on social infrastructure

This chapter organizes the study results relating to the damage effects of blast waves and heat rays on the constituent structures that make up the social infrastructure indicated in Table 2.1. It then qualitatively describes the aspects of damage to social infrastructure in light of the damage to constituent elements.

4.1 Effects of blast waves and heat rays on the constituent elements of social infrastructure

The power of the atomic bombs, overpressure, and distance at which different degrees of damage occur (threshold) were arranged for the constituents that make up social infrastructure: structures (Table 4.1), non-structural elements of buildings (Table 4.2), highway bridges (Table 4.3), automotive vehicles (Table 4.4), above-ground storage tanks (Table 4.5), railroad bridges (Table 4.6), railroad vehicles (Table 4.7), sewerage facilities (Table 4.8), water supply systems (Table 4.9), electrical power facilities (Table 4.10), and communications facilities (fixed telephone lines) (Table 4.11).[3-5] See each table for details.

4.2 Effects of blast waves and heat rays on social infrastructure

This section describes the aspects of damage to social infrastructure caused by a 20-kt, 100-kt, and 1,000-kt atomic bomb. Figures 4.1 to 4.3 arrange the damage to main structures that make up social infrastructure of a nuclear explosion and the distance over which damage occurs for a 20-kt, 100-kt, and 1,000-kt atomic bomb, respectively.[3-5]

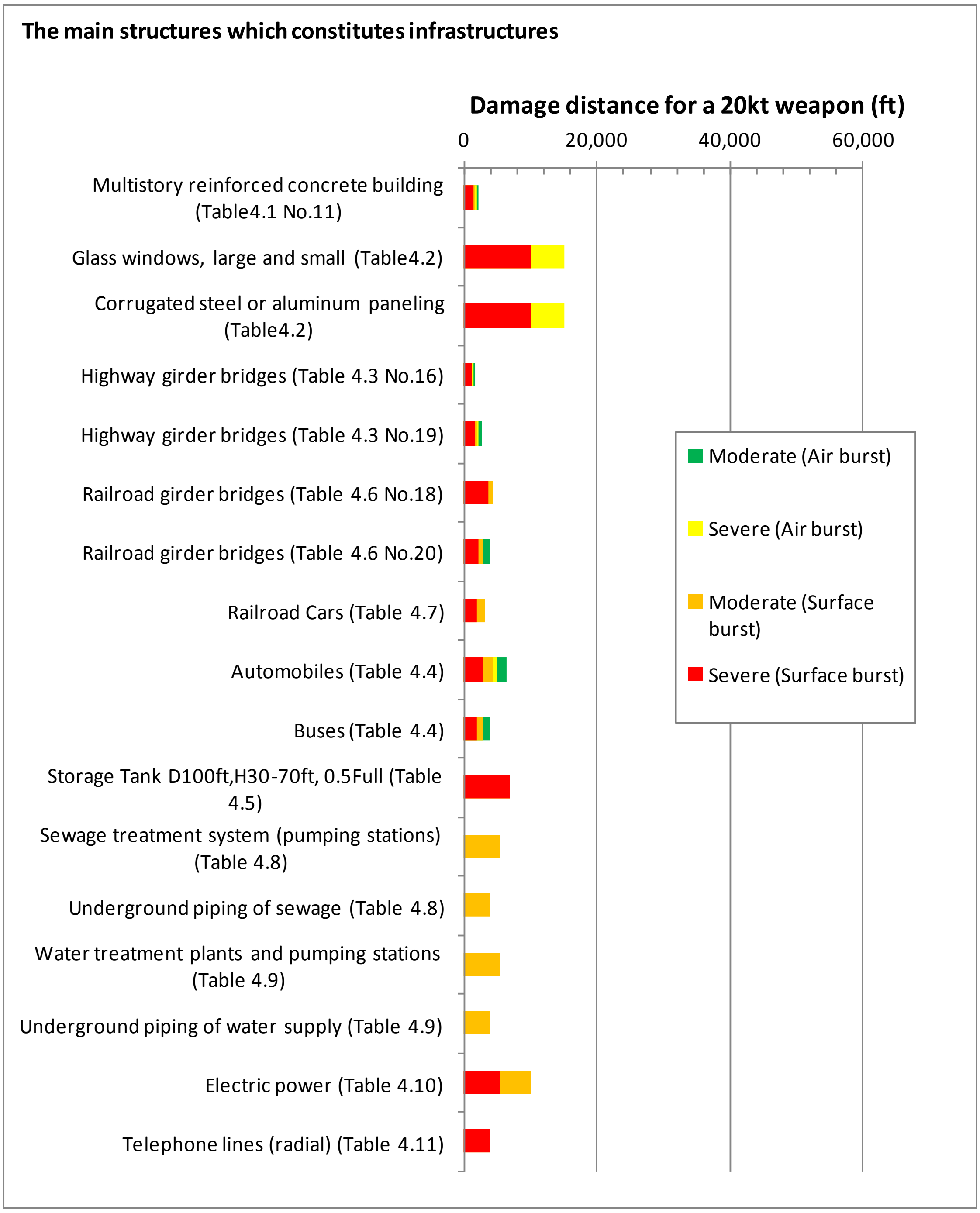

Figure 4.1 Relationship between the main structures and distance over which damage is caused by a 20-kt atomic bomb[3)-5)]

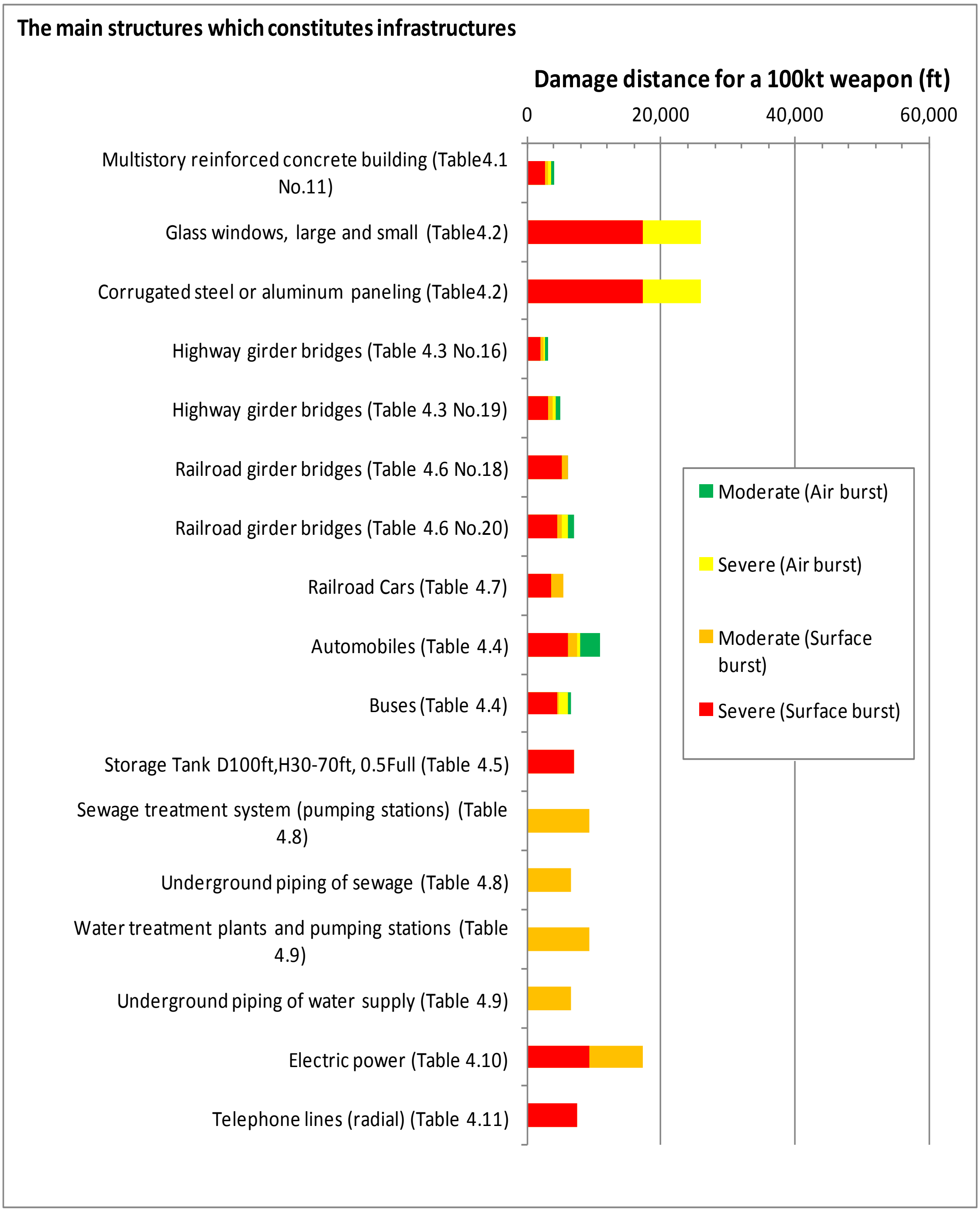

Figure 4.2 Relationship between the main structures and distance over which damage is caused by a 100-kt atomic bomb[3)-5)]

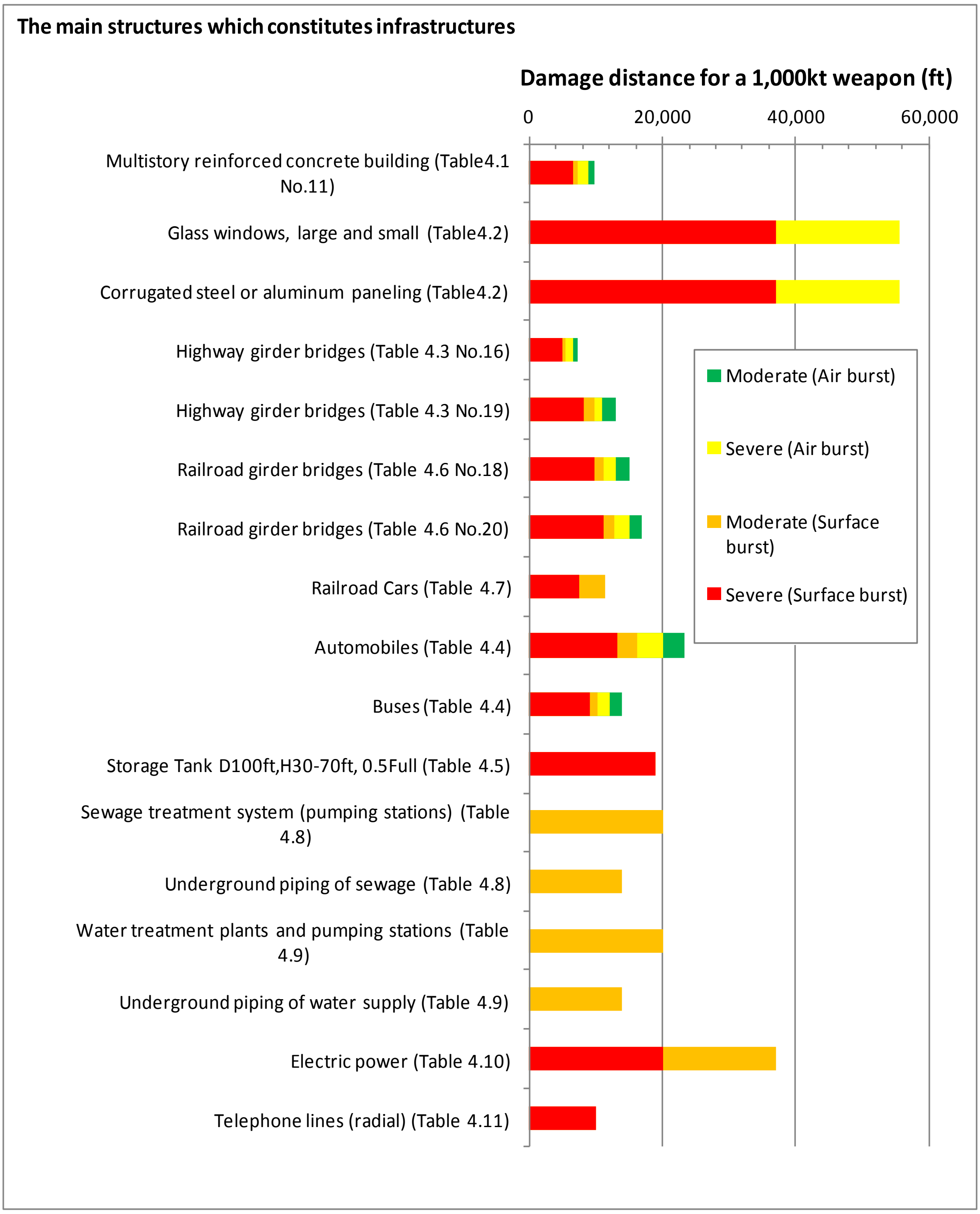

Figure 4.3 Relationship between the main structures and distance over which damage is caused by a 1,000-kt atomic bomb[3)-5)]

(1) 20-kt air burst

i) Description of damage within a 3,280-ft (1 km) radius of ground zero

Many highway bridges have collapsed or are severely damaged but some are only moderately damaged depending on the type of structure (Table 4.3(a)). Nearly all cars and buses, etc., are inoperable (Table 4.4). Warehouse buildings with reinforced concrete walls seen at harbors and heavy steel-frame industrial buildings are a mixture of collapsed or severely damaged buildings and buildings with moderate damage (Table 4.1(a) items 2, 7, and 8). Many storage tanks with a diameter of 100 feet or less are severely damaged (Table 4.5). Structures at airport facilities are a mixture of collapsed or severely damaged structures and structures with moderate, light, or no damage; however, even where structural damage is light or non-existent, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Depending on the type of structure, railroad bridges are a mixture of collapsed or severely damaged structures and structures with moderate, light, or no damage (Table 4.6(a)). Most railroad vehicles are severely damaged but some are operable (Table 4.7). Station buildings with steel frames or reinforced concrete frames are a mixture of collapsed or severely damaged buildings and buildings with moderate, light, or no damage; however, even where structural damage is light or non-existent, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Public rental housing and structures at educational facilities are a mixture of collapsed or severely damaged structures and structures with moderate, light, or no damage; however, even where structural damage is light or non-existent, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). As for lifeline facilities, water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping have been catastrophically damaged and have stopped functioning (Tables 4.8 to 4.11). Additionally, building facilities for agriculture, forestry and fisheries as well as post offices are a mixture of collapsed or severely damaged structures and structures with moderate, light, or no damage; however, even where structural damage is light or non-existent, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)).

ii) Description of damage within a 3,280- to 16,400-ft (1 to 5 km) radius of ground zero

Many highway bridges have light or no damage (Table 4.3(a)). Cars and other small vehicles are inoperable but buses and other large vehicles are operable (Table 4.4). While some moderate damage is seen in warehouse buildings with reinforced concrete walls seen at harbors and heavy steel-frame industrial buildings, many have light or no damage; however, even where structural damage is light or non-existent, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 2, 7, and 8, and Table 4.2(a)). Regarding storage tanks with a diameter of 100 feet or less, those that are about half full or empty have collapsed or are severely damaged (Table 4.5). Structures at airport facilities have light or no damage; however, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). As for railroad facilities, most railroad vehicles have no damage while railroad bridges have mostly light or no damage (Table 4.6(a) and Table 4.7). Station buildings with steel frames or reinforced concrete frames have structurally light or no damage; however, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Public rental housing and educational facilities have light or no damage; however, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Water supply, sewerage systems, industrial water supply, electrical power, and telephones are damaged and inoperable closer to ground zero and operable near 16,400 feet (Tables 4.8 to 4.11). Buildings for agriculture, forestry and fisheries as well as post offices have structurally light or no damage if they have steel frames or reinforced concrete frames; however, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)).

iii) Description of damage within a 16,400- to 32,800-ft (5 to 10 km) radius of ground zero

Many highway bridges have light or no damage and are usable while cars as well as buses and other large vehicles are also operable (Table 4.3(a) and Table 4.4). In harbor areas, warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings closer to ground zero have no structural damage and non-structural elements such as glass windows and outer walls are also undamaged (Table 4.1(a) items 2, 7, and 8, and Table 4.2(a)). Some empty storage tanks with a diameter of 100 feet or less have collapsed or are severely damaged (Table 4.5). The structures and non-structural elements of airport facilities are undamaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). As for railroad facilities, railroad bridges and railroad vehicles are undamaged (Table 4.6(a) and Table 4.7). The structures and non-structural elements of station buildings with steel frames or reinforced concrete frames are undamaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). The structures and non-structural elements of medium- and low-rise public rental housing and educational facilities with reinforced concrete frames are undamaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone systems are undamaged and operable (Tables 4.8 to 4.11). The structures and non-structural elements of buildings for agriculture, forestry and fisheries as well as post offices are undamaged (le 4.1(a) items 9 and 11, and Table 4.2(a)).

(2) 100-kt air burst

i) Description of damage within a 3,280-ft (1 km) radius of ground zero

Many highway bridges have collapsed or are severely damaged and are impassable; however, girder bridges with a 75-ft span have moderate or lighter damage (Table 4.3(a)). Nearly all cars, buses, and other automobiles are inoperable (Table 4.4). Many warehouse buildings with reinforced concrete walls seen at harbors and heavy steel-frame industrial buildings have collapsed or are severely damaged (Table 4.1(a) items 2, 7, and 8). Many storage tanks with a diameter of 100 feet or less are severely damaged (Table 4.5). The structures of many buildings at airport facilities have collapsed or are severely damaged and non-structural elements such as glass windows and outer walls are also severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). As for railroad facilities, most railroad bridges and vehicles have collapsed or are severely damaged and many routes have stopped running (Tables 4.6(a) and 4.7). The structures of many station buildings with steel frames or reinforced concrete frames have collapsed or are severely damaged and non-structural elements such as glass windows and outer walls are also severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Medium- and low-rise public rental housing and educational facilities with reinforced concrete frames are severely damaged, and non-structural elements are also severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping have been catastrophically damaged and have stopped functioning (Tables 4.8 to 4.11). The structures of buildings for agriculture, forestry and fisheries as well as post offices have collapsed or are severely damaged and are unusable (Table 4.1(a) items 9 and 11).

ii) Description of damage within a 3,280- to 16,400-ft (1 to 5 km) radius of ground zero

Highway bridges are a mixture of collapsed or severely damaged structures and structures with moderate, light or no damage (Table 4.3(a)). Railroad vehicles with moderate, light or no damage tend to increase the farther away they are from ground zero (Table 4.4). In harbor areas close to ground zero, warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings have collapsed or are severely damaged (Table 4.1(a) items 2, 7, and 8). Many storage tanks with a diameter of 100 feet or less are severely damaged (Table 4.5). At airport facilities, some buildings have collapsed or are severely damaged but the structural damage of medium- and low-rise buildings with steel frames or reinforced concrete frames is light or non-existent (Table 4.1(a) items 9 and 11). Non-structural elements such as glass windows and outer walls are severely damaged (Table 4.2(a)). While some railroad bridges closer to ground zero have collapsed or are severely damaged, many have moderate, light, or no damage (Table 4.6(a)). Although some railroad vehicles are moderately damaged, many have light or no damage (Table 4.7). Many station buildings with steel frames or reinforced concrete frames have light or no damage; however, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Medium- and low-rise public rental housing and educational facilities with reinforced concrete frames have light or no damage; however, non-structural elements are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). As for lifeline facilities, water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping closer to ground zero have been catastrophically damaged and have stopped functioning (Table 4.8) but are operable in areas farther away from ground zero (Tables 4.8 to 4.11). The structures of building facilities for agriculture, forestry and fisheries as well as post offices have light or no damage, but non-structural elements are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)).

iii) Description of damage within a 16,400- to 32,800-ft (5 to 10 km) radius of ground zero

Most highway bridges have light or no damage and vehicles are operable (Tables 4.3(a) and 4.4). Warehouse buildings with reinforced concrete walls in harbor areas and heavy steel-frame industrial buildings have light or no damage (Table 4.1(a) items 2, 7, and 8). Empty storage tanks with a diameter of 100 feet or less are severely damaged, but others are nearly undamaged (Table 4.5). Buildings at airport facilities have light or no damage; however, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Most railroad bridges and vehicles have light or no damage (Tables 4.3(a) and 4.4). Many station buildings with steel frames or reinforced concrete frames have light or no damage; however, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Medium- and low-rise public rental housing and educational facilities with reinforced concrete frames have light or no damage; however, non-structural elements are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). As for lifeline facilities, water supply, sewerage systems, industrial water supply, electrical power, and telephones are useable as normal (Tables 4.8 to 4.11). The structures of building facilities for agriculture, forestry and fisheries as well as post offices have light or no damage, but non-structural elements are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)).

(3) 1,000-kt air burst

i) Description of damage within a 3,280-ft (1 km) radius of ground zero

Highway bridges have been catastrophically damaged and are impassable (Table 4.3(a)). Cars, buses, and other vehicles are almost all inoperable (Table 4.4). In harbor areas, warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings have collapsed or are severely damaged (Table 4.1(a) items 2, 7, and 8). All tanks with a diameter of 100 feet or less are severely damaged (Table 4.5). The structures and non-structural elements of all buildings at airport facilities have collapsed or are severely damaged (Table 4.1(a) items 9 and 11). As for railroad facilities, all railroad bridges and vehicles have collapsed or are severely damaged (Tables 4.6(a) and 4.7). The structures and non-structural elements of station buildings are severely damaged (Table

4.1(a)). The structures and non-structural elements of public rental housing and educational facilities have collapsed or are severely damaged (Table 4.1(a) items 9 and 11 and Table 4.2(a)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping have been catastrophically damaged and have stopped functioning (Tables 4.8 to 4.11). The structures and non-structural elements of buildings for agriculture, forestry and fisheries as well as post offices have collapsed or are severely damaged (Table 4.1(a)).

ii) Description of damage within a 3,280- 16,400-ft (1 to 5 km) radius of ground zero

Many highway bridges have collapsed or are severely damaged; however, some girder bridges with a span of around 75 feet have moderate or lighter damage (Table 4.3(a)). Nearly all cars, buses, and other automobiles are inoperable; however, some large vehicles farther away from ground zero are operable (Table 4.4). In harbor areas, many warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings have collapsed or are severely damaged; however, some industrial buildings with moderate damage are seen at harbors farther from ground zero (Table 4.1(a) items 2, 7, and 8). All storage tanks with a diameter of 100 feet or less are severely damaged (Table 4.5). Some of the structures and non-structural elements of buildings at airport facilities have collapsed or are severely damaged while others have moderate, light, or no structural damage with severely damaged non-structural elements (Table 4.1(a) items 9 and 11, and Table 4.2(a)). As for railroad facilities, nearly all railroad bridges have collapsed or are severely damaged, but some railroad vehicles are operable (Tables 4.6(a) and 4.7). Station buildings are a mixture of collapsed or severely damaged structures and structures with moderate, light, or no damage; however, even where structural damage is light or non-existent, non-structural elements are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Public rental housing and educational facilities are a mixture of collapsed or severely damaged structures and structures with moderate, light, or no damage, and non-structural elements have collapsed or are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping have been catastrophically damaged and have stopped functioning (Tables 4.8 to 4.11). Building facilities for agriculture, forestry and fisheries as well as post offices are a mixture of collapsed or severely damaged structures and structures with moderate, light, or no damage, and non-structural elements are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)).

iii) Description of damage within a 16,400- to 32,800-ft (5 to 10 km) radius of ground zero

Many highway bridges have light or no damage (Table 4.3(a)). As for vehicles, some cars are severely damaged but many are operable. Buses and other large vehicles are operable (Table 4.4). In harbor areas, the structures of warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings have light or no damage, but non-structural elements are severely damaged (Table 4.1(a) items 2, 7, and 8, and Table 4.2(a)). Regarding storage tanks with a diameter of 100 feet or less, the lower their content, the more severely damaged they are (Table 4.5). The structures of buildings at airport facilities have light or no damage, but non-structural elements are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). As for railroad facilities, many railroad bridges are undamaged and most vehicles are operable (Tables 4.6(a) and 4.7). The structures of railroad stations have light or no damage, but non-structural elements are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). The structures of public rental housing and educational facilities have light or no damage, but non-structural elements are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone base stations are severely damaged and have stopped functioning (Tables 4.8 to 4.11). Building facilities for agriculture, forestry and fisheries as well as the structures of post offices have light or no damage, but non-structural elements are severely damaged (Table 4.1(a) items 9 and 11, and Table 4.2(a)).

(4) 20-kt surface burst

i) Description of damage within a 3,280-ft (1 km) radius of ground zero

Some highway bridges have collapsed or have severe or moderate damage but some have light or no damage depending on the type of structure (Table 4.3(b)). Cars, buses, and other vehicles are a mixture of ones that are inoperable and ones with moderate damage (Table 4.4). Warehouse buildings with reinforced concrete walls seen at harbors and heavy steel-frame industrial buildings are a mixture of collapsed or severely damaged buildings and buildings with moderate, light or no damage (Table 4.1(b) items 2, 7, and 8). Many storage tanks with a diameter of 100 feet or less are severely damaged (Table 4.5). Buildings at airport facilities have collapsed or have severely or moderately damage structures, but many buildings have light or no damage (Table 4.1(b) items 9 and 11). Even where structures have light or no damage, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.2(b)). As for railroad facilities, railroad bridges are a mixture of collapsed or severely damaged bridges and bridges with moderate, light, or no damage depending on their structural type and span (Table 4.3(b)). While some railroad vehicles are severely damaged some are operable (Table 4.7). Station buildings with steel frames or reinforced concrete frames are a mixture of collapsed or severely damaged structures and structures with moderate, light or no damage; however, even where structural damage is light or non-existent, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). Public rental housing and structures at educational facilities are a mixture of collapsed or severely damaged structures and structures with moderate, light or no damage; however, even where structural damage is light or non-existent, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). As for lifeline facilities, water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping have been catastrophically damaged and have stopped functioning (Tables 4.8 to 4.11). Building facilities for agriculture, forestry and fisheries as well as post offices are a mixture of collapsed or severely damaged structures and structures with moderate, light, or no damage; however, even where structural damage is light or non-existent, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)).

ii) Description of damage within a 3,280- to 16,400-ft (1 to 5 km) radius of ground zero

Many highway bridges have light or no damage (Table 4.3(b)). While some cars are inoperable, buses and other large vehicles are operable (Table 4.4). Many warehouse buildings with reinforced concrete walls seen at harbors and heavy steel-frame industrial buildings have light or no damage, but non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(b) items 2, 7, and 8 and Table 4.2(b)). Regarding storage tanks with a diameter of 100 feet or less, many that are about half full or empty have collapsed or are severely damaged (Table 4.5). Building structures at airport facilities have light or no damage, but non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). As for railroad facilities, most vehicles have no damage while railroad bridges mostly have light or no damage, except for single-track girder bridges with a long span (Tables 4.6(b) and 4.7). Station buildings with steel frames or reinforced concrete frames structurally have light or no damage, but non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). Public rental housing and structures at educational facilities have light or no damage, but non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone systems closer to ground zero have been damaged and have stopped functioning, but those near 16,400 feet are operable (Tables 4.8 to 4.11). Buildings for agriculture, forestry and fisheries as well as post offices that have steel frames or reinforced concrete frames structurally have light or no damage, but non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)).

iii) Description of damage within a 16,400- to 32,800-ft (5 to 10 km) radius of ground zero

Many highway bridges have light or no damage and are usable while cars as well as buses and other large vehicles are operable (Tables 4.3(b) and 4.4). In harbor areas, warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings have no structural damage and non-structural elements such as glass windows and outer walls are also undamaged (Table 4.1(b) items 2, 7, and 8 and Table 4.2(b)). Some empty storage tanks with a diameter of 100 feet or less have collapsed or are severely damaged (Table 4.5). The structures and non-structural elements of airport facilities are undamaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). As for railroad facilities, railroad bridges and vehicles are undamaged (Tables 4.6(b) and 4.7). The structures and non-structural elements of station buildings with steel frames or reinforced concrete frames are undamaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). The structures and non-structural elements of medium- and low-rise public rental housing and educational facilities with reinforced concrete frames are undamaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone systems are undamaged and operable (Tables 4.8 to 4.11). The structures and non-structural elements of buildings for agriculture, forestry and fisheries as well as post offices are undamaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)).

(5) 100-kt surface burst

i) Description of damage within a 3,280-ft (1 km) radius of ground zero

Nearly all highway bridges have collapsed or are severely damaged and are impassable, but some girder bridges with a span of 75 feet have roughly moderate damage (Table 4.3(b)). Cars, buses, and nearly all other vehicles are inoperable (Table 4.4). Nearly all warehouse buildings with reinforced concrete walls seen at harbors and heavy steel-frame industrial buildings have collapsed or are severely damaged (Table 4.1(b) items 2, 7, and 8). Many storage tanks with a diameter of 100 feet or less are severely damaged (Table 4.5). At airport facilities, there is a mixture of collapsed or severely damaged buildings and buildings with moderate, light or no damage with some buildings showing no apparent structural damage. Non-structural elements such as glass windows and outer walls are severely damaged in all buildings (Table 4.1(b) items 9 and 11, and Table 4.2(b)). As for railroad facilities, nearly all railroad bridges and vehicles have collapsed or are severely damaged and many routes have stopped running (Tables 4.6(b) and 4.7). Many station buildings with steel frames or reinforced concrete frames are a mixture of collapsed or severely damaged buildings and buildings with moderate, light or no damage; however, non-structural elements such as glass windows and outer walls are severely damaged in all buildings (Table 4.1(b) items 9 and 11, and Table 4.2(b)). Medium- and low-rise public rental housing and educational facilities with reinforced concrete frames are a mixture of collapsed or severely damaged buildings and buildings with moderate, light or no damage; however, non-structural elements are severely damaged in all buildings (Table 4.1(b) items 9 and 11, and Table 4.2(b)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping have been catastrophically damaged and have stopped functioning (Tables 4.8 to 4.11). The structures of buildings for agriculture, forestry and fisheries as well as post offices have collapsed or are severely damaged and are unusable (Table 4.1(b) items 9 and 11).

ii) Description of damage within a 3,280- to 16,400-ft (1 to 5 km) radius of ground zero

Some highway bridges are moderately damaged but most have light or no damage and are passable (Table 4.3(b)). Some vehicles closer to ground zero are inoperable but many vehicles have light damage or are operable (Table 4.4). In harbor areas closer to ground zero many warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings have moderate or lighter damage and there are also many buildings with light or no damage (Table 4.1(b) items 2, 7, and 8). Storage tanks with a diameter of 100 feet or less that are no more than half full are severely damaged (Table 4.5). Some buildings at airport facilities are moderately damaged but most have light or no damage (Table 4.1(b) items 9 and 11). Meanwhile, non-structural elements such as glass windows and outer walls are severely damaged (Table 4.2(b)). As for railroad facilities, some railroad bridges are moderately damaged but many have light or no damage (Table 4.6(b)). Some railroad vehicles are moderately damaged but many have light or no damage (Table 4.7). Many station buildings with steel frames or reinforced concrete frames have light or no damage, but non-structural elements such as glass windows and outer walls are severely damaged (Table 4.1(b) items 9 and 11 and Table 4.2(b)). Medium- and low-rise public rental housing and educational facilities with reinforced concrete frames have light or no damage, but non-structural elements are severely damaged (Table 4.1(b) items 9 and 11 and Table 4.2(b)). Regarding lifeline facilities, water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping closer to ground zero are damaged and have stopped functioning, whereas they are operable in areas farther away from ground zero (Tables 4.8 to 4.11). Building facilities for agriculture, forestry and fisheries as well as post offices have structurally light or no damage, but non-structural elements are severely damaged (Table 4.1(b) items 9 and 11 and Table 4.2(b)).

iii) Description of damage within a 16,400- to 32,800-ft (5 to 10 km) radius of ground zero

Most highway bridges have light or no damage and vehicles are operable (Tables 4.3(b) and 4.4). Warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings in harbor areas have light or no damage (Table 4.1(b) items 2, 7, and 8). Empty storage tanks with a diameter of 100 feet or less are severely damaged, but others are mostly undamaged (Table 4.5). Buildings at airport facilities have light or no damage; non-structural elements such as glass windows and outer walls are damaged in some buildings but undamaged in many buildings (Table 4.1(b) items 9 and 11, and Table 4.2(b)). As for railroad facilities, most railroad bridges and vehicles have light or no damage (Tables 4.3(b) and 4.4). Many station buildings with steel frames or reinforced concrete frames have light or no damage; non-structural elements such as glass windows and outer walls are damaged in some buildings but undamaged in many buildings (Table 4.1(b) items 9 and 11, and Table 4.2(b)). Medium- and low-rise public rental housing and educational facilities with reinforced concrete frames have light or no damage, and non-structural elements are also undamaged in many buildings (Table 4.1(b) items 9 and 11, and Table 4.2(b)). As for lifeline facilities, water supply, sewerage systems, industrial water supply, electrical power, and telephones are useable as normal (Tables 4.8 to 4.11). Building facilities for agriculture, forestry and fisheries as well as post offices have structurally light or no damage, and non-structural elements are also undamaged in many buildings (Table 4.1(b) items 9 and 11, and Table 4.2(b)).

(6) 1,000-kt surface burst

i) Description of damage within a 3,280-ft (1 km) radius of ground zero

Highway bridges have been catastrophically damaged structurally and all are impassable (Table 4.3(b)). Cars, buses, and nearly all other vehicles are inoperable (Table 4.4). In harbor areas, warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings have collapsed or are severely damaged (Table 4.1(b) items 2, 7, and 8). All storage tanks with a diameter of 100 feet or less are severely damaged (Table 4.5). At airport facilities, the structures and non-structural elements of all buildings have collapsed or are severely damaged (Table 4.1(b) items 9 and 11). As for railroad facilities, all railroad bridges and vehicles have collapsed or are severely damaged (Tables 4.6(b) and 4.7), and the structures and non-structural elements of station buildings are severely damaged (Table 4.1(b)). The structures and non-structural elements of public rental housing and educational facilities have collapsed or are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping have been catastrophically damaged and have stopped functioning (Tables 4.8 to 4.11). The structures and non-structural elements of building facilities for agriculture, forestry and fisheries as well as post offices have collapsed or are severely damaged and are unusable (Table 4.1(b)).

ii) Description of damage within a 3,280- to 16,400-ft (1 to 5 km) radius of ground zero

Many highway bridges have collapsed or are severely damaged but some bridges have moderate or lighter damage (Table 4.3(b)). Nearly all vehicles, including cars and buses, are inoperable, but some larger vehicles in locations father away from ground zero are operable (Table 4.4). Warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings in harbor areas closer to ground zero have collapsed or are severely damaged, but those in harbors farther away from ground zero have moderate or lighter damage (Table 4.1(b) items 2, 7, and 8). All storage tanks with a diameter of 100 feet or less are severely damaged (Table 4.5). The structures and non-structural elements of some buildings at airport facilities have collapsed or are severely damaged while others have structures with moderate, light or no damage and non-structural elements that are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). As for railroad facilities, there is a mixture of collapsed or severely damaged bridges and bridges with moderate, light, or no damage. Many railroad vehicles have moderate or light or no damage and some are operable (Tables 4.6(b) and 4.7). Station buildings are mixture of collapsed or severely damaged structures and structures with moderate, light, or no damage and non-structural elements that are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone base facilities as well as underground piping have been catastrophically damaged and have stopped functioning (Tables 4.8 to 4.11). Building facilities for agriculture, forestry and fisheries as well as post offices are mixture of collapsed or severely damaged structures and structures with moderate, light, or no damage and non-structural elements that are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)).

iii) Description of damage within a 16,400- to 32,800-ft (5 to 10 km) radius of ground zero

Many highway bridges have light or no damage (Table 4.3(b)). Most vehicles are operable (Table 4.4). In harbor areas, the structures of warehouse buildings with reinforced concrete walls and heavy steel-frame industrial buildings have light or no damage, but non-structural elements are severely damaged (Table 4.1(b) items 2, 7, and 8, and Table 4.2(b)). Regarding storage tanks with a diameter of 100 feet or less, the lower their content is below half full, the more severely damaged they are (Table 4.5). The structures of buildings at airport facilities have light or no damage, but non-structural elements are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). As for railroad facilities, many railroad bridges are undamaged and most vehicles are operable (Tables 4.6(b) and 4.7). The structures of railroad stations have light or no damage, but non-structural elements are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). The structures of public rental housing and educational facilities have light or no damage, but non-structural elements have collapsed or are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)). Water supply, sewerage systems, industrial water supply, electrical power, and telephone base stations are severely damaged and have stopped functioning (Tables 4.8 to 4.11). Building facilities for agriculture, forestry and fisheries as well as the structures of post offices have light or no damage, but non-structural elements are severely damaged (Table 4.1(b) items 9 and 11, and Table 4.2(b)).

Table 4.1(a) Damage-distance relationships for buildings (the optimum height)[4)]

Type of structure	Description of Structure	Damage	Distance from ground zero (ft)		
			20kt	100kt	1000kt
1)	Multistory reinforced concrete building with reinforced concrete walls, blast resistant design for 30 psi Mach region pressure from I MT, no windows	Severe	1,700	3,000	6,400
		Moderate	2,000	3,400	7,100
		Light	—	—	—
2)	Multistory reinforced concrete building with concrete walls, small window area, three to eight stories	Severe	3,200	6,000	13,000
		Moderate	4,000	7,100	16,000
		Light	—	—	—
3)	Multistory wall-bearing building, brick apartment house type, up to three stories	Severe	5,800	10,000	20,000
		Moderate	6,900	11,000	23,000
		Light	—	—	—
4)	Multistory wall-bearing building, monumental type, up to four stories	Severe	4,000	7,000	15,000
		Moderate	4,800	8,000	17,000
		Light	—	—	—
5)	Wood frame building, house type, one or two stories	Severe	3,200	13,000	29,000
		Moderate	4,100	15,000	33,000
		Light	—	—	—
6)	Light steel-frame industrial building, single story, with up to5-ton crane capacity; low strength walls which fail quickly	Severe	3,200	6,200	18,000
		Moderate	4,100	8,000	20,000
		Light	—	—	—
7)	Heavy steel-frame industrial building, single story, with 25 to 50-ton crane capacity; lightweight, low strength walls which fail quickly	Severe	2,800	5,100	14,000
		Moderate	3,500	6,100	16,000
		Light	—	—	—
8)	Heavy steel-frame industrial building, single story, with 60 to100-ton crane capacity; lightweight low strength walls which fail quickly	Severe	2,400	4,700	11,000
		Moderate	3,000	5,200	12,000
		Light	—	—	—
9)	Multistory steel-frame office-type building, 3 to 10 stories. Lightweight low strength walls which fail quickly, earthquake resistant construction	Severe	1,600	3,100	8,000
		Moderate	2,000	3,800	9,000
		Light	—	—	—
10)	Multistory steel-frame office-type building, 3 to 10 stories. Lightweight low strength walls which fail quickly, non-earthquake resistant construction	Severe	2,000	4,000	11,000
		Moderate	2,600	4,900	12,000
		Light	—	—	—
11)	Multistory reinforced concrete-frame office-type building. 3 to 10 stories; light- weight low strength walls which fail quickly. Earthquake resistant construction	Severe	1,900	3,500	8,900
		Moderate	2,200	4,100	9,700
		Light	—	—	—
12)	Multistory reinforced concrete-frame office-type building. 3 to 10 stories; lightweight low strength walls which fail quickly. Non-earthquake resistant construction	Severe	2,200	4,200	11,000
		Moderate	2,900	5,000	12,000
		Light	—	—	—

Table 4.1(b) Damage-distance relationships for buildings (at the surface) [4)]

Type of structure	Description of Structure	Damage	Distance from ground zero (ft)		
			20kt	100kt	1000kt
1)	Multistory reinforced concrete building with reinforced concrete walls, blast resistant design for 30 psi Mach region pressure from I MT, no windows	Severe	1,275	2,250	4,800
		Moderate	1,500	2,550	5,325
		Light	—	—	—
2)	Multistory reinforced concrete building with concrete walls, small window area, three to eight stories	Severe	2,400	4,500	9,750
		Moderate	3,000	5,325	12,000
		Light	—	—	—
3)	Multistory wall-bearing building, brick apartment house type, up to three stories	Severe	4,350	7,500	15,000
		Moderate	5,175	8,250	17,250
		Light	—	—	—
4)	Multistory wall-bearing building, monumental type, up to four stories	Severe	3,000	5,250	11,250
		Moderate	3,600	6,000	12,750
		Light	—	—	—
5)	Wood frame building, house type, one or two stories	Severe	2,400	9,750	21,750
		Moderate	3,075	11,250	24,750
		Light	—	—	—
6)	Light steel-frame industrial building, single story, with up to5-ton crane capacity; low strength walls which fail quickly	Severe	2,400	4,650	13,500
		Moderate	3,075	6,000	15,000
		Light	—	—	—
7)	Heavy steel-frame industrial building, single story, with 25 to 50-ton crane capacity; lightweight, low strength walls which fail quickly	Severe	2,100	3,825	10,500
		Moderate	2,625	4,575	12,000
		Light	—	—	—
8)	Heavy steel-frame industrial building, single story, with 60 to 100-ton crane capacity; lightweight low strength walls which fail quickly	Severe	1,800	3,525	8,250
		Moderate	2,250	3,900	9,000
		Light	—	—	—
9)	Multistory steel-frame office-type building, 3 to 10 stories. Lightweight low strength walls which fail quickly, earthquake resistant construction	Severe	1,200	2,325	6,000
		Moderate	1,500	2,850	6,750
		Light	—	—	—
10)	Multistory steel-frame office-type building, 3 to 10 stories. Lightweight low strength walls which fail quickly, non-earthquake resistant construction	Severe	1,500	3,000	8,250
		Moderate	1,950	3,675	9,000
		Light	—	—	—
11)	Multistory reinforced concrete-frame office-type building. 3 to 10 stories; light- weight low strength walls which fail quickly. Earthquake resistant construction	Severe	1,425	2,625	6,675
		Moderate	1,650	3,075	7,275
		Light	—	—	—
12)	Multistory reinforced concrete-frame office-type building. 3 to 10 stories; lightweight low strength walls which fail quickly. Non-earthquake resistant construction	Severe	1,650	3,150	8,250
		Moderate	2,175	3,750	9,000
		Light	—	—	—

Table 4.1(c) Description of damage to buildings[4)]

Structural Type	Severe	Moderate	Light
1)	Walls shattered, severe frame distortion, incipient collapse.	Walls breached or on the point of being so, frame distorted, entranceways damaged, doors blown in or jammed, extensive spalling of concrete.	Some cracking of concrete walls and frame.
2)	Walls shattered, severe frame distortion, incipient collapse.	Exterior walls severely cracked, interior partitions severely cracked or blown down. Structural frame permanently distorted, extensive spalling of concrete.	Windows and doors blown in, interior partitions cracked.
3)	Collapse of bearing walls, resulting in total collapse of structure.	Exterior walls severely cracked, interior partitions severely cracked or blown down.	Windows and doors blown in, interior partitions cracked.
4)	Collapse of bearing walls, resulting in collapse of structure supported by these walls. Some walls may be shielded by intervening walls so that part of the structure may receive only moderate damage.	Exterior walls facing blast severely cracked, interior partitions severely cracked with damage toward far end of building possibly less intense.	Windows and doors blown in, interior partitions cracked.
5)	Frame shattered re-suiting in almost complete collapse.	Wall framing cracked. Roof severely damaged, interior partitions blown down.	Windows and doors blown in, interior partitions cracked.
6)	Severe distortion or collapse of frame.	Minor to major distortion of frame; cranes, if any, not operable until repairs made.	Windows and doors blown in, light siding ripped off.
7)	Severe distortion or collapse of frame.	Some distortion to frame; cranes not operable until repairs made.	Windows and doors blown in, light siding ripped off.
8)	Severe distortion or collapse of frame.	Some distortion or frame; cranes not operable until repairs made.	Windows and doors blown in, light siding ripped off.
9)	Severe frame distortion, incipient collapse.	Frame distorted moderately, interior partitions blown down.	Windows and doors blown in, light siding ripped off, interior partitions cracked.
10)	Severe frame distortion, incipient collapse.	Frame distorted moderately, interior partitions blown down.	Windows and doors blown in, light siding ripped off, interior partitions cracked.
11)	Severe frame distortion, incipient collapse.	Frame distorted moderately, interior partitions blown down, some spalling of concrete.	Windows and doors blown in, light siding ripped off, interior partitions cracked.
12)	Severe frame distortion, incipient collapse.	Frame distorted moderately, interior partitions blown down, some spalling of concrete.	Windows and doors blown in, light siding ripped off, interior partitions cracked.

Table 4.2(a) Damage-distance relationships for non-structural elements of buildings (the optimum height) [4)]

Non-structural elements	Failure	Approximate side-on peak overpressure (psi)	Distance from ground zero (ft)		
			20kt	100kt	1000kt
Glass windows, large and small	Shattering usually, occasional Frame failure (Severe)	0.5-1.0	15,100	25,900	55,700
Corrugated asbestos siding	Shattering (Severe)	1.0-2.0	15,100-10,100	25,900-17,200	55,700-37,100
Corrugated steel or aluminum paneling	Connection failure followed by buckling (Severe)	1.0-2.0	15,100-10,100	25,900-17,200	55,700-37,100
Brick wall panel, 8 in. or 12 in. thick (not reinforced)	Shearing and flexure failures (Severe)	3.0-10.0	6,300-3,800	10,800-6,500	23,200-13,900

Table 4.2(b) Damage-distance relationships for non-structural elements of buildings (at the surface burst) [4)]

Non-structural elements	Failure	Approximate side-on peak overpressure (psi)	Distance from ground zero (ft)		
			20kt	100kt	1000kt
Glass windows, large and small	Shattering usually, occasional Frame failure (Severe)	0.5-1.0	10,000	17,200	37,100
Corrugated asbestos siding	Shattering (Severe)	1.0-2.0	10,000-6,300	17,200-10,800	37,100-23,200
Corrugated steel or aluminum paneling	Connection failure followed by buckling (Severe)	1.0-2.0	10,000-6,300	17,200-10,800	37,100-23,200
Brick wall panel, 8 in. or 12 in. thick (not reinforced)	Shearing and flexure failures (Severe)	3.0-10.0	4,400-2,800	7,500-4,700	16,200-10,200

Table 4.3(a) Damage-distance relationships for highway bridges (the optimum height) 4)

Type of structure	Damage	Distance from ground zero (ft)		
		20kt	100kt	1000kt
13) Highway truss bridges, 4-lane, spans 200 to 400 ft	Severe	2,200	4,300	11,000
	Moderate	2,800	5,100	12,000
	Light	—	—	—
14) Highway truss bridges, 2-lane, spans 200 to 400 ft.	Severe	2,700	5,100	13,000
	Moderate	3,200	6,000	15,000
	Light	—	—	—
16) Highway girder bridges, 4-lane through, spans 75 ft	Severe	1,400	2,700	6,500
	Moderate	1,700	3,100	7,300
	Light	—	—	—
17) Highway girder bridges, 2-lane deck, 2-lane through, 4-lane deck, spans 75 ft	Severe	1,800	3,400	9,000
	Moderate	2,100	4,000	10,000
	Light	—	—	—
19) Highway girder bridges, 2-lane through, 4-lane deck or through, spans 200 ft	Severe	2,100	4,200	11,000
	Moderate	2,700	5,000	13,000
	Light	—	—	—
20) Highway girder bridges, 2-lane deck, spans 200 ft	Severe	3,000	6,000	15,000
	Moderate	3,900	7,000	17,000
	Light	—	—	—

Table 4.3(b) Damage-distance relationships for highway bridges (at the surface) 4)

Type of structure	Damage	Distance from ground zero (ft)		
		20kt	100kt	1000kt
13) Highway truss bridges, 4-lane, spans 200 to 400 ft	Severe	1,650	3,225	8,250
	Moderate	2,100	3,825	9,000
	Light	—	—	—
14) Highway truss bridges, 2-lane, spans 200 to 400 ft.	Severe	2,025	3,825	9,750
	Moderate	2,400	4,500	11,250
	Light	—	—	—
16) Highway girder bridges, 4-lane through, spans 75 ft	Severe	1,050	2,025	4,875
	Moderate	1,275	2,325	5,475
	Light	—	—	—
17) Highway girder bridges, 2-lane deck, 2-lane through, 4-lane deck, spans 75 ft	Severe	1,350	2,550	6,750
	Moderate	1,575	3,000	7,500
	Light	—	—	—
19) Highway girder bridges, 2-lane through, 4-lane deck or through, spans 200 ft	Severe	1,575	3,150	8,250
	Moderate	2,025	3,750	9,750
	Light	—	—	—
20) Highway girder bridges, 2-lane deck, spans 200 ft	Severe	2,250	4,500	11,250
	Moderate	2,925	5,250	12,750
	Light	—	—	—

Table 4.3(c) Description of damage to highway bridge4)

Damage state	Description of Damage
Severe	Total failure of lateral bracing or anchorage, collapse of bridge.
Moderate	Substantial distortion of lateral bracing or slippage on supports, significant reduction in capacity of bridge.
Light	Capacity of bridge not significantly reduced, slight distortion of some bridge components.

Table 4.4 Peak overpressures and GZ distance for blast damage to vehicle[4)]

Type of Vehicle	Damage	Overpressure (psi)	Distance (ft) from ground zero					
			Air burst			Surface burst		
			20kt	100kt	1000kt	20kt	100kt	1000kt
Automobiles	Inoperable	5-6	5000	8000	20000	3000	6000	13200
	Moderate	3-5	6300	10800	23200	4400	7500	16200
Buses	Inoperable	10-12	3000	6000	12000	2000	4500	9000
	Moderate	6-10	3800	6500	13900	2800	4700	10200
Fire Trucks	Inoperable	10-12	3000	6000	12000	2500	4500	10200
	Moderate	6-10	3800	6500	13900	2800	4700	14000
Repair Trucks	Inoperable	10-12	3000	5000	12000	2500	4500	10200
	Moderate	6-10	3800	6500	13900	2800	4700	9000
Earth and Debris Moving Equipment	Inoperable	30-35	1000	3000	7000	1500	2700	5800
	Moderate	20-30	2500	4200	9100	1900	3200	7000
Truck-Mounted Engineering Equipment	Inoperable	15-17	3000	5500	12000	2300	3800	9000
	Moderate	12-15	3800	6500	13900	2800	4000	9500

Table 4.5 Peak overpressures and GZ distance for severe blast damage to floating- or conical-roof tanks of diameter[4)]

Diameter(ft)	Height(ft)	Quantity	Peak overpressure (psi) for severe damage			Distance (ft) from ground zero for severe damage	
			State	1～500kt explosion	500kt～ explosion	1～500kt explosion	500kt～ explosion
100.0	30.0-70.0	0.9FULL	Severe	12.7-22.5	6.6-6.7	6000-4000	19000
	30.0-70.0	0.5FULL		8.8-11.3	6.6-6.7	7000-6000	19000
	30.0-70.0	EMPTY		1.4-0.9	1.3-0.9	25000	50000
75.0	22.5-52.5	0.9FULL	Severe	5.7-9.0	5.8-5.3	8600	20000
	22.5-52.5	0.5FULL		5.7-9.0	5.8-5.3	8600	20000
	22.5-52.5	EMPTY		1.4-0.9	1.3-0.9	25000	50000
50.0	15.0-35.0	0.9FULL	Severe	5.9-6.2	5.8-4.1	9400	21000
	15.0-35.0	0.5FULL		5.9-4.3	5.8-4.1	10000	21000
	15.0-35.0	EMPTY		1.4-0.8	1.3-0.9	25000	50000

Table 4.6(a) Damage-distance relationships for railroad bridges (the optimum height) 4)

Type of structure	Damage	Distance (ft) from ground zero		
		20kt	100kt	1000kt
13) Railroad truss bridges, double track ballast floor, spans 200 to 400 ft	Severe	2,200	4,300	11,000
	Moderate	2,800	5,100	12,000
	Light	—	—	—
14) Railroad truss bridges, single track ballast or double track open floors, spans 200 to 400 ft; railroad truss bridges, single track open floor, spans 400 ft.	Severe	2,700	5,100	13,000
	Moderate	3,200	6,000	15,000
	Light	—	—	—
15) Railroad truss bridges, single track open floor, spans 200 fl.	Severe	3,000	5,900	15,000
	Moderate	3,800	7,000	17,000
	Light	—	—	—
17) Railroad girder bridges, double-track deck, open or ballast floor, spans 75 ft; railroad girder bridges, single or double track through, ballast floors, spans 75 ft.	Severe	1,800	3,400	9,000
	Moderate	2,100	4,000	10,000
	Light	—	—	—
18) Railroad girder bridges, single track deck, open or ballast floors, spans 75 ft; railroad girder bridges, single or double track through, open floors, spans 75 ft	Severe	2,700	5,000	13,000
	Moderate	3,200	6,000	15,000
	Light	—	—	—
19) Railroad girder bridges, double track deck or through, ballast floor, spans 200 ft.	Severe	2,100	4,200	11,000
	Moderate	2,700	5,000	13,000
	Light	—	—	—
20) Railroad girder bridges, single track deck or through, ballast floors, spans 200 ft; railroad girder bridges, double track deck or through, open floors, spans 200 ft.	Severe	3,000	6,000	15,000
	Moderate	3,900	7,000	17,000
	Light	—	—	—
21) Railroad girder bridges, single track deck or through, open floors, spans 200 ft.	Severe	4,800	9,000	23,000
	Moderate	6,000	11,000	27,000
	Light	—	—	—

Table 4.6(b) Damage-distance relationships for railroad bridges (at the surface) 4)

Type of structure	Damage	Distance (ft) from ground zero		
		20kt	100kt	200kt
13) Railroad truss bridges, double track ballast floor, spans 200 to 400 ft	Severe	1,650	3,225	8,250
	Moderate	2,100	3,825	9,000
	Light	—	—	—
14) Railroad truss bridges, single track ballast or double track open floors, spans 200 to 400 ft; railroad truss bridges, single track open floor, spans 400 ft.	Severe	2,025	3,825	9,750
	Moderate	2,400	4,500	11,250
	Light	—	—	—
15) Railroad truss bridges, single track open floor, spans 200 fl.	Severe	2,250	4,425	11,250
	Moderate	2,850	5,250	12,750
	Light	—	—	—
17) Railroad girder bridges, double-track deck, open or ballast floor, spans 75 ft; railroad girder bridges, single or double track through, ballast floors, spans 75 ft.	Severe	1,350	2,550	6,750
	Moderate	1,575	3,000	7,500
	Light	—	—	—
18) Railroad girder bridges, single track deck, open or ballast floors, spans 75 ft; railroad girder bridges, single or double track through, open floors, spans 75 ft	Severe	3,750	5,175	9,750
	Moderate	4,500	6,000	11,250
	Light	—	—	—
19) Railroad girder bridges, double track deck or through, ballast floor, spans 200 ft.	Severe	1,575	3,150	8,250
	Moderate	2,025	3,750	9,750
	Light	—	—	—
20) Railroad girder bridges, single track deck or through, ballast floors, spans 200 ft; railroad girder bridges, double track deck or through, open floors, spans 200 ft.	Severe	2,250	4,500	11,250
	Moderate	2,925	5,250	12,750
	Light	—	—	—
21) Railroad girder bridges, single track deck or through, open floors, spans 200 ft.	Severe	6,750	9,000	17,250
	Moderate	8,250	12,000	20,250
	Light	—	—	—

Table 4.6(c) Description of damage to railroad bridge[4)]

Damage state	Description of Damage
Severe	Total failure of lateral bracing or anchorage, collapse of bridge.
Moderate	Substantial distortion of lateral bracing or slippage on supports, significant reduction in capacity of bridge.
Light	Capacity of bridge not significantly reduced, slight distortion of some bridge components.

Table 4.7 Peak overpressures and GZ distance for burst damage to railroad cars and locomotive[4)]

Type of Railroad Vehicle	Damage	Overpressure (psi)	Distance (ft) from ground zero		
			20kt	100kt	1000kt
Railroad Cars	Inoperable	25	2000	3500	7600
	Moderate	15	3150	5350	11500
Locomotives	Inoperable	80	0	0	0
	Moderate	30	1600	2800	6100

Table 4.8 Peak overpressures and GZ distance for blast damage to sewerage[4) ,5)]

Type of lifeline facility	Damage	Overpressure (psi)	Distance from ground zero (ft)		
			20kt	100kt	1000kt
Sewage treatment system (pumping stations)	Operable	At least 5	5500	9300	20000
Underground piping	Safe	Below 10-15	3800	6500	13900

Table 4.9 Peak overpressures and GZ distance for blast damage to water system[4) ,5)]

Type of lifeline facility	Damage	Overpressure (psi)	Distance from ground zero (ft)		
			20kt	100kt	1000kt
Water treatment plants and pumping stations	Operable	Less than 5	5500	9300	20000
Water system (service connections and piping in buildings)	Failure	Above 2	10100	17200	37100
Underground piping	Safe	Below 10-15	3800	6500	13900

Table 4.10 Peak overpressures (PSI) and GZ distance for blast damage to electric power[4) ,5)]

Type of lifeline facility	Damage	Overpressure (psi)	Distance from ground zero (ft)		
			20kt	100kt	1000kt
Electric power	Outage	Above 5	5500	9300	20000
	Moderate	2-5	10100	17200	37100
	Minimal	Outside of the 2	15100	25900	37100
Utility poles and transmission towers	Severe (Collapse)	About 3	6300	10800	23200
Lines radial	Severe (Bring down)	Above 4-5	6300	10800	23200
Well-anchored antenna towers	Severe (Failure)	4-6	6300	10800	23200
A pole-mounted transformer	Severe (Broken)	About 3	12000	21000	29000

Table 4.11(a) Peak overpressures and GZ distance for blast damage to telephone line (the optimum height) [4),5)]

Type of lifeline facility	Damage	Distance from ground zero (ft)		
		20kt	100kt	1000kt
Telephone lines (radial)	Severe	4,000	7,500	10,000
	Moderate	4,000	7,500	10,000
	Light	—	—	—
Telephone lines (transverse)	Severe	5,000	10,000	13,000
	Moderate	5,000	10,000	13,000
	Light	—	—	—

Table 4.11(b) Peak overpressures and GZ distance for blast damage to telephone line (at the surface) [4),5)]

Type of lifeline facility	Damage	Distance from ground zero (ft)		
		20kt	100kt	1000kt
Telephone lines (radial)	Severe	3,000	5,625	7,500
	Moderate	3,000	5,625	7,500
	Light	—	—	—
Telephone lines (transverse)	Severe	3,750	7,500	9,750
	Moderate	3,750	7,500	9,750
	Light	—	—	—

5. Process of restoration and reconstruction of social infrastructure

Below are results of an examination into the possibility of conducting restoration and reconstruction work of social infrastructure, given the effects of residual radiation.

Given a wind speed of 10 knots (5.1 m/s), the idealized early fallout dose rate contour for no more than 0.01 sievert per hour in a 20-kt surface burst would have a downwind distance of 792 kilofeet (241 km) and a maximum width of 79 kilofeet (24 km). In a 100-kt surface burst it would have a downwind distance of 1,584 kilofeet (482 km) and a maximum width of 158 kilofeet (48 km). In a 1,000-kt surface burst it would have a downwind distance of 4,224 kilofeet (1,287 km) and a maximum width of 422 kilofeet (128 km) (Figure 5.1 and Table 5.1). At this distance, it would take about 30 days for the dose rate to drop below the Ministry of the Environment’s current standard value[6] (3.8 microsieverts per hour, 8 hours outdoors and 16 hours indoors), making it possible to start restoration and reconstruction work.

Given a wind speed of 10 knots (5.1 m/s), the idealized early fallout dose rate contour for 30 sieverts per hour would have a downwind distance of 15.8 kilofeet (4.8 km) and a maximum width of 0.5 kilofeet (0.15 km) in a 20-kt surface burst, a downwind distance of 37 kilofeet (11 km) and a maximum width of 2.1 kilofeet (0.64 km) in a 100-kt surface burst, and a downwind distance of 95 kilofeet (28 km) and a maximum width of 14.8 kilofeet (4.5 km) in a 1,000-kt surface burst. At this distance, it would take about seven years before restoration and reconstruction work could be started.

Considering that it took two to three years to complete restoration and reconstruction work of social infrastructure over an area approximately 20 km east to west and 5 to 6 km north to south following the Great Hanshin Earthquake, and taking into account the above-mentioned interval over which residual radiation will have an effect, restoration and reconstruction could be possible in at least 9 to 10 years in the case of a 1,000-kt surface burst and shorter in the cases of 100-kt and 20-kt bombs.

The radiation dose in the case of an air burst is about 0.35 times that of a surface burst. Accordingly, it would take about four years before restoration and reconstruction work could be started in the area close to ground zero where the dose rate was 30 sieverts per hour. It is assumed that it would take six to seven years until restoration and reconstruction work was completed in the case of an air burst.

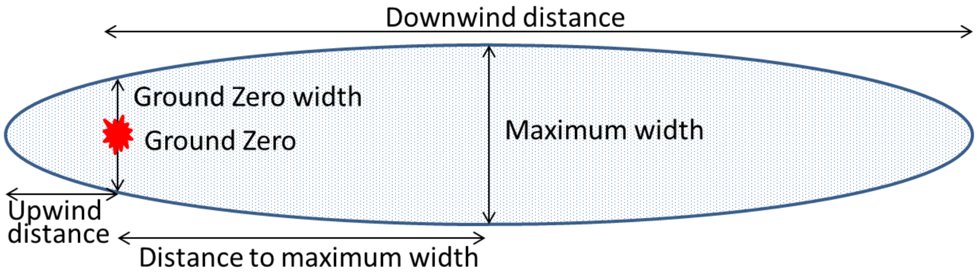

Figure 5.1 Idealized early fallout dose rate contour[3)]

Table 5.1 Parameter of idealized early fallout dose rate contour, such as Downwind Distance, Maximum Width, Distance to Maximum Width, Ground Zero Width and Upwind Distance, 10 Knot Effective Wind[3)]

Power of atomic bomb (kt)	Downwind Distance (kft)							
	30Sv/h	10Sv/h	3Sv/h	1Sv/h	0.3Sv/h	0.1Sv/h	0.03Sv/h	0.01Sv/h
20	15.8	31.7	95.0	158.4	290.4	422.4	580.8	792.0
100	37.0	79.2	184.8	369.6	633.6	950.4	1161.6	1584.0
1000	95.0	205.9	528.0	1056.0	1584.0	2376.0	3168.0	4224.0
Power of atomic bomb (kt)	Maximum Width (kft)							
	30Sv/h	10Sv/h	3Sv/h	1Sv/h	0.3Sv/h	0.1Sv/h	0.03Sv/h	0.01Sv/h
20	0.5	1.8	5.3	10.6	21.1	37.0	52.8	79.2
100	2.1	6.3	13.2	26.4	52.8	79.2	105.6	158.4
1000	14.8	31.7	63.4	105.6	158.4	237.6	316.8	422.4
Power of atomic bomb (kt)	Distance to Maximum Width (kft)							
	30Sv/h	10Sv/h	3Sv/h	1Sv/h	0.3Sv/h	0.1Sv/h	0.03Sv/h	0.01Sv/h
20	7.9	10.6	31.7	63.4	79.2	184.8	264.0	369.6
100	13.2	26.4	63.4	158.4	237.6	369.6	528.0	792.0
1000	18.5	63.4	105.6	422.4	792.0	1056.0	1584.0	2112.0
Power of atomic bomb (kt)	Ground Zero Width (kft)							
	30Sv/h	10Sv/h	3Sv/h	1Sv/h	0.3Sv/h	0.1Sv/h	0.03Sv/h	0.01Sv/h
20	0.8	1.6	4.0	7.9	9.5	13.2	15.8	21.1
100	1.8	4.0	10.6	13.2	18.5	21.1	31.7	37.0
1000	7.9	15.8	26.4	37.0	44.9	63.4	79.2	105.6
Power of atomic bomb (kt)	Upwind Distance (kft)							
	30Sv/h	10Sv/h	3Sv/h	1Sv/h	0.3Sv/h	0.1Sv/h	0.03Sv/h	0.01Sv/h
20	0.4	0.8	2.0	4.0	4.8	6.6	7.9	10.6
100	0.9	2.0	5.3	6.6	9.2	10.6	15.8	18.5
1000	4.0	7.9	13.2	18.5	22.4	31.7	39.6	52.8

Table 5.2 Fission Product Decay Factors Normalized to Unity at 1 Hour after Detonation[3)]

Time After Explosion (days)	Time After Explosion (hour)	Fission Product Decay Factors
0.0	1	1.00000000
0.4	10	0.06000000
5.0	120	0.00300000
10.0	240	0.00150000
30.0	720	0.00030000
180.0	4320	0.00004000
365.0	8760	0.00000700
1825.0	43800	0.00000015
3650.0	87600	0.00000004
7300.0	175200	0.00000002

6. Conclusion

This paper estimated the damage to 15 areas: roads; harbors; aviation; railroads; public rental housing; sewerage systems; waste treatment; water supply; municipal parks; educational facilities; agriculture, forestry and fisheries; postal services; and industrial water supply, which are defined as social infrastructure (social capital) by the Cabinet Office, as well as electrical power and communications.

The damage estimates were made for six scenarios in terms of atomic bomb power and type of burst: 20-kt, 100-kt, and 1,000-kiloton atomic bomb with either an air burst or surface burst during the daytime on a sunny day. For air bursts, the results of past research were referenced to set the burst height so as to maximize the extent of the overpressure’s constant pressure lines. The effects examined were the damage caused by the overpressure (sudden rise in pressure) and heat rays produced by an atomic bomb.

In the estimate of damage to social infrastructure caused by blast waves and heat rays, the results of past research were referenced to arrange the relationship among the power of the atomic bombs, overpressure, and distance from ground zero at which different degrees of damage occur (threshold) for the constituents, which are: various building structures, non-structural elements of buildings (e.g. exterior cladding, windows), highway bridges, automotive vehicles, above-ground storage tanks, railroad bridges, railroad vehicles, sewerage facilities, water supply systems, electrical power facilities, and communications facilities (fixed telephone lines). Then, a qualitative description of the aspects of damage to social infrastructure was given in light of the damage to constituent elements. The aspects of damage were described for the above-mentioned six scenarios in terms of atomic bomb size and type of burst at distances from ground zero of less than 1 km, 1 to 5 km, and 5 to 10 km.

Finally, estimates were given for the periods needed for restoration and reconstruction after an atomic bomb, taking into consideration time for reduction of residual radiation and time for the social infrastructure restoration and reconstruction work.

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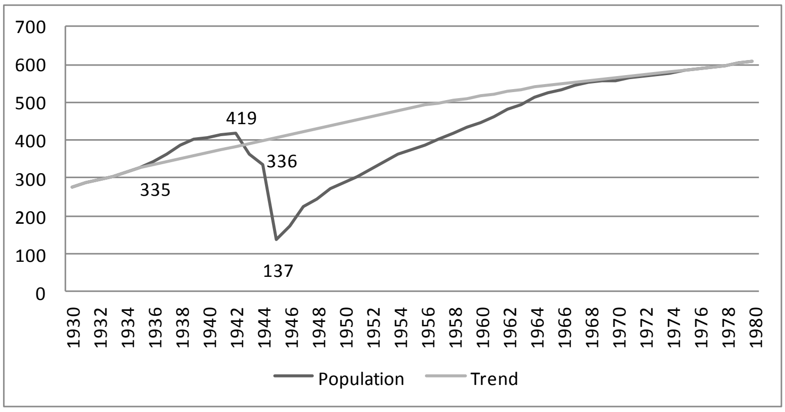
Chapter 4. Economic Impacts of the Use of Nuclear Weapons

Kanemi Ban

1. Introduction

Human and material damage from the use of nuclear weapons and its economic impact are immeasurable. Figure 1 shows changes in the population of Hiroshima City and demographic trends on the assumption of no atomic bombing between 1930 and 1980. The population as of 1944 dwindled to 336,000 from the 1942 peak of 419,000 due to evacuation to the countryside in order to avoid air strikes, and declined sharply by as many as 199,000 to only 137,000 immediately after the atomic bombing. Hiroshima's population recovered to the 1944 level in 1953, but Davis and Weinstein (2002), who analyzed the impact on Japan's urban population of U.S. air raids during World War II, estimate that the population of Hiroshima City returned to the demographic trends of 1925-1940 before the atomic bombing only around 1975. They also estimated the population of Nagasaki City returned to the demographic trends around 1960. In either city, the impact of the atomic bombing, from the perspective of resilience of the population, is described as far greater than the Great Tokyo Air Raids or the Great Osaka Air Raids, both in March 1945. Population trends are an important indictor in considering the economic impact, but the recovery of the cities where the atomic bombs were dropped took many years, and in the case of Hiroshima, it took more than 30 years to restore itself to its former state.

Figure 1 Population of Hiroshima City (in thousands) (Hiroshima City Statistical Book)



The atomic bomb dropped over Hiroshima was equivalent to 16 kilotons of TNT, but the destructive power of nuclear weapons has been significantly enhanced during the Cold War. The U.S. Office of Technology Assessment (1979) estimated the damage in detail when a nuclear weapon equivalent to 25 megatons of TNT exploded over Detroit. Since the city is the heartland of the U.S.

automotive industry, the damage would be significantly higher than Hiroshima.

This paper is intended to examine the impact of the use of nuclear weapons on the economy, but instead of direct assessment, it is designed for indirect assessment by looking at the economic impacts of wars and various natural disasters the world has gone through until now.

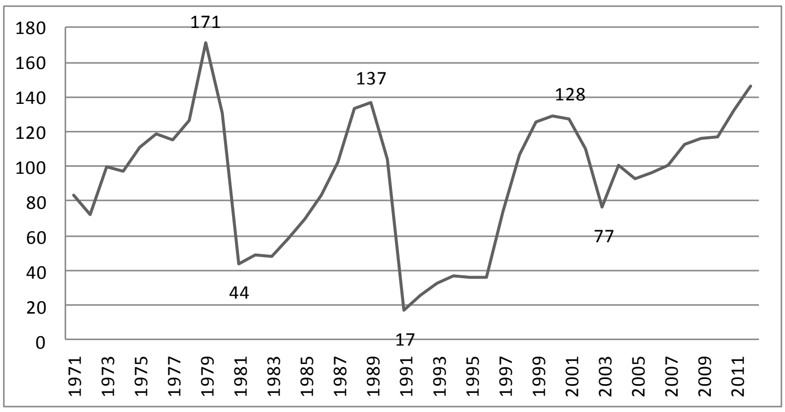
This paper attempts to assess the impacts of the dwindling of the production capacity stemming from human and capital loss, the impact of the breakup of networks, particularly the impact of the fracturing of the supply chain, and the impact of the financial market turmoil.

2. Impacts of Human Loss/Capital Loss

2.1 Iraq

Iraq waged war rather frequently, and the impact of war is reflected in production of crude oil most expressly. Figure 2 shows changes in crude oil production by Iraq. The first war is the Iran-Iraq War, which began on September 22, 1980, and lasted until the ceasefire agreement reached on August 20, 1988. As a result of the war, which was fought over their territorial claims to the Shatt al-Arab river, the strategic export point for both countries, Iraq's crude oil output fell sharply to 44 megatons in 1981, just one-fourth of 171 megatons in 1979. The second war, the Gulf War, started with air raids on Iraq by the coalition forces on January 17, 1991, against Iraq's invasion of Kuwait on August 2, 1990, and ended with ceasefire on April 6, 1991. Due to the war, Iraq's crude oil production fell steeply to 17 megatons in 1991, only one-eighth of 137 megatons in 1989. The third war began on March 20, 2003, with air raids against Iraq by the U.S.-led coalition forces. The large-scale fighting came to a close in May 2003, but the Iraq War officially ended on August 31, 2010, with the United States declaring an end to the fighting. During the war, crude oil production by Iraq dropped 40% from 128 megatons in 2001 to 77 megatons in 2003. It is important to note that it took several years for crude oil production to restore to the pre-war level. The restoration of human loss and capital loss by war requires some time.

Figure 2 Crude Oil Production by Iraq (Mt) (IEA, Energy Statistics)



The wars and the resulting declines in crude oil production have had a major impact on the Iraqi economy. Figure 3 shows Iraq's real gross domestic production (GDP) between 2000, the latest year for which data is available, and 2012. GDP, which had been on the decline since 2000, stood at US$97.0 billion in 2002, but declined to US$57.0 billion in 2003. Drops in Iraq's crude oil production influence international crude oil prices, and thus is likely to give a major impact on the global economy through crude oil prices. According to Figure 4, crude oil prices increased during these wars, except for the Gulf War that lasted for a relatively short period of time.

Figure 3 Real GDP of Iraq (2005 PPP US$, US$billions)
(World Bank, World Development Indicators)

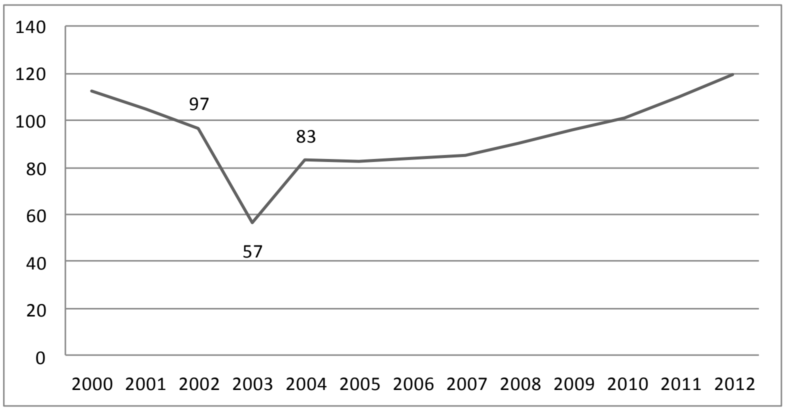
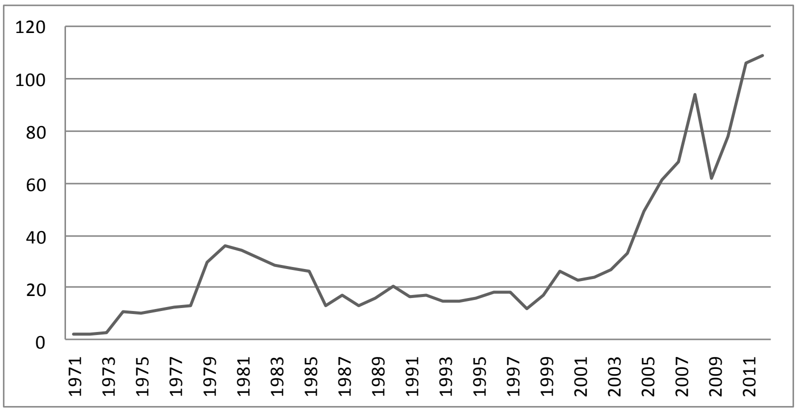


Figure 4 Dubai Crude Oil Prices (US$/barrel) (IMF, International Finacial Statistics)



2.2 Louisiana, the United States

Hurricane Katrina, which hit the State of Louisiana on August 29, 2005, dealt a devastating blow to New Orleans, leaving 80% of the city's land area submerged below the water level. Figure 5 shows changes in the population of Louisiana, which declined by 30,000 to 430,000 in 2006 from 460,000 in 2004. The recovery of the state's population has been slow, and had yet to restore to the pre-hurricane level as of 2012. Figure 6 shows changes in real GDP of Louisiana as compared with GDP of the entire United States. Louisiana's GDP remained stagnant until it recovered the pre-hurricane level in 2010.

Figure 5 Population of Louisiana (in thousands) (US Census Bureau)

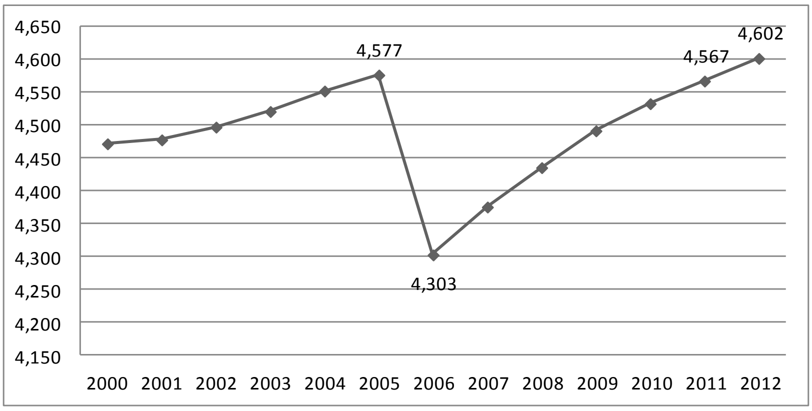
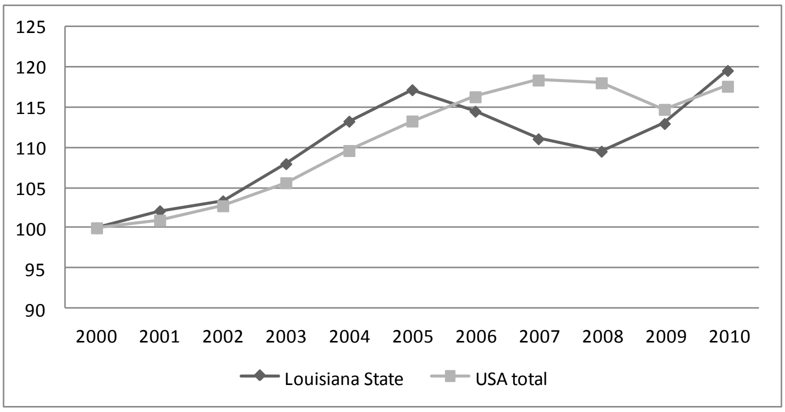


Figure 6 Real GDP of Louisiana (2010 dollars & 2000=100) (US Bureau of Economic Analysis)



2.3 The Great Hanshin-Awaji Earthquake

On January 17, 1995, the Great Hanshin-Awaji Earthquake occurred, with the epicenter in northern Awaji Island. The near-field earthquake with a magnitude of 7.3, which registered 7 on the Japanese seismic scale, caused major damage, most severely in Kobe City, dealing devastating blows to infrastructures and lifelines, including railroads, roads, electricity, water and gas supplies. The resumption of railway services came only on April 1 for JR Kobe Line and on April 8 for Sanyo Shinkansen Bullet Trains, meaning Japan's railroad network was divided east and west for some three months. The resumption of private railway services was delayed further, with Hankyu railways starting running again on June 12 and Hanshin Electric Railway services resuming on June 26, requiring more than five months before the resumption.

Figure 7 shows changes in the population of Kobe City. The population of the city declined by 100,000 to 1.42 million in 1995 from 15.2 million in 1994, and it took until 2004 to restore the pre-quake population. Figure 8 shows changes in real GDP of Kobe City as compared with total GDP for Japan. As data is given on a fiscal year basis, the 1994 data includes data for January-March 1995. Considering this, the figure indicates that economic activities came to an almost complete halt, and the recovery thereafter made little headway due to the damage to capital equipment, including infrastructure and buildings. While the recovery trend became evident in 1996, this primarily reflected projects to restore infrastructure and reconstruction of buildings and homes that crumbled due to the earthquake. This recovery only had the role of restoring impaired capital, with the gap with the national level rather widening instead of narrowing.

Figure 7 Population of Kobe City (in thousands) (Kobe City Statistical Book)

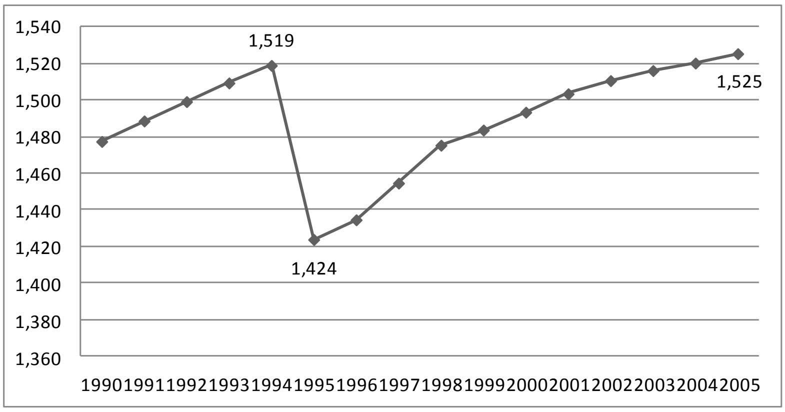
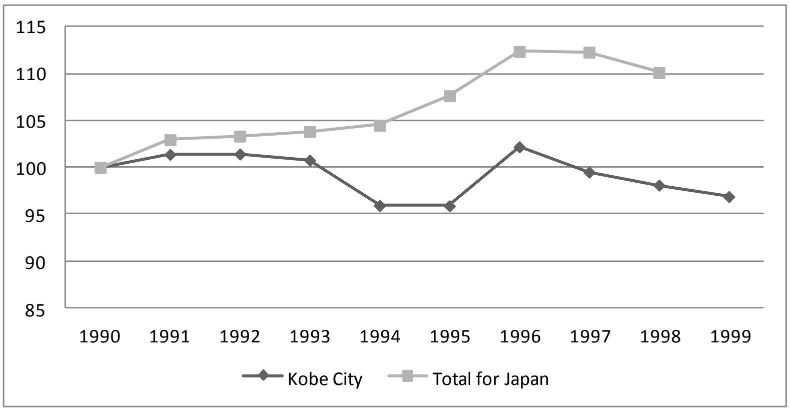


Figure 8 Impact on Real GDP (1990 yens & 1990=100)
(Cabinet Office, Prefectural Citizens' Economic Accounts, Note: Data is on a fiscal year basis.)



2.4 The Great East Japan Earthquake

On March 11, 2011, the large-scale earthquake with a magnitude of 9.0 occurred, with the wide focal region covering from areas off Iwate Prefecture to areas off Ibaraki Prefecture, with the great loss of human life due to the massive tsunami hitting the Pacific coast. Furthermore, the total loss of power at the Fukushima Dai-ni nuclear power station of Tokyo Electric Power Co. resulted in the melting of reactor cores at its No. 1 to No. 3 reactors, and a number of hydrogen explosions destroyed the nuclear reactor buildings, releasing massive amounts of radioactive materials into the atmosphere. At the same time, a large number of factories were destroyed by the Great East Japan Earthquake, leading to the suspension of production. A lot of thermal power stations were also damaged by the earthquake, and the resultant shortage of power led to rolling blackouts, putting major constraints on economic activities. Figure 9 shows changes in the quarterly estimates of GDP. The figure indicates that the effects of the Great East Japan Earthquake were felt intensively in the first quarter (January-March) and the second quarter (April-June), resulting in the loss of ¥12 trillion at an annual rate.

Figure 9 Quarterly Estimates of GDP (Cabinet Office, “National Income Accounts”)
(2005 yens, real terms, annual rate, % changes from the previous quarter)

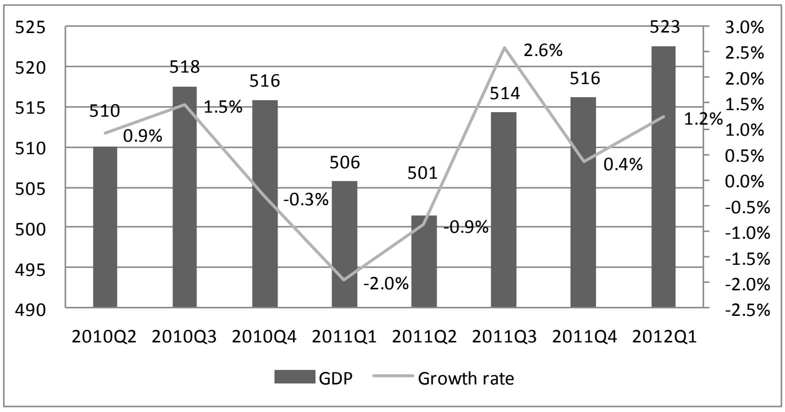


Figure 10 Population of Fukushima Prefecture (as of the first day of each month, in thousands)
(Fukushima Prefecture, Monthly Survey on the Current Population)

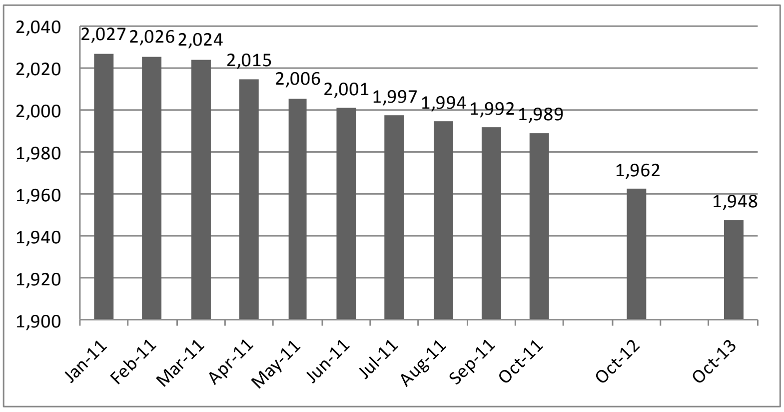


Figure 10 shows the population of Fukushima Prefecture, parts of which were designated as areas for evacuation following the accident at the Fukushima Dai-ni nuclear power station. The prefecture's population, which stood at 2,027,138 as of January 1, 2011, came to 1,947,580 as of October 1, 2013, a decline of 80,000 or 3.9%.

The important issue related to the accident at the Fukushima Dai-ni nuclear power station is the cost of decontamination. According to Tetsuo Yasutaka and Wataru Naito (2013) of the National Institute of Advanced Industrial Science and Technology, the cost of decontamination is estimated to reach ¥5.13 trillion at a maximum. The cost largely depends on decontamination methods and decontamination target values. A total of ¥1.6 trillion was spent on decontamination from 2011 to 2013, with an additional ¥500 billion budgeted for 2014. Reichmuth, Short, Wood, Rutz and Schwartz (2005) of the Pacific Northwest National Laboratory estimated the cost of decontamination in the event of the use of nuclear weapons in an act of terrorism. While the cost of decontamination is greatly influenced by decontamination target values, in the event that a nuclear bomb in the size of the Hiroshima atomic bomb equivalent to 13 kilotons of TNT, it is estimated to require US$5 trillion to get the contamination level to one millisievert or less and US$4 trillion to get it down to 5 millisieverts or less.

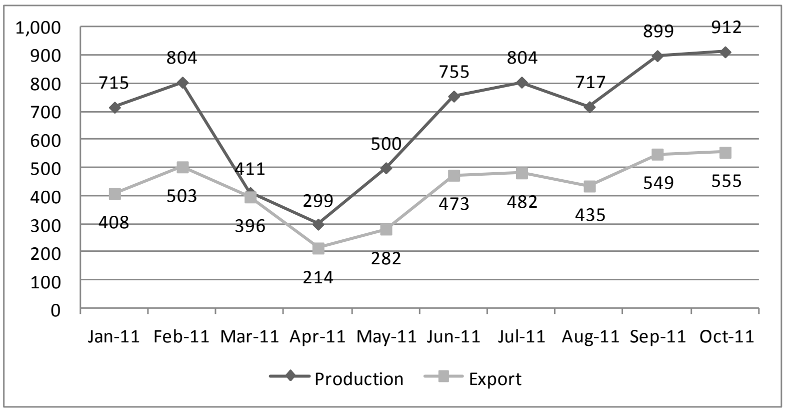
3. Impacts of Interrupted Networks

The economic impacts of the use of nuclear weapons may include the total destruction of industrial infrastructure at a location where a nuclear bomb was dropped and the resultant complete halt to production activities, causing far-reaching damage. This section covers this particular problem.

3.1 Supply Chains

In the Great East Japan Earthquake, as shown in Figure 11, automobile production was halved to 411,000 units in March 2011 from 804,000 units in February 2011, and declined further to 299,000 units in April 2013, a drop of as much as 63% from the peak production level. Automobile production restored the original level only in November 2011.

Figure 11 Automobile Production and Exports (in thousand units) (Ministry of Economy, Trade and Industry, Statistics Survey of Current Industrial Production. Ministry of Finance, Trade Statistics)



A series of processes for delivery of products to consumers, from the procurement of materials and production to distribution and sales, is called the supply chain. When the supply chain is disrupted, manufacturers cannot procure parts and components, and even industrial plants that escaped the damage from an earthquake cannot manufacture products. Sharp falls in automobile production at the time of the Great East Japan Earthquake are believed to have stemmed from Renesas Electronics Corp.'s inability to supply auto parts from its Naka Plant (Hitachinaka City, Ibaraki Prefecture), which is responsible for output of parts essential for production of control devices in automobiles, due to the quake damage.

3.2 Information and Telecommunications Networks

Contemporary society functions with the support of the information and telecommunications network. The supply chain also depends greatly on the information and telecommunications network. If the network is destroyed, its impact would be enormous. It is still fresh in our minds that in the Great East Japan Earthquake, the information and telecommunications systems were damaged and the disruption in the means of communication proved to be a major hindrance to relief operations.

At 7 a.m. on March 1, 2003, the flight plan information-processing system operated by the Tokyo Area Control Center of the Ministry of Land, Infrastructure, Transport and Tourism stopped working due to some troubles. This made it impossible for any aircraft to depart from airports across Japan for 20 minutes. One system recovered at 7:45 a.m., and both systems recovered at 10:58 a.m. Due to the system shutdown, however, the control center had to operate air traffic control by manual input of flight plan information and the resulting phased lifting of restrictions on departures caused major hindrances to flights even after the restoration of the systems. As a consequence, a total of 215 flights were canceled, 1,500 flights delayed for long hours and as many as 300,000 passengers stranded. The troubled were caused by programming glitches and the systems could be restored in a relatively short period of time. In the event of the use of nuclear weapons, however, the human and material damage would be enormous to make it impossible to restore the systems in a short period of time. In the meantime, no aircraft would be able to depart from airports across Japan.

Recognizing the necessity of the core structure for information security measures, in April 2005 the government established the Information Security Policy Council, which sets the basic strategy for Japan's information security policy, and the National Information Security Center in the Cabinet Secretariat as an organization for executing it. The National Information Security Center defines social infrastructure that provides essential services to people's daily lives and social activities, as extremely difficult to be substituted by other things and could have significant impacts on social and economic activities if its function is suspended as "critical infrastructure," and designated the ten sectors of "data communication," "finance," "airlines," "railways," "electric power," "gas," "the government and administrative services," "medicine," "water service" and "logistics" as "critical infrastructure" to be protected. The impacts of the Great East Japan Earthquake on critical infrastructure are summarized in Hitachi, Ltd. (2012).

According to the information contained in it, some 1.5 million fixed phone lines of Nippon Telegraph and Telephone East Corp. (NTT East) experienced communication failures, centering on the Tohoku Region, as of March 13, 2011. NTT East mobilized over 150 mobile power source cars, including those borrowed from Nippon Telegraph and Telephone West Corp. (NTT West), to communication facilities in East Japan, and 85% of such facilities restored normal operations by March 28, and 99% of fixed phone lines were restored on May 16.

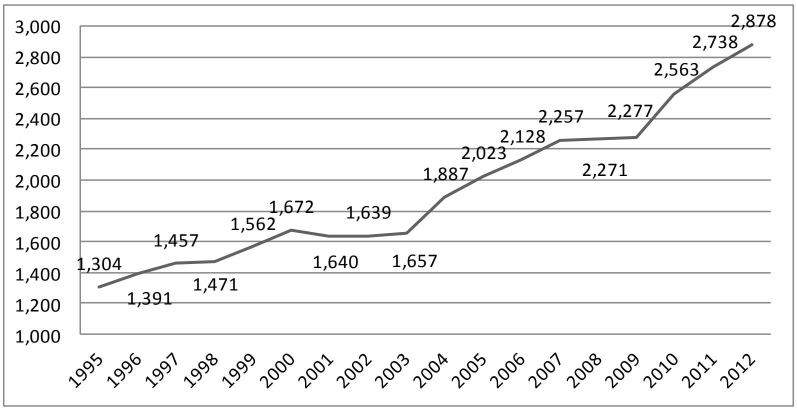
The Yamada Branch of the Bank of Iwate in Yamada-machi, Iwate Prefecture, where over 500 people lost their lives, leased a room in the town office as an ad-hoc subbranch to provide residents with banking services from March 30. Open for business for just four hours from 10 a.m. to 2 p.m. on weekdays, the subbranch set the limit of "¥100,000 per day per depositor" on deposits that could be withdrawn, and catered to depositors who lost bank passbooks or seals in the aftermath of the earthquake and tsunami. Similar services were provided by banks at the time of the Great Hanshin-Awaji Earthquake.

3.3 Terrorism and Infectious Diseases

In the wake of the use of nuclear weapons, the suspension of the operation of the air traffic control system and the stoppage of air transportation by affected countries can be conceived. At the same time, the materialization of the risk of the use of nuclear weapons could be expected to have major ripple effects internationally.

Figure 12 shows that the number of passengers carried by aircraft globally is greatly influenced by terrorism and infectious diseases. In particular, the synchronized terrorist attacks that occurred on September 11, 2001, prompted people all over the world to refrain from flying by reminding them of the possibility of terrorism spreading globally. Needless to say, the slow air traffic during this period was also partly affected by the global recession in the wake of the bursting of the IT bubble, but fears of terrorism had a much larger impact. Aggravating the sluggish air transportation was the spread of the severe acute respiratory syndrome (SARS), the new type of pneumonia. SARS broke out in November 2002, but the outbreak of the disease was internationally recognized in February 2003, when a person developed its symptoms aboard a plane bound for Singapore from China and died despite treatment after the plane's emergency landing in Vietnam, together with those who treated the patient. The World Health Organization (WHO) issued a global warning on SARS in March 2003. Global transportation by air remained sluggish until an end to the spread of SARS was declared in July 2003.

Figure 12 Passengers Carried by Aircraft Globally (in millions)
(ICAO, Annual Report of the Council)



The number of passengers carried by aircraft globally was also slack from 2007 through 2009, apparently because of the sluggish global economy stemming from the financial market turmoil triggered by the subprime loan shock and the ensuing Lehman Shock. Also contributing greatly to the slow movements of people by air was the onset of type A and subtype H1N1 influenza, which began spreading in Mexico in April 2009 and declared as a pandemic by the WHO in June of the same year. The pandemic drew keen attention partly because the infectious morbidity was reported to be very high in Mexico in the early stage of the spread. The alert level was removed after the influenza did not show the morbidity as high as SARS globally.

However, as onboard checks were conducted at airports initially and infected individuals were committed to forced hospitalization, many people refrained from air travels out of fear for infection risk.

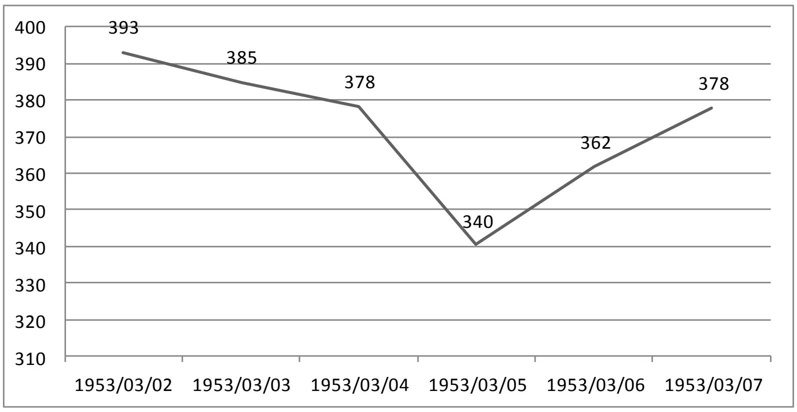
4. Impact of the Financial Market Turmoil

One of the biggest impacts of the use of nuclear weapons on the global economy may be a heightening sense of insecurity over the future of the world. Thus far, the global economy has been buffeted by a variety of shocks, but if nuclear weapons are actually used, its effects would be immeasurable. In the contemporary economic society, the financial system, founded upon credit as well as human and material assets, is playing a major role, and we cannot take our eyes off financial assets and liabilities within that system. Shocks that stem from credit uncertainty in the financial market could significantly influence activities of companies and households instantly. Thus, any use of nuclear weapons would cause tremendous adverse impacts on the economic society by significantly undermining credit. This is because asset prices, as represented by stock prices on the stock market and bond prices on the bond market, which have a major role to play on the financial market, are formed on the basis of expectations on the future of the economy and credit, and if expectations on and risks concerning the future heighten unexpectedly as a result of the use of nuclear weapons, asset prices might decline or even evaporate instantly. And the decline or evaporation of asset prices could have a serious impact on economic activities of companies and households.

4.1 The Stalin Shock

On March 1, 1953, then Soviet Communist Party Joseph Stalin dropped and passed away on March 5. In Japan, Stalin was reported to be in serious condition on March 4 and his death was reported on the morning of March 5. At the time, the Nikkei average on the Tokyo Stock Exchange fell by a sharp ¥38, or 10%, from ¥378 to ¥340. The news sent shock waves through the Japanese economy, which was then in a state of bubble thanks to the special procurement boom traced to the Korean War, as Stalin’s death was expected to bring forward an end to the Korean War and the Korean War-related special demand that underpinned the Japanese economy might fade away. In fact, a ceasefire in the Korean War was declared on July 27, 1953, and the end to the special demand stemming from the Korean War sent the Japanese economy spiraling into a recession in reaction.

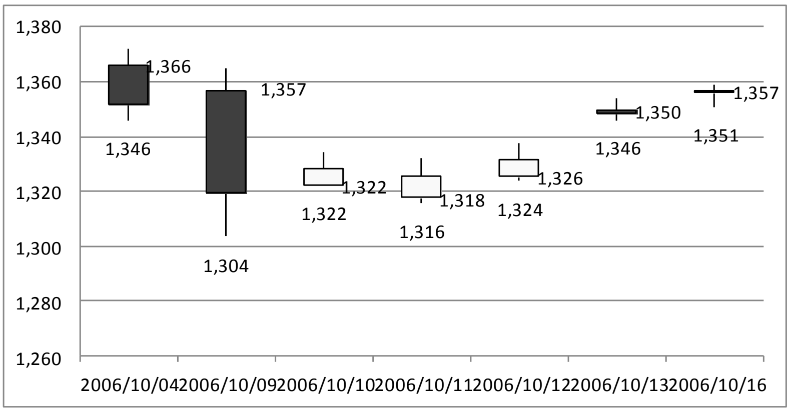
Figure 13 Nikkei Stock Average (March 2, 1953 – March 7, 1953)
(Nihon Keizai Shimbun Sha (Nikkei Inc.))



4.2 Nuclear Tests by North Korea

North Korea conducted an underground nuclear test at 10:35 a.m. on October 9, 2006. Figure 14 shows movements of the Korea Composite Stock Price Index (KOSPI) on the Korea Exchange. KOSPI tumbled on the news of the underground nuclear test from the opening of 1,357 to touch 1,304 at one point, a decline of 3.9%. KOSPI remained subdued until October 12.

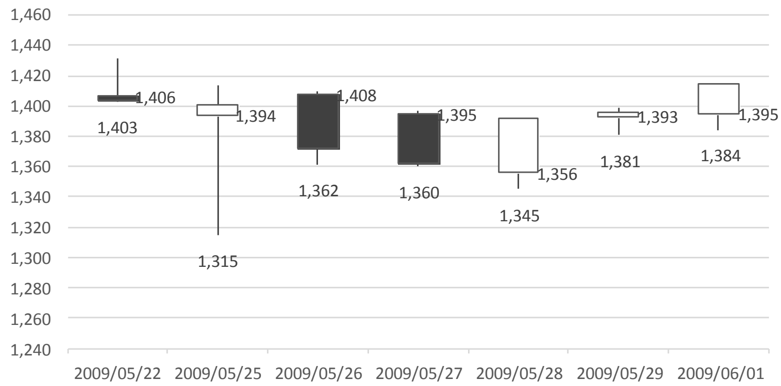
Figure 14 Korea Composite Stock Price Index (October 4, 2006 – October 16, 2006)
(Korea Exchange, Upper row=Opening price/Lower row=Lowest price)



North Korea conducted its second underground nuclear test at 9:54 a.m. on May 25, 2009. Figure 15 shows that although KOSPI fell by a sharp 5.7% from the opening of 1,394 to 1,315 at one point, renewed buying on the market later pushed the index back to 1,401, near the previous day’s closing. While the impact on stock prices, in terms of closing prices, was minor relative to the nuclear test in 2006, the closing levels between May 26 and May 28 remained down 2.5% from the closing on May

22. Nuclear tests by North Korea are having a significant impact on South Korean stock prices, though for a relatively short period of time.

Figure 15 Korea Composite Stock Price Index (May 22, 2009 – June 1, 2009)
(Korea Exchange, Upper row=Opening price/Lower row=Lowest price)



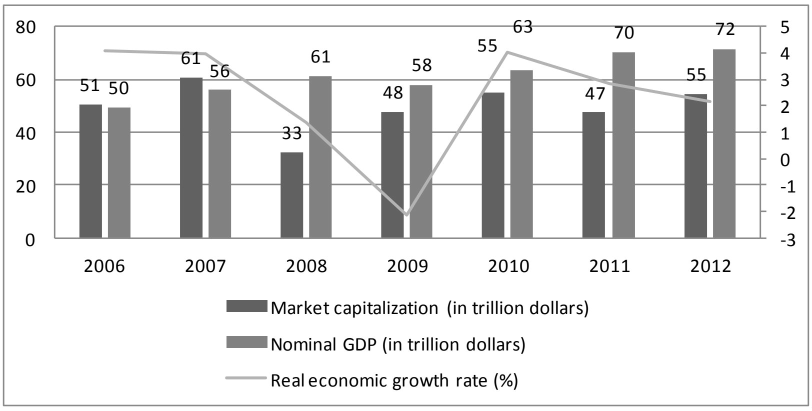
4.3 The Lehman Shock

The U.S. subprime loan problem that came to the fore in 2007 gave rise to the steep drops in asset prices, impaired the financial strength of major financial institutions in various countries, and led to the collapse of Lehman Brothers, which filed for Chapter 11 protection under U.S. federal bankruptcy law on September 15, 2009. Lehman Brothers had total liabilities of US$600 billion, and its bankruptcy was feared to adversely affect companies holding corporate bonds and investment trust instruments issued by Lehman Brothers to give rise to chain-reaction bankruptcies, and deepening concerns over the American economy ultimately resulted in the global financial crisis.

Figure 16 shows the global market capitalization, nominal global GDP, and the real global GDP growth rate. The market capitalization of stocks shrank as much as 46% from US$61 trillion in 2007 to US$33 trillion in 2008, meaning asset value was halved in just one year. As a consequence, though nominal global GDP all but leveled off, the real global GDP growth rate declined from 4.0% in 2007 to 1.4% in 2008, and to negative 2.2% in 2009. Stock prices, formed on the basis of forecast future investment returns, fell sharply on rising anxieties over the future amid the global financial crisis. Slumping stock prices make it difficult for companies spending on equipment investment to develop funding plans and procure funds, while the dwindling value of household assets led to a major setback in consumption, both giving significant effects on the economy. The use of nuclear weapons is certain to increase risk in the future and significantly decelerate the global economy.

Figure 16 Global Market Capitalization and Global GDP (in US$ trillions)

(World Federation of Exchange Statistics, World Bank, World Development Indicators)



5. Conclusion

The final report of the Working Group on the Consideration of Measures to Deal with an Earthquake Occurring Directly under Tokyo of the government's Central Disaster Prevention Council estimates the death toll of 23,000 in the event of an earthquake with a magnitude of 7 occurring in the inner Tokyo area, with 610,000 buildings collapsing or on fire and people evacuating reaching 7.2 million. At the same time, the report assumes that 50% of power supply would be shut down, the power outage would disrupt the communication network, the water supply and sewerage systems would be out of service, and railway services would be halted for about a month. The amount of damage is estimated to total ¥95 trillion, including ¥48 trillion from the suspension of or decline in production and services on top of the direct damage to buildings and others worth ¥47 trillion.

The economic impacts of the use of nuclear weapons would be far greater than those of earthquakes. In addition, the cost of decontamination, one of the key issues in the wake of the accident at the Fukushima Dai-ni nuclear power station, is estimated to amount to US$4 trillion to US$6 trillion with a nuclear detonation in size equivalent to the Hiroshima atomic bomb occurring over New York City.

Furthermore, as seen in the changes in the population of Hiroshima City, the use of nuclear weapons would require longer than 30 years for the population of affected areas to restore the pre-bombing level. In other words, the number of years required for the recovery is certain to be far greater than that of the Great Hanshin-Awaji Earthquake. In that sense, it is obvious that the economic loss resulting from the use of nuclear weapons would be far more enormous than that from earthquakes.

The economic damage from the use of nuclear weapons would have effects on a global scale, not limited to areas where nuclear weapons were used. As experienced immediately after the Great East Japan Earthquake, the fracturing of the supply chains would cause the suspension of production activities on a global scale. If a nuclear weapon is used in Japan, it can be expected to have an extensive impact on China and Southeast Asian countries because there are the solid division of labor and collaboration systems for “manufacturing” in place among Japan, China and Southeast Asian countries.

Finally, the most serious of global economic impacts is the threat to the financial system. The networks of the financial systems, founded upon credit instead of goods and services, are spread across various countries around the world. We witnessed only recently that the nonperformance of subprime loans to low-income households in the United States sent banks in Europe into bankruptcies and the global financial system fell into a crisis in the wake of the Lehman Shock, throwing the world economy into chaos. We must not forget that the use of nuclear weapons presents the risk of not only causing human and material damage to targeted countries but also disrupting the supply systems for goods and services on a global scale and giving a devastating impact on the financial system.

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Afterword

In this paper, we made an analysis of various impacts of the detonation of nuclear weapons by the physical, medical, disaster engineering and macroeconomic methods.

We chose a 16-kiloton Hiroshima-class atomic bomb and a 1-megaton hydrogen bomb as the destructive force of nuclear weapons. In order to estimate the impacts of their detonation, we calculated the distances, the casualty rates, aftereffects of the atomic bombs over 50 years after the bombings, and in particular the incidence rates of leukemia and cancer through an exhaustive analysis of various research data on the impacts of the atomic bombing attacks on Hiroshima and Nagasaki, and accumulated and organized basic data on the effects of atomic bombs on the human body.

Then, we assumed a city with a population of one million people in the contemporary world and analyzed the impacts of the midair detonation of a 16-kiloton atomic bomb 600 meters above and of a one-megaton hydrogen bomb 2,400 meters above by primarily referencing the basic data on the atomic bombing of Hiroshima as well as the Effects of Nuclear Weapons, a report published by the U.S. government in 1977, and estimated for each bomb detonation the casualty rate and the number of excess cases of leukemia over a period of 50 years, the scope of urban destruction, the extent of destruction of urban infrastructure, and the post-detonation continuation of long-term economic collapse.

We were able to assume that the detonation of both the atomic bomb and the hydrogen bomb would cause the high casualty rate and the large number of incidence of aftereffects that match or substantially exceed those of the atomic bombings on Hiroshima and Nagasaki 69 years ago and would also lead to the extensive destruction of urban infrastructure and the long-term economic collapse.

It has become obvious that such nuclear detonation, if occurred over a densely-populated city without any prior warning, would result in the indiscriminate massacre of urban residents, young and old, regardless of whether they are civilians or military personnel. It has also become obvious that such nuclear detonation would cause the near-complete loss of medical personnel, medical institutions, firefighters and relief and rescue organizations, effectively rendering substantive relief and rescue operations impossible. There is no doubt that the destruction of urban infrastructure would delay the restoration from the damage by several decades, hamper the recovery of the population in the meantime and make urban reconstruction extremely difficult.

Given the fact we obtained through analysis of Hiroshima and Nagasaki atomic bomb disasters and the assumption above on virtual nuclear attack to a modern city, we conclude that the detonation of nuclear weapons under any circumstances would bring unbearable nonhumanitarian consequences.