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CHAPTER 6

Experiences and Extrapolations from Hiroshima and Nagasaki

CHRISTINE C. HARWELL (Editor)

Primary Contributions by: T. Ohkita, Y. Shimazu, T. Urabe, M. A. Harwell, J. Jacobsen, A. M. Katz, A. Leaf, D. Liverman, D. Mileti, J. Mitchell, P. Slovic, G. F. White

Additional Contributions: M. Glantz, W. Isard, R. J. Lifton, M. Lystad, A. Postnov, W. Riebsame, A. Schweiger

This chapter examines the events following the atomic bombings of Hiroshima and Nagasaki in 1945 and extrapolates from these experiences to further understand the possible consequences of detonations on a local area from weapons in the current world nuclear arsenal.

The first section deals with a report of the events that occurred in Hiroshima and Nagasaki just after the 1945 bombings with respect to the physical conditions of the affected areas, the immediate effects on humans, the psychological response of the victims, and the nature of outside assistance. Because there can be no experimental data to validate the effects on cities and their populations of detonations from current weapons, the data from the actual explosions on Hiroshima and Nagasaki provide a point of departure.

The second section examines possible extrapolations from and comparisons with the Hiroshima and Nagasaki experiences. The limitations of drawing upon the Hiroshima and Nagasaki experiences are discussed. A comparison is made of the scale of effects from other major disasters for urban systems, such as damages from the conventional bombings of cities during World War II, the consequences of major earthquakes, the historical effects of the Black Plague and widespread famines, and other extreme natural events. The potential effects of detonating a modern 1 MT warhead on the city of Hiroshima as it exists today are simulated. This is extended to the local effects on a targeted city from a global nuclear war, and attention is directed to problems of estimating the societal effects from such a war.

6.1 LESSONS FROM HIROSHIMA AND NAGASAKI

6.1.1 Introduction

At 08 : 15, 6 August 1945, an atomic bomb was detonated over Hiroshima, and three days later, on 9 August 1945, at 11 : 02, another atomic bomb was exploded over Nagasaki. The energy yields of these two bombs were estimated to be 15 (± 3) kT at Hiroshima and 21 (± 2) kT at Nagasaki (Ishikawa and Swain, 1981; U.S.–Japan Joint Workshop, 1985), which are very small compared to the present stage of development of nuclear weapons.

Hiroshima is built on a delta at the mouth of the Ota River, which flows into the Seto Inland Sea from the northern mountains. The east and west are walled off by hills, and the southern delta area faces the Seto Inland Sea. Because the explosion occurred at a height of about 580 m above the center of this fanshaped, flat city, the damage extended throughout the city in all directions. The degree of damage decreased with distance from the hypocenter, but 92% of all structures were damaged to some extent. Virtually the entire city was devastated instantaneously.

Soon after the explosion many fires broke out in the devastated area, merging quickly and spreading in all directions. In Hiroshima, thousands of wooden dwellings and shops were crowded together along narrow streets and were filled with combustible materials. The level terrain was conducive to rapid firespread, and there had been no rain for three weeks, conditions ideal for a firestorm. Winds reached a velocity of 18 m sec^{-1} within two to three hours, with the outbreak of the firestorm. From 11 : 00 to 15 : 00, a violent wind blew locally from the center toward the northern part of the city (Uda et al., 1953). The wind gradually decreased and became calm by about 17 : 00. All combustible materials within a radius of 2 km of the hypocenter were burned by the firestorm.

Nagasaki is built around the Nakashima River basin, the Urakami River basin, and Nagasaki Bay, into which both rivers flow. The city's two basin districts are separated by a hill about 200 m above sea level. The commercial center, the prefectural and municipal offices, and other government offices were concentrated in the Nakashima River district. Along the Urakami River district lies a relatively broad expanse between hills running north and south. There were intermittent rows of factories on the west bank of Nagasaki Bay, and there were also many residences and schools in this district.

The atomic bomb exploded at a height of about 500 m above the center of the Urakami River district. The damages caused by thermal radiation and blast were almost entirely restricted to this area, while most of the Nakashima River district was protected by the hills; however, 36% of all structures in both districts were damaged.

Fires broke out about 90 minutes after the explosion at several locations quite far from the hypocenter. Though the firestorm in Nagasaki was not so large as that in Hiroshima, about two hours after the explosion, when the fire became violent, a southeast wind blew between the hills at a speed of 15 m sec^{-1}. This wind extended the fire toward the north of the valley, where there were fewer residences. About seven hours later, the direction of the wind changed to the east, with a drop in wind speed (Nagasaki City Office, 1977).

The fire-fighting facilities were almost totally destroyed in Hiroshima and Nagasaki. Even where facilities and fire-fighting personnel escaped disaster, blocked roads interfered with fire-fighting activities except along the perimeters of the firestorm areas. Countless water pipes inside damaged buildings were broken, and pumping stations were disabled by the interruption of electric power, causing loss of water pressure and water supply.

In Hiroshima, a mild wind was blowing toward the west at the time of the explosion, and the 'black rain', containing radioactive materials, fell from the north to the west of the hypocenter. Radioactivity was later detected throughout a wide area in the part where rain fell (Yamazaki, 1953; Pace and Smith, 1959; Takeshita, 1975).

In Nagasaki, a wind was blowing toward the east-northeast at the time of the explosion, and rain containing radioactivity was concentrated near the Nishiyama water reservoir 3 km east of the hypocenter. Substantial radioactivity was detected at the Nishiyama district (Shinohara et al., 1953; Pace and Smith, 1959; Takeshita, 1975). It has been said that there were cases of serious biological damage among the persons exposed to black rain or to residual radiation, but there are insufficient objective data available to confirm this.

Many factors influenced the scope of destruction and the number of casualties. Those factors pertaining to the bombs, such as energy, height, and location of the explosion, were highly significant (Glasstone and Dolan, 1977; Ishikawa and Swain, 1981), but the experiences in Hiroshima and Nagasaki reveal the importance of the conditions within the target area as affecting the degree of the catastrophe.

The first factor was the surprise nature of the attack. In neither city was an air-raid alert sounded at the time of the bombings. A large part of the population was in the open or in light wooden dwellings and thus received a minimum amount of protection. The second factor was the protection provided by the terrain. The flat terrain in Hiroshima gave almost no protection, except in the shadow of Hijiyama hill, located about 2 km east of the hypocenter. The rivers within the city, about 100 to 150 m wide, had little or no limiting effect on the firestorm. Because of the hilly terrain in Nagasaki, the area of destruction was largely confined to the Urakami valley district. Moreover, the reported mortality and casualty rates were lower in those parts of the bombed area shielded by the hills, even in districts at about the same distance from the hypocenter (Oughterson and Warren, 1956). The third factor was the immediate paralysis of fire fighting, rescue work, and medical care. There were heavy casualties among physicians and nurses, in the fire-fighting and police personnel, and among local government officials. Many institutions central to the medical, rescue, and fire-fighting systems were completely destroyed. The consequent hampering of rescue work and medical care increased the total mortality in the general population.

6.1.2 Immediate Effects on Humans

According to observations in Hiroshima and Nagasaki, the general course of atomic bomb injury can be divided into four stages (Science Council of Japan, 1951; Glasstone and Dolan, 1977; Ishikawa and Swain, 1981):

1.) initial stage—The greatest number of casualties occurred from immediately after the explosion until the end of the second week; approximately 90% of the fatalities occurred during this stage. The majority of the injured persons receiving medical care for several days after the explosion complained of burn injuries.

2.) intermediate stage—Many moderate injuries caused by radiation were encountered from the beginning of the third week until the end of the eighth week, and most of the remaining 10% of the fatal cases died. The initial and intermediate stages encompassed the acute stage of injury.

3.) late stage—From the beginning of the third month until the end of the fourth, most of those injured survivors showed some improvement, although a few cases died from complications. By the end of the fourth month, most persons suffering from the disasters in both cities had recovered from the acute effects.

4.) delayed effects—After five months, there were various delayed effects: distortions, contractures, and keloids following recovery from burn injuries or mechanical injuries; anemia as a result of bone marrow depression caused by radiation exposure; and disturbances to reproductive functions, such as sterility.

6.1.2.1 Blast

The blast pressures generated by the Hiroshima and Nagasaki bombs at ground zero are estimated to have been 6.4–9.5 psi (44–66 kPa) and 8.5–11.4 psi (59–79 kPa), respectively. The blast wave consisted of two phases: compression and suction. The duration of the compression phase is estimated to have been approximately 0.5–1.0 second. Mechanical injuries resulting from the blasts were direct and indirect, mostly the latter, and were mainly from collapsing buildings, flying debris, or both. There are no reliably established deaths attributable to direct blast effects, that is, resulting from the direct blast pressure on human bodies alone, exclusive of blast-induced contact with other objects. Indirectly, the blasts caused many instantaneous deaths. Middleton (1982) estimated that the LD_{50} for blast alone (i.e., the level at which 50% of those exposed would be directly killed) is about 12 psi, and that some humans could survive blasts of up to 30 psi. The incidence of indirect mechanical injuries among survivors was inversely proportional to the exposure distance from the hypocenter (Table 6.1). Blast injuries occurred mostly among people in structures, less among those outdoors with shielding, and least frequently among those outdoors without shielding—exactly the reverse order from that of burns. Under the condition of enormous blast pressure, buildings and walls offered more risk than protection, especially at close range.

Blast-induced physical injuries of survivors were of all degrees, from minor scratches to severe lacerations and compound fractures. The most common injury was laceration by small glass fragments. Fractures were infre-

TABLE 6.1

TYPES AND SEVERITY OF INJURIES IN RELATION TO EXPOSURE AT HIROSHIMA[a]

Distance from Hypocenter (km)		0	1	2	3	4	5	6
Outdoors (unshielded)	Blast	high	low					
	Burn	high	mod.	low	low			
	Radiation	high	mod.	low	low			
Outdoors (shielded)	Blast	low	low					
	Burn	low	low					
	Radiation	mod.	low	low				
Indoors (wood structure)	Blast	high	high	mod.	mod.	low	low	
	Burn	low	low					
	Radiation	mod.	low	low				
Indoors (concrete structure)	Blast	low	low					
	Burn	low	low					
	Radiation	mod./low						

Casualty Rate (%): high = 50%-100%; moderate = 10%-50%; low = 0-10%.

[a] Data from Science Council of Japan (1951).

quent, but many who did not survive probably had severe fractures. With the extreme scarcity of medical care soon after the bombings and because of lowered white blood cell counts resulting from ionizing radiation, minor lacerations and abrasions, which ordinarily would have promptly healed, often resulted in severe infections.

Rupture of eardrums was considered evidence of direct blast injury among survivors, but its frequency was rather low. For instance, less than 10% of a sample of 200 Nagasaki survivors exposed within 1 km had ruptured eardrums. Several percent of survivors were also reported as temporarily deaf. Other less-defined symptoms may have been blast-related, such as vertigo, buzzing or ringing in the ears, and headache without evidence of trauma. About 15% of the survivors surveyed soon after the bombings complained of these symptoms. Most of them had been within 2.5 km. Transitory unconsciousness immediately after the explosions was frequently described. These symptoms were more likely caused by violent displacement, such as being thrown to the ground, rather than by direct blast. Regarding later effects of mechanical injuries, no data for precise numbers of disabled survivors are available.

6.1.2.2 Thermal Radiation

The intensity of the heat generated by the explosions in Japan is estimated to have been 3000–4000°C at ground level near the hypocenters. Its duration was exceedingly short, approximately 0.5–1.0 second. The heat markedly attenuated with increasing distances from the hypocenters (Table 6.1). There is, however, evidence (e.g., peeling of granite surfaces) that it was more than 575°C at distances of 1.1 and 1.6 km from the hypocenters in Hiroshima and Nagasaki, respectively.

Thermal radiation caused burns directly, or indirectly from fires ignited by the flash from the fireball. Direct burns, often called 'flash burns', were characteristically restricted to one side of the body and were sharply outlined. Indirect burns, or 'flame burns', might involve any part of the body and tended to penetrate much deeper than flash burns. Both types of burns were often combined, but those observed among survivors were predominantly flash burns. When the bombs were dropped, most people wore only short-sleeved, light summer clothes. The effects of radiant heat were enhanced on the bare skin, since clothing was protective to a variable degree, depending on its quality and color and the intensity of the heat. The frequency of burn injuries was exceptionally high. Those in the open without appreciable protection received severe burns within 1.5 km of the hypocenters together with significant doses of ionizing radiation, moderate but still fatal burns within 2.5 km, and mild burns at distances of 3.0–4.0 km. According to a survey conducted in Hiroshima, the frequency of burns was nearly 100%

among unshielded survivors who were alive after 60 days and were exposed at a distance up to 2.5 km; beyond 3 km, it decreased abruptly. Burns were, of course, most frequent in persons outdoors and unshielded, considerably less frequent in those outdoors and shielded, and least frequent among those who were indoors. Persons inside buildings were burned by flash only when the thermal radiation reached them through doors or windows. After the healing of severe burns, overgrowth of scar tissue or keloids was frequently observed, especially among female survivors who were within 2.5 km of the hypocenters. Though it was once suggested that this might have been a consequence of radiation effects, there is no clear evidence to support this. By 1952, there was appreciable regression of protruding scars or keloids in most cases (Ishikawa and Swain, 1981).

6.1.2.3 Ionizing Radiation

Because of the relatively low explosive yields of the atomic bombs, the initial radiation (fast neutrons and gamma rays) produced during a period of about one minute after the explosions played the essential role in radiation-induced health effects. The air dose values of the initial radiation decreased with increasing distances from the hypocenters (Table 6.1). Reassessment of the radiation dosimetry by a joint committee of scientists in Japan and the United States is now in progress, and the final conclusions of this committee are expected in 1986. According to the latest dose estimates, made in 1965 (known as the Tentative 1965 Dose or T65D), air dose values were about 450 rad at 1.0 km and 2.5 rad at 2 km in Hiroshima. In Nagasaki, these values were 925 rad and 18 rad, respectively (Milton and Shohoji, 1968). After extensive surveys of radioactivity over wide areas, including the bombed and fallout areas, conducted by Japanese and American teams, it is generally accepted that residual radiation in the bombed areas mainly resulted from induced radioactivity, and that the contribution of early fallout was not great, except within a few hours after the explosions. Radioactive fallout areas closely approximated the black rain areas, and biological effects of the residual radiation were much less than that of the initial radiation in both cities.

Little is known of the severe radiation injuries that caused instantaneous deaths because these cases were not autopsied in the chaotic conditions immediately after the detonations. For victims who survived for a week or so, the course of those having acute radiation syndrome was predictable by the severity and duration of the early symptoms, dependent on the quantity of radiation doses absorbed. The symptoms and signs of typical radiation injuries resulting from whole-body exposure can be categorized chronologically in the following phases:

1.) the prodromal radiation syndrome, usually consisting of lassitude and gastrointestinal symptoms, such as nausea, vomiting, and anorexia, starting shortly after the exposure and persisting for one or more days;

2.) a period of relative well-being of variable duration inversely proportional to the exposure dose;

3.) a febrile period lasting several weeks, with epilation, oropharyngeal ulcerations, infections, hemorrhagic manifestations, and diarrhea; and

4.) either death or prolonged convalescence with eventual recovery.

In the most severely injured, the febrile phase usually began between the fifth and seventh days, sometimes as early as the third, severe diarrhea being its most prominent manifestation, continuing until death. Many suffered from cerebral symptoms, including convulsions and delirium. The severely exposed usually died within two weeks. In the less severely injured, epilation began about one to two weeks after exposure and initiated the febrile phase, soon followed by pupura and oropharyngeal ulcerations. The less severely but fatally exposed died, as a rule, before the end of the sixth to eighth week after exposure.

The cells of the human body that are very active in proliferation are, in general, most sensitive to radiation exposure. For example, cells of lymphatic tissue, proliferating immature blood cells in the bone marrow, gastrointestinal epithelia, spermatogonia of the testes, and follicle cells of the ovaries are particularly liable to injury from radiation. Among these, depletion of bone marrow cells and denudation of intestinal epithelia by a sufficiently large dose of deeply penetrating ionizing radiation are considered to be the most critical mechanisms for mortality.

The first case of radiation-induced cataract in Hiroshima was discovered in 1948 (Ikui, 1967), and this was followed by many reports of this disease in both Hiroshima and Nagasaki (Hirose and Fujino, 1950). Leukemia among survivors first appeared in 1945 in Nagasaki (Misao et al., 1953) and in 1946 in Hiroshima (Komiya, 1947). Its incidence rose gradually thereafter, reaching its peak between 1950 and 1953, and has maintained high levels since. From 10 to 15 years after the explosion, a general trend in the increase of various cancers, such as thyroid, breast, lung, and multiple myeloma was found among those receiving significant doses of radiation. Microcephaly and other developmental disturbances were encountered among children exposed in utero, particularly within about 17 weeks of gestation (Miller and Blot, 1972). Chromosome aberrations of blood lymphocytes and bone marrow cells have been detected among heavily exposed survivors.

Genetic effects have also been carefully studied. Investigations to date have revealed no adverse genetic effects in the first filial generation born to exposed parents (Kato and Shigematsu, 1985). These results, however, do not necessarily mean that radiation would not cause genetic effects. The genetic effects have thus far proved to be too small to be detected by the methods available during the last four decades (Hamilton, 1985). Although no statistically significant genetic effects have yet been detected in the first filial generation, it is possible that recessive effects will appear in later generations. It is somewhat reassuring that humans do not exhibit a high sensitivity to radiation-induced genetic disorders, but it may be premature to conclude that genetic changes will not occur later from the exposure in Hiroshima and Nagasaki. Investigations need to be continued.

6.1.2.4 Epidemics

Questions have been raised as to whether there were epidemics among the surviving populations of Hiroshima and Nagasaki. The ingredients for development of an epidemic are:

1.) a sufficient number of susceptible individuals in a population to sustain a high incidence of the disease in epidemic proportions;

2.) an infectious agent of sufficient infectivity and virulence to sustain a high prevalence of the disease in the community; and

3.) a means of spreading the infectious agent through the population.

These conditions were fulfilled in the aftermath of the Japanese atomic bombings. The many unburied corpses, the large numbers of injured in unsanitary shelters, the destruction of city water supplies, the failure of the sewage system, the proliferation of flies, and other potential vectors would seem to provide the necessary ingredients. However, the very large proportions of the population which sustained some blast, thermal, or radiation injuries, all of which increase likelihood of secondary infections, make it difficult to distinguish which diarrhea and which sepsis resulted from incidental infection unrelated to the atomic bomb injury and which were directly related to the primary injury. Undoubtedly, the unsanitary conditions that prevailed in both cities in the period immediately following the bombings could have set the stage for epidemics of infectious diseases. However, the extensive injuries would make it almost impossible to separate epidemic infections from those subsequent to the bomb injuries.

Furthermore, bacteriologic facilities were not sufficiently available to isolate infectious organisms to determine whether particular strains were responsible for the many infections that occurred or whether infectious organisms were manifold as expected among the secondary infections contracted by the many injured individuals. In fact, there are only two reports of bacteriological examinations conducted within two months after the bombings. In the first report, blood cultures of 19 survivors who had symptoms of radiation illness, especially with high fever, were carried out in Hiroshima on 30 August and 4 September 1945. Of these, positive results suggesting septicaemia were obtained in five patients. None of these patients survived. Bacteriological examinations of stool from the survivors with mucoid bloody diarrhea, who had symptoms suggesting bacillary dysentery, were performed in August on 200 such cases. Only one case had a positive culture. Results of examinations for typhoid fever on the same survivors were all negative. Stool cultures were also performed on 100 patients with radiation illness. Results were all negative for usual pathogens (U. S. Strategic Bombing Survey, 1946). In the second report, stool cultures were carried out in Nagasaki from 14–22 September 1945, on 37 survivors with diarrhea, or who had past history of severe diarrhea up to that time. Dysentery bacilli were detected in one case (E'njoji and Inoue, 1953). It is presumed that more cases of bacillary dysentery might have been found among victims with mucoid bloody diarrhea, which was generally thought to be one of the symptoms of acute radiation illness, if stool cultures could have been properly performed during the period following the bombings. No such service was available and, accordingly, no conclusion can be drawn about the occurrence of epidemics in either city.

6.1.3 Psychological Responses of Victims

6.1.3.1 Acute Psychological Responses

The psychological state of survivors was the subject of an interview survey conducted in Hiroshima from 1949 to 1952 (Kubo, 1952). An initial, instinctive behavior for protection from various dangers of the devastation of the atomic detonations was for survivors to leave as a mass exodus from the vicinity of destruction. Second, when they recognized the calamity caused by the bombing and observed the disastrous damages never experienced before, they fell into a 'chaotic' state of consciousness in which they could not judge what had happened. Panic occurred, and they took reckless actions which could be considered a reaction to catastrophe. Third, the panic was intensified by further stimuli, including the sudden change of environment because of the disaster and loss of information. With this, they lost the ability to react to external stimuli. They simply followed others and arrived finally at a place which seemed to be safe, where they rested, slept, received nursing care, and at last began to recover their mental function.

Proximally exposed persons, however, were greatly hindered from recognizing the situation because they had developed physical disorders including burns, external wounds, etc., so that their mental conditions cannot be considered apart from their physical condition. However, some of the physical disturbances were later thought to be psychogenic disturbances.

Kubo (1952) reports that recovery of mental function proceeded rapidly soon after the bombing. Proximally exposed survivors developed acute radiation illness in the period one to three weeks after the bombing and again lived in fear of death. It is understood that survivors who did not develop acute radiation illness established a posture of accommodation by confirming the death of family members and the destruction of the community to which they belonged, displaying understanding and judgment of their own situation. Some survivors showed neurasthenic symptoms from 2–3 weeks to 2–3 months after the bombing and some of them developed neuroses (Okumura and Hidaka, 1949).

6.1.3.2 Long-term Psychological Impacts

In a neuropsychiatric study of survivors 10–20 years after the bombing, it was reported that psychosomatic and/or neurotic complaints and symptoms were more frequent in the survivors than in controls (Nishikawa and Tsuiki, 1961). Survivors have what can be considered neurotic conditions; they continue to have mental adherence to the atomic bombings. These complaints have increased with age; a variety of neurotic complaints and symptoms appears in some cases (Konuma et al., 1953). Konuma describes this as the developmental mechanism of a diencephalic syndrome.

As years elapsed after the bombings, survivors remained psychologically precarious for several reasons. First, there was always the threat to their health from delayed radiation effects. Second, there was the fear that their children would be unhealthy or malformed. Third, economic instability threatened if delayed radiation effects decreased their ability to work or care for themselves and also required increased medical expenses. Fourth, death, sickness, and decline or loss of ability to work and manage could further accelerate the disintegration of their families. Fifth, discrimination against them by non-victims added to difficulties in social life, especially the burned victims whose suffering and distress were intensified by the appearance of keloid scars. These multiple effects on health, life, and livelihood imposed a great psychological burden on the victims.

The existence of almost purely psychological phenomena, however, cannot be denied. Such are closely connected with what Lifton (1967) terms the 'taint of death' and 'death guilt', or what Ishida (1973) explains as a 'sense of guilt and shame'. Lifton's 'taint of death' refers to a consciousness deeply imprinted in the minds of the bombing victims 'by three aspects of their ordeal: the suddenness and totality of their death saturation, the permanent taint of death associated with radiation aftereffects, and their continuing group relationship to world fears of nuclear extermination' (Lifton, 1967).

The 'death guilt' he described as stemming from the profoundly inappropriate premature death of many people, which provoked in the survivors the virtually insurmountable feeling that their survival was made possible by others' deaths. Ishida's 'sense of guilt and shame' refers to the victims' self-condemnation with respect to the behavior they inevitably engaged in immediately following the bombings (Ishida, 1973).

6.1.4 Outside Assistance

In addition to examining the purely physical and psychological effects of the bombing, there are other factors which deserve attention, including those which affected the ability of the population to deal with and recover from the bombings. Of particular significance was the availability of assistance to the survivors from both within and without the communities directly affected by the detonations. The nature and extent of this assistance reveal important insights into the ability of communities to cope with such unexpected and unprecedented events.

Prior to August 1945, the city and prefecture of Hiroshima had, under the Wartime Casualties Care Law, established an air defense headquarters, evacuated people, demolished certain buildings to create firebreaks, organized a medical rescue system, and stocked medical supplies. The bombing of Hiroshima on the morning of 6 August left the entire city momentarily immobilized. A 1943 directive by the governor of Hiroshima Prefecture had authorized an 'air defense medical rescue plan', which forbade evacuation of medical doctors and ordered formation of medical rescue squads consisting of one physician, one dentist, one pharmacist, three nurses, and one clerk. Township councils and civil defense teams were to work with these medical squads for the protection and relief of each local district. Of the 298 mobilized doctors in Hiroshima, 270 became atomic bomb victims. Casualty rates among pharmacists and nurses ranged between 80–93%. The well-prepared medical care system for conventional air raids was rendered totally useless. Prefecture and municipal agencies, where the air defense headquarters were located, also suffered heavy damage to personnel and buildings.

By the evening of 6 August, a temporary air defense headquarters was set up by surviving officials of the Hiroshima Prefecture. Requests were sent to the national government and to neighboring prefectures for doctors, and medical and food supplies.

Even though the casualties of military personnel were also great, eleven relief stations were set up soon after the bombing to take care of the injured victims. Relief crews from army and navy bases in and near the city serviced these relief stations. In this immediate post-detonation period, military units played a major role in securing food and drinking water, disposing of corpses, removing debris, and restoring communications and transport services. Japanese military leadership came to an end, however, with the surrender on 15 August 1945.

Right after the detonation, the surviving members of the Hiroshima City Medical, Dental, and Pharmacists Associations were actively engaged in relief efforts, despite the fact that they themselves were suffering from injuries. Doctors from medical associations in adjacent cities and counties and from outside the Hiroshima Prefecture reached the city beginning on 7 August. The number of relief stations in the city reached a peak of 53 on 9 August, gradually decreasing to 11 by 5 October.

Medical teams also came from outside hospitals; it was reported that more than 3000 medical personnel were in Hiroshima by 5 October. A medical survey team was sent on 8 August by the Army Medical School and the Tokyo First Army Hospital. Subsequently, other survey teams came from Tokyo, Kyoto, and Osaka Universities. Apart from the medical relief teams, many persons came from outside the city to assist in coping with the devastation.

At the same time, streams of survivors were flowing out of Hiroshima to the towns and villages of adjacent counties. The total number of people who left Hiroshima at this time is estimated to have been about 150,000 (Hiroshima A-bomb Medical Care History Editorial Committee, 1961). Faced with this sudden influx of refugees, the surrounding towns and villages had an urgent need of increased medical personnel and supplies, but in most of these places it was impossible to meet the demand for help. Thousands of injured persons were accommodated in provisional relief stations such as primary schools and were taken into private homes, without receiving any substantial medical treatment.

In Nagasaki, the defense headquarters had been established in 1944, and the Nagasaki Defense Mobilization Council in 1945. Rescue and relief precautions centered on the city's medical association. There were 22 designated relief stations, and 327 persons were organized to service these stations. Nagasaki Medical University Hospital and Mitsubishi Hospital were also expected to serve as key relief centers (Nagasaki City Office, 1977). But the destructive power of the atomic bomb far exceeded such defense and relief capabilities.

The main buildings and lecture rooms of Nagasaki Medical University were demolished and burned, and almost all teaching staff either died instantly or within a few days. The number of casualties among the administrative staff, nursing staff, and medical and pharmacy students was great. Three other hospitals in the bombed area had similar conditions.

Wounded civilians gathered at places designated prior to the bombing as relief stations. Relief work was begun, despite the lack of medical supplies, in more than 10 such provisional shelters by surviving staff of the medical university and of other hospitals as well as other surviving medical personnel.

Medical relief teams also soon reached the city from naval hospitals, army hospitals, and outside medical associations.

Large numbers of victims left the city soon after the bombing by foot, truck, and train. Hospitals outside the area received more than several thousand surviving patients. Neighboring towns and villages also received streams of injured victims. It was reported that approximately 20% of these patients died within the next two months.

6.2 EXTRAPOLATIONS FROM HIROSHIMA AND NAGASAKI AND OTHER DISASTERS

In addition to examining the factual data about the effects of the bombings of Hiroshima and Nagasaki in order to understand the lessons that can be drawn, it can be instructive to appraise these data to formulate more general conclusions about the effects of large-scale but localized disasters. To put this information into proper perspective, discussions in the following section deal with comparisons of the effects of other disasters which have been visited on communities and populations from sources both natural and anthropogenic.

6.2.1 Comparisons with Other Major Disasters for Urban Systems

When the possible destructiveness for humans of a major nuclear war is estimated, whether for a major exchange or even a single 1 MT detonation, it is difficult to find disasters in recent centuries that are comparable in magnitude and severity. The Hiroshima and Nagasaki explosions were much smaller than any now expected from strategic weapons.

Table 6.2 presents estimates of the human deaths that occurred following a variety of extreme epidemics and natural and technological events for which moderately detailed data are available. Table 6.3 summarizes the estimates of mortalities for the nuclear war scenarios published by the World Health Organization Committee (Bergstrom et al., 1983), Ambio (Ambio Advisory Group, 1982), and the U.S. Office of Technology Assessment (OTA, 1979). From these it is seen that only a few of the recorded historical episodes were of the minimum size contemplated in the nuclear war scenarios considered in this report, and that none approached in absolute terms the expected losses. When the fatalities are taken as proportions of the total population at risk from the threat, only a few of the past episodes are noteworthy.

The largest non-nuclear disasters, in terms of the proportion of affected population that died, were in places devastated by earthquakes, tidal storms, floods, and the plague. In absolute numbers, the two World Wars exacted heavy tolls of lives, rivaling in size the world-wide influenza epidemic of 1919.

In considering the potential effects of current disasters, both nuclear and non-nuclear in origin, several factors should be noted. The concentration of population into big cities is accelerating. The gap between overall capacities of urban and rural areas appears to be increasing in many regions, so that large urban systems become too big to be supported in an emergency by the immediately surrounding areas. Today, in general, levels of food stocks at individual homes are low, and distribution systems are centralized; situations are similar in energy supply and consumption. In these regards, urban systems are becoming even more vulnerable to catastrophes.

The nature of current nuclear weapons makes many advance actions other than evacuation useless. Even if a mass evacuation outside a city could be effectively done, there would be no homes to return to. For example, precautions against fires would be insignificant in the reduction of injuries because the primary fire by the thermal radiation from a detonated nuclear weapon is so intense. Casualties per unit area are great; thus, medical aid is crucial after a nuclear attack. The British Medical Association report (1983) on the medical effects of nuclear war reached the conclusion that such a nuclear attack would cause the medical services in a country to collapse (see also Abrams and von Kaenal, 1981). The possibility of providing individual medical or nursing attention for victims of a nuclear attack could become remote, at some point disappearing completely, with only primitive first aid attention from fellow survivors available.

6.2.1.1 Earthquakes

To predict the impacts of local nuclear attack to cities, the lessons from other types of disasters may be useful. Earthquakes have a special relevance, at least in Japan.

Japan is a seismically active region, and the statistics imply that a major earthquake with $M = 8$ occurs on the average of once every century. The Tokyo earthquake of September, 1923, with an intensity of $M = 7.9$, is described briefly here for reference. The disasters accompanying this earthquake were characterized by secondary mass fires which burned an area of 38 km^2, or 44% of the entire city. Total deaths were 68,600, of which 90% were losses associated with the fires. Mass fires broke out in 92 places, and a firestorm was generated with wind speeds reaching 30 m sec^{-1}. The fires were not brought under control until 42 hours after the earthquake. The causes of fire outbreak were: home kitchens (34%), storage of chemicals (31%), and commercial kitchens (28%). The high density of wooden houses was the major factor in exacerbating the damage from the mass fire. Within 30 days of the earthquake, 2,221,000 people, or about half the total inhabitants who lost their houses, were moved to other cities as refugees.

Martial law was instituted and the urban systems were maintained by military troops coming from surrounding areas. Since the support system at

MAJOR DISASTERS IN HISTORY[a]

TABLE 6.2

	EVENT	FATALITIES	POPULATION AFFECTED	AREA AFFECTED	REFERENCE
FLOODS	1887 Huang Ho, Yellow River, China	1.5 -7.0 x 10^6	1500 villages	$1x10^4mi^2$	Champ (1982)
	1931 Yangtze, China	$3.7x10^6$	------	$7x10^4mi^2$	Champ (1982)
	1938 Honin, Yellow River, China	$0.5x10^6$	$6.0x10^6$	------	Champ (1982)
FAMINES	1869-1870 Bengal, India	3.0-10.0 x 10^6	30%	-----	Gibney (1978)
	1876-1877 Madras, India	$3.5x10^6$	$20.0x10^6$	$4.0x10^4mi^2$	Gibney (1978)
	1877-1878 North China	9.5-13.0 x 10^6	$70x10^6$	-----	Nash (1977)
	1968-1974 Sahel, Africa	$0.1\text{-}0.2x10^6$	$22.0x10^6$	$1.5x10^6mi^2$	Glantz (1976)
EARTHQUAKES	1556 Honan, Shensi, Shansi, China	$0.83x10^6$	-----	-----	U.S. Department of Commerce (1979)
	1773 Calcutta, India	$0.3x10^6$	-----	-----	Nash (1977)
	1976 Hopei, China	$0.2\text{-}0.99x10^6$	$12.8x10^6$	$1.0x10^4mi^2$	Time (9 Aug 1976)
STORMS	1737 Bay of Bengal, India	$0.3x10^6$	-----	-----	Nash (1977)
	1970 Ganges Delta, East Pakistan	$0.16\text{-}0.5x10^6$	$3.0x10^6$	$3.0x10^3mi^2$	Time (7 Dec 1970)
FIRES	1857 Tokyo, Japan	$10.7x10^4$	-----	-----	Ishikawa and Swain (1981)
	1923 Tokyo, Japan	$6.8x10^4$	$4.0x10^6$	38 km^2	this volume
VOLCANOS	1793 Miya-Yama, Java	$5.3x10^4$	-----	-----	Nash (1977)
	1883 Krakatoa, Java	$3.6x10^4$	-----	-----	Nash (1977)

[a] Compiled by Axel Schweiger.

	EVENT	FATALITIES	POPULATION AFFECTED	AREA AFFECTED	REFERENCE
AVALANCHES	218 B.C., Alps	1.8×10^4	4.6×10^4	——	Nash (1977)
	1962 Huascaran, Peru	0.4×10^4	9 villages	——	Nash (1977)
INDUSTRIAL	1949 Joh.-Georgenstadt, East Germany	$0.3\text{-}0.4 \times 10^4$	——	——	Nash (1977)
	1984 Bhopal, India	$0.14\text{-}1.0 \times 10^4$	2.0×10^5	——	Der Spiegel (22 Apr 1985)
SHIPS	1865 Sultana USA	0.15×10^4	0.24×10^4	——	Nash (1977)
	1912 Titanic Britain	0.15×10^4	0.22×10^4	——	Nash (1977)
AIR CRASHES	1974 Orly France	346	346	——	Ferrara (1979)
	1977 Teneriffe	582	652	——	Newsweek (11 Apr 1977)
	1980 Riyad Saudi Arabia	301	301	——	New York Times (21 Aug 1980)
	1985 Ireland	329	329	——	The Times (UK) (24 June 1985)
	1985 Tokyo Japan	520	524	——	The Times (UK) (14Aug 1985)
RAILROAD	1915 Guadalajara, Mexico	600	900	——	Nash (1977)
	1917 Modane, France	543	1200	——	Nash (1977)
EPIDEMICS	1346-1350 plague Europe, Asia	25×10^6	30%	——	McNeill (1976); Garb and Eng(1969)
	1919 influenza worldwide	20×10^6	1.65×10^9	——	Garb and Eng(1969)
WARS	1914-1918 World War I	12×10^6	——	——	Richardson (1960)
	1939-1945 World War II	$30\text{-}40 \times 10^6$	——	——	Richardson (1960)
	1945 Hiroshima	0.12×10^6	3.2×10^6	——	Ishikawa and Swain (1981)

TABLE 6.3

FATALITIES AND CASUALTIES FROM HYPOTHESIZED NUCLEAR ATTACKS[a]

SCENARIO	FATALITIES	INJURIES	POPULATION AFFECTED	AREA AFFECTED	REFERENCE
Hiroshima (1 MT)	$0.4\text{-}0.6 \times 10^6$	0.2×10^6	1.0×10^6	-----	Urabe (1985)
W.H.O. (10,000 MT)	1.15×10^9	1.1×10^9	4.0×10^9	world	W.H.O. (1983)
AMBIO (5700 MT)	0.75×10^9	0.34×10^9	1.29×10^9	Northern Hemisphere	AMBIO (1982)
limited nuclear war	$8.0\text{-}14.0 \times 10^6$	$8.0\text{-}14.0 \times 10^6$	2.2×10^8	U.S.	Katz (1982)
Harwell (5700 MT)	$1.2\text{-}1.3 \times 10^7$	$3.0\text{-}5.0 \times 10^6$	2.2×10^8	U.S.	Harwell (1984)

[a] Compiled by Axel Schweiger.

the national level was effective, the recovery was rather rapid; e.g., electric service was reinstituted within 9 days, telephones within 29 days, and transportation by railroad within 3 days. Infectious disease cases were twice those in the normal summer; prices of food and other daily necessities doubled for a month. Total damages cost three times the national government budget of Japan in 1923 (Tokyo City Office, 1925).

On 28 July 1976, the city of Tangshan, China, was virtually destroyed by an earthquake of $M = 7.8$. At least 250,000 people died, according to city officials. The greatest damage occurred around the railway line that connects Peking, 150 km to the west, with Shenyang, an industrial city to the northeast. All electrical power and communications were disrupted. Notice to the outside came from reconnaissance overflights; outside assistance appeared 12 hours after the initial shock. Within two weeks, 100,000 army troops were transported to Tangshan, along with 30,000 medical personnel and 30,000 construction workers. Injured civilians were evacuated by airlift. Bodies of the dead were buried in mass graves in a deserted open-pit mine.

The city has largely been rebuilt, with new buildings designed to resist a maximum shock of $M = 6.3$. The population of the city and surrounding countryside has increased since the time of the earthquake from ≈ 1.0 to 1.3 million (Burns, 1985).

Table 6.4 compares damages from the Tokyo earthquake of 1923 with the Tokyo air raid of 1945 and the atomic bombings of Hiroshima and Nagasaki. The extraordinarily high number of deaths per unit area in Hiroshima and Nagasaki implies that the type of destructive force used led to more deaths than injuries in the burned areas, compared to the effects of the other forces on Tokyo, although the Hiroshima and Nagasaki numbers partly include retarded secondary deaths and deaths of non-permanent residents.

TABLE 6.4

COMPARISON OF DESTRUCTION IN JAPAN[a]

	Tokyo Earthquake 1923	Tokyo Air Raid 1945	Hiroshima 1945	Nagasaki 1945
Population ($\times 10^6$)	4.0	6.5	0.26	0.17
Burned area (km^2)	38	40	13[b]	6.7[b]
Demolished/burned buildings	0.37×10^6	0.27×10^6	0.05×10^6	0.13×10^6
Fatalities (number) (% of population)	68,000 0.017%	83,600 0.013%	>118,000 45%	>60,000 35%
Fatalities km^{-2}	1,600	2,100	>9,000	>8,900

[a] After Shimazu (1985).

[b] Areas subjected to blast and thermal radiation (primary fire) are included with areas burned by secondary fires.

Disasters by both earthquake and air raids in Tokyo were characterized by large numbers of fatalities from secondary fires. Some conclusions are that requiring the fire- and earthquake-proofing of buildings by revision of building codes is effective in reducing casualties, and that promotion of precautions against firespread is also quite effective. These are the major objectives of the urban disaster reduction program in Japan since World War II. They have been fairly well achieved, and the outbreaks of fires and deaths by burning have been significantly reduced in subsequent earthquakes. For instance, there was no mass fire and only 27 persons were lost by an earthquake of M = 7.4 which struck Sendai city (population 640,000) in 1978.

This is mainly a result of the revision of building codes and the switching off of the sources of fire by civilians. Use of shock-sensitive oil heaters was also helpful. Such actions, however, are not likely to affect substantially the initiation, propagation, and development of urban fires from a nuclear detonation.

Although damage by fire after earthquakes has been reduced significantly in Japan, another type of urban disaster has risen in importance: paralysis of urban systems of electricity, water, gas, food supplies, communications, and transportation. In the Sendai earthquake, for instance, it took more than one month before the water and gas supplies were restored, and the overload of telephone lines caused panic among civilians. Damage of traffic signals also led to large traffic jams, which inhibited evacuation from devastated areas and inhibited influx of outside assistance.

One major problem in counteracting the effects of a disaster is the possibility of an outbreak of mass panic, although in many modern disasters neither panic nor rioting and looting occurred. Urban systems are characterized by a separation of living place and working place, i.e., a significant increase in the daytime center city population density; therefore, outward movement from the city centers would start immediately after the warning.This transient stage is highly vulnerable to the occurrence of damage from disasters such as earthquakes. Detailed simulation of a coupling of warning with the potential behavior of civilians implies that it would take about three times the length of normal commuting time to evacuate a city center (Leaning and Keyes, 1983). This evacuation of a normal daytime population is improbable when the population of the city exceeds 2 million. This means that if a warning were to be issued several hours before a projected earthquake in a city the size of Tokyo, evacuation would likely reach a catastrophic state before the earthquake occurred (Hiramatsu, 1980).

6.2.1.2 Conventional Bombings of World War II

Tokyo was attacked by numerous mass air raids during World War II (see Table 6.4). Among 130 attacks, the largest one occurred on 10 March 1945, from which 40 km^2 were burned; 267,000 houses and 83,600 people were lost within two hours from mass fires caused by conventional weapons totalling only 1.7 kT in energy yield. The fire attack was aimed at the downtown areas with a population density of 5,000 people km^{-2}. The deaths per kT from the bombing on 10 March were about 20 times the average from attacks on other Japanese cities. According to the reports by bomber crews, the height of the ensuing firestorm was greater than 10 km and could be observed 250 km from Tokyo. The wind speed of the firestorm at the surface was estimated at 30 m sec^{-1}. Another major air raid on Tokyo occurred in May 1945, and the urban systems nearly collapsed. The population decreased from 6.5 million before 10 March to 3.5 million after May 1945.

The estimates made of total loss of life in Germany from bombing attacks by the Allied Air Forces during World War II approach 800,000. The greatest losses of life in individual attacks were those where great fires occurred, particularly Dresden and Hamburg. Attacks in July 1943 on Hamburg led to one large fire from which 60,000 persons perished. Reports from Dresden indicate as many as 300,000 deaths there from attacks during the closing days of the war in 1945 (Bond, 1946).

The most prominent causes of death, studied at the time by the German Luftwaffe, were: 1.) death from external injury—burial under rubble and debris and injury from flying fragments; 2.) secondary injuries from explosions—drowning, scalding, chemical burns, poisoning from by-products of exploded bombs; 3.) burns; 4.) tetanus secondary to burns; and 5.) internal injuries.

There was a definite relationship between the type of bomb dropped and the mechanism of death or injury. An incendiary raid was expected to cause more dead than wounded, through the effects of heat and carbon monoxide; in bombings with high explosives, on the other hand, mechanical injuries outnumbered deaths. Season, geographical location, and type of city bombed were important factors in the evaluation of air raid casualties (Bauer, 1945).

During the attack on Hamburg, incendiary bombs started fires which spread particularly in inhabited areas in a very short period of time. The heat increased rapidly and produced a wind of typhoon strength, creating the conditions necessary for a firestorm. It is estimated that within 20 minutes of the initiation of bombing, two of every three buildings were burning within a 11.7 km^2 area; the rising column of heated air created an incoming draft of ground-surface air which reached a speed of 33 km hr^{-1}. In a short time, the temperature reached the ignition point for all combustibles, and the entire area was ablaze. Because of the rapid spread of the fires, people crowded into shelters which were already occupied beyond their capacity. As the temperatures increased in the streets from the spread of the firestorm, many of the occupants of the shelters realized the danger in the situation, yet few tried to escape. Carbon monoxide poisoning became the major cause of death of those who stayed in the shelters (Bond, 1946).

By comparison of proportions of casualties from the single nuclear weapon detonations over Hiroshima and Nagasaki and the conventional bombing attacks on Dresden and Hamburg, the total effectiveness of the bombings could be said to have been the same. The creation of firestorms led to the majority of casualties from fire in all instances. The differences lie not in the effects of the weapons themselves, but in the ease and economy with which these weapons could be delivered. In Hiroshima and Nagasaki, delivery of single weapons from single planes effected the same degree of damage as from all the planes and all the weapons dropped over Hamburg and Dresden.

6.2.1.3 Leningrad

The siege of Leningrad lasted 29 months, beginning in September, 1941. The city was virtually isolated from the mainland. In 1939, Leningrad's population was approximately 3 million; at the beginning of the siege, there were more than 2.5 million inhabitants there (Pavlov, 1967). By the end of 1943, the population had dropped to approximately 600,000. Deaths caused by bombardment totalled about 17,000, and about 800,000 perished because of starvation and cold.

Considerable food stocks were lost because of bombardment and the fires which ensued, in addition to the loss of food imports from surrounding areas because of the siege. Rationing was instituted, but civilians received fewer then their alloted calories as a result of difficulties in obtaining food supplies in large volumes for distribution, in spite of the evacuation of almost one million residents. This major loss of life occurred in spite of the continued existence of a social infrastructure in the city and despite the relatively small physical damage which was incurred.

6.2.1.4 Plague

It has been suggested by some that the bubonic plague which swept from the Crimea through Europe during the 14th century, with the total losses presented in Table 6.2, was most nearly comparable to what might be expected following a nuclear war. The spread of the Black Death (*Pasteurella pestis*), beginning in 1331 and peaking during 1346–1350 (McNeill, 1976), brought tremendous loss of life. McNeill estimated that approximately one-third of the total population of Western Europe died. The estimates for Great Britain range between 20–45%. Some places, such as Milan, were unaffected, while some smaller towns were totally extinguished.

The impacts, however, were not comparable to those expected from nuclear war for at least six reasons:

1.) No buildings, roads, or other physical infrastructures were destroyed, although some suffered from lack of maintenance.

2.) Plants and domestic animals were not directly affected, so that agricultural production was reduced chiefly by lack of labor.

3.) The health of the survivors, especially of those immune to the disease, was not impaired seriously in either the short- or long-range time period, although their state of mind was affected.

4.) Thus, the survivors were left with access to increased stocks of physical equipment and natural resources per capita.

5.) The plague left few places of long-lasting contamination inasmuch as the survivors were immune.

6.) The spread of the infestation occurred over periods of months or years, and while the death rate typically showed pronounced peaks during the epidemic, there usually were periods of slow build-up and decline.

For these reasons, the social impacts of the plague, beyond those of the high mortality and the psychological distress, have little in common with those likely to follow nuclear war.

6.2.1.5 Famines

Throughout history, famines have involved people living impoverished lives who experience an extreme, usually natural, event such as drought, flood, or crop disease. Famine is defined here as severe hunger occurring long enough and over a large enough area to result in deaths sufficiently in excess of normal death rates to cause social disruption. While an extreme event is not in itself a sufficient condition for famine (e.g., the United States weathered the 1930's Dust Bowl years without famine), probably an extreme event is a necessary condition for famine. The event need not be natural; extreme human-caused events are entirely capable of causing famine, as war has throughout history. Human intervention can exacerbate the consequences of an extreme event; for example, food price increases can turn a modest production decline into a famine, and aid that is little, late, or misdirected can allow what would have been merely a bad year to evolve into famine.

The condition required for famine has historically been a particular kind of poverty; i.e., the absence of methods of coping with lean years.People in societies that are vulnerable to famines either have never had, or have been deprived of having practices that provide some form of insurance to rely on in bad years: either stored food or saved wealth with which to buy food.

Famine experiences help put into perspective the problems that might arise following a nuclear war concerning the potential shortages of food and other resources necessary to produce food. Any country on Earth with people living precarious lives without a buffer against lean years might experience famine in the event of a major disaster, such as nuclear war, even though food supplies were adequate. Dominant political events can cause and exacerbate famine; economic events can worsen slight declines in physical outputs of food. Both the climatic effects and the social and economic disarray likely to accompany nuclear war could trigger famine among countries and among people living outside the combatant zone.

In a compilation of famine statistics, Walford (1878) listed 350 famines covering roughly a 250-year period. Europe, and especially the British Isles, dominate the list prior to 1700, though China, Russia, Mexico, and Africa each appear once, and India appears several times. After 1700, 34 of the 58 famines listed occurred in India. Except for the Chinese famine of 1877-78, the remainder occurred in Europe, notably Ireland. Since World War II, famine has been limited almost exclusively to Africa, especially the Sahel region and Ethiopia. The major exception is the Bangladeshi famine of 1974, and some war-related hunger that has occurred in Southeast Asia, most notably Cambodia (McHenry and Bird, 1977; Stief, 1980) and Vietnam (Karnow, 1983).

Lucas (1930) synthesized numerous medieval sources to describe the famine that affected virtually all of Europe in the early part of the 14th century. The famine followed continuous and extraordinary rainfall during the summer and fall of 1315 that ruined nearly all crops in that one harvest year. In Ireland during the mid-1800's, the failure of the potato crops from blight and the bitterly cold winters brought an estimated 2.4 million people to starvation levels (Woodham-Smith, 1962). Between 1860 and 1890, India suffered continual famine years partly because of the changeover to a more national agricultural economy (Bhatia, 1967).

A situation more applicable to the problems of food supply in a post-nuclear war world occurred in Bengal during 1943. Part of the 1942 winter rice crop was destroyed by a typhoon, followed by floods and fungal disease. Rice imports from Burma had been cut off, resulting in about 10% less rice than usual available in Bengal. Despite this seemingly modest decline, an estimated three million people died over the next year. This appears to have resulted from government response to the initiation of starvation, uncontrolled price increases, and maldistribution of the remaining crops (Sen, 1981).

In the 1970's, famine struck Ethiopia and the Sahel region of Africa, primed by an insufficiency of rainfall over a prolonged period. In 1973–74, it is estimated that 200,000 people out of a population of 27 million died of starvation and hunger-related diseases in Ethiopia (Shepherd, 1975). A similar number died in the Sahel between 1968 and 1973 (Sheets and Morris, 1976). The poor distribution system within the country or area and the lack of immediate recognition of the severity of the problem allowed the numbers of deaths to reach such levels, despite the fact that the overall supplies of food in the regions were not drastically reduced nor was there significantly increased demand throughout the time period of drought.

Historical famine situations suggest that even small overall decreases in agricultural production might have very large effects on populations. The major factor in the large numbers of deaths in years with low productivity seems to have been the response of the social system as opposed to solely the absolute levels of food supplies (Glantz, 1976). The failure of distribution systems, inappropriate decisions on exports, and the inability to enforce equalized methods of conservation appear more likely to affect the numbers of deaths than the failure of crops or decreases in yields caused by natural adversities, when agricultural yields fall by a few percent. At higher levels of food reductions, the societal responses may further exacerbate a situation in which food is insufficient in absolute terms.

6.2.1.6 *Other Hazards*

Prospects for large-scale survival and early recovery from major environmental dislocations are not promising if the modern record of responses to natural disasters is taken as a guide. Although some impressive gains in improved safety and shorter recovery times have been registered in connection with floods, hurricanes, severe storms, landslides, volcanic eruptions, and earthquakes, disaster losses appear to be accelerating throughout much of the world, largely as a result of increasing human vulnerability to natural hazards and the failure to adopt mitigating measures.

The anticipated pervasiveness and severity of nuclear war-induced events exceed any natural disaster yet experienced. Scientific understanding of human responses to extreme natural catastrophes is limited and does not permit confident prediction of behavior in unprecedented situations. Nonetheless, past and present disasters offer some information about potential consequences of a nuclear catastrophe (Clausen and Dombrowsky, 1983; Burton et al., 1978; Drabek and Key, 1983; Dynes, 1975; Fritz, 1968; Mileti et al., 1975; Quarantelli and Dynes, 1973). For example, involuntary local self-reliance is widely assumed to be characteristic of a post-nuclear war world. Small oceanic islands provide opportunities to test the effectiveness of disaster responses in the absence of significant external assistance. Available data suggest that disaster impacts on islands are disproportionately severe and long-lasting and are associated with extremely high potential for further catastrophe. Many similar lessons from natural events are available. They relate to responses to warnings, evacuation operations, the organization of relief, and numerous other aspects of catastrophic episodes. These have been appraised from the standpoint of organizations (Clausen and Dombrowsky, 1983) as well as in terms of the mental health of individuals (Lystad, 1985).

Insofar as a large-scale nuclear war would be a previously unexperienced event, the record of responses to newly emergent hazards is instructive. Lack of knowledge, indecision, and delayed responses have characterized the handling of compound natural and technological hazards at Three Mile Island, Bhopal, Times Beach, Sevesa, Italy, and other locations. Unaccustomed and portentous natural disasters may compel increased public attention, but that does not guarantee that resulting responses will be either prompt or entirely effective.

Recent sub-continental droughts reflect another possible distinguishing feature of a nuclear war, namely, the existence of extreme, spatially extensive, and protracted atmospheric changes. While there is mounting evidence that developed nations can successfully absorb the impacts of significant but smaller-scale climatic fluctuations, experience from the Sahel illustrates both the counterproductive nature of poorly implemented large-scale disaster relief and the stunted capacity of many low-income nations to survive long-lasting natural disasters by using impoverished indigenous coping strategies.

At the global scale, as indicated in the discussion of famine in section 6.2.1.5, areas of marginal human subsistence and particularly those in course of social transition are disproportionately subject to chronic severe disasters. In a post-nuclear war world, the areas of concentration of inhabitants would likely shrink and become more fragmented, and social systems would be stressed, thus magnifying the types of conditions that existing natural disaster relief programs have been least able to ameliorate.

While much can be learned about prospective human responses to a nuclear war by close analysis of natural disaster analogs, the transfer of experience is subject to at least two obvious limitations: 1.) natural disaster impacts occur on considerably smaller geographic scales; and 2.) natural disasters are widely perceived as temporary departures from an assumed normal state.

6.2.2 Extrapolations Beyond Hiroshima and Nagasaki

The remainder of this chapter deals with the possibility of extrapolating information from the Hiroshima and Nagasaki experiences and of using Hiroshima as a case study in order to illustrate potential effects on one city of a nuclear detonation from a modern arsenal. Local effects are viewed in the framework of quantifying the direct effects of a hypothesized 1 MT warhead detonated on Hiroshima and of discussing the local effects on a targeted city of a global nuclear war.

There are many limitations to drawing upon the Hiroshima and Nagasaki experiences during World War II directly to extrapolate potential effects from the use of a modern warhead on a city such as Hiroshima, among which are:

1.) quantitative—Contemporary nuclear warheads are much larger than those used at Hiroshima and Nagasaki. Because of the inherent limitations of extrapolating for effects from a smaller warhead experience, a simulation model for the human impacts of a local attack from a 1 MT warhead was developed.

2.) qualitative—While in the case of a global exchange, the direct effects of each detonation is a local attack from the target perspective, support from outside cannot be expected at either the regional or national level. In addition, urban systems have become much more sophisticated during the past forty years, especially in their dependency on administration and information systems. Vulnerability of urban systems has increased with respect to energy, food supply, transportation, and communication.

6.2.3 Direct Effects of a Modern Warhead: Hiroshima as a Case Example

In 1945, the city of Hiroshima was destroyed by the first use of an atomic bomb. Approximately one-third of the total population of 320,000 was killed, and another one-third was injured (Table 6.5). As people acquired some knowledge about radioactivity, they came to believe that no life would return to Hiroshima for hundreds of years. The city has been successfully reconstructed, however, and its present population is about 900,000, or three times that in 1945. Many survivors still suffer from long-term effects of the atomic detonation. The number of 'health book holders' living in Hiroshima, i.e., civilians known to be injured by exposure to the atomic detonation in 1945, amounted to over 100,000 in 1977, or about 12% of the total population. It is instructive to compare the potential effects of present weapons with those of the 1945 bombing, which caused long-term effects which still persist.

TABLE 6.5

COMPARISON OF CASUALTIES FROM ACTUAL EXPERIENCE AND SIMULATED 1 MT DETONATION ON HIROSHIMA[a]

	15 kT Observed in 1945	1 MT Simulated Ground Burst (SE wind)	(S wind)	Air Burst
Uninjured	118,613	0.5×10^6	0.4×10^6	0.25×10^6
Injured	0.2×10^6 (severe) 48,606 (less severe)	30,524	0.15×10^6	0.15×10^6
Fatalities	118,661	0.4×10^6	0.5×10^6	0.6×10^6
Unknown	3,677			

[a] Simulations conducted by T. Urabe.

6.2.3.1 Background

Hiroshima is located about 800 km west of Tokyo, on a small plain surrounded by mountains and the Seto Inland Sea. The population pattern obtained by the census in 1980 had a density exceeding 20,000 km^{-2} in some areas. The total population of the illustrated area, containing Hiroshima and its adjacent towns, is about 1.1 million. It is noted that almost all of the flat area is covered by housing. Recently, development into the mountain area has occurred. Since all the arable area is now urban, agricultural self-support within the illustrated area after a nuclear war is very unlikely.

The railway runs along the shore, and the super express railway (Shinkansen) runs straight in an east-west direction through the Hiroshima station. Main roads run parallel to the railway, and the industrial zone has been constructed on land reclaimed from the sea. The city center has a high population density even at night, while larger cities like Tokyo show a clear contrast between low night population and high daytime population in the central business district. The daytime population pattern in Hiroshima differs little from the night population, with only a small increase in the central zone of the city and industrial areas.

6.2.3.2 Simulations of a 1 MT Detonation

As discussed in Volume I (Pittock et al., 1985), the effects from a surface burst and from an air burst are different in many ways. If the altitude of detonation is low enough so that the fireball comes into direct contact with the ground surface, then much of the energy associated with the blast wave is directed into the excavation of surface materials. In addition, much of the thermal energy that originates from absorption of the thermal X-rays by the air immediately surrounding the nuclear detonation would be absorbed by the surface itself or by particles entrained in the fireball associated with a surface burst. These factors reduce the area affected by the blast wave and thermal pulse in a surface burst compared to an air burst detonation (Glasstone and Dolan, 1977).

The distances to which particular levels of effects from the blast wave, the thermal pulse, and initial ionizing radiation extend follow relationships specified in Glasstone and Dolan (1977). These distances are a function of the yield of the warhead, the height of burst, and the local conditions at the point of detonation, such as atmospheric transmissivity. The present discussion is concerned with a 1 MT detonation, for which the effects are characterized in Table 6.6.

A simulation model of the effects of a 1 MT detonation from an air or surface burst was developed and analyzed by T. Urabe for the SCOPE–ENUWAR project. In addition to the effects of blast, thermal radiation,

TABLE 6.6

DIRECT EFFECTS OF A 1 MT DETONATION[a]

	BLAST EFFECTS[b]		THERMAL EFFECTS[c]		INITIAL RADIATION EFFECTS[d]	
	5 psi	2 psi	100%	50%	450 rem	200 rem
	(all distances are ground ranges [km] from ground zero)					
Surface[e] burst	4.56	7.57	8.55	10.92	2.7	2.8
Air[f] burst	6.72	12.41	12.62	16.35	2.7	2.8

[a] Tabulated values from Harwell (1984) based on formulae from Glasstone and Dolan (1977).

[b] The 5 psi distance is considered to define the lethal area (Lewis, 1979; Barnaby and Rotblat, 1982; Harwell, 1984); the 2 psi distance is considered to define the injury area (Katz, 1982; Harwell, 1984).

[c] From Harwell (1984) based on data from Glasstone and Dolan (1977); 100% lethality is assumed to occur to those individuals exposed to about 8 to 10 cal cm^{-2}; 50% lethality, 50% injury is assumed to occur to those individuals exposed to between 6 and 8 cal cm^{-2}. Distances are based on a visibility of 20 km.

[d] Ground distances at which the least indicated dose would be absorbed by exposed individuals from the initial burst of fast neutrons and gamma rays; does not include exposure to residual radiation (fallout). From Harwell (1984), based on data in Glasstone and Dolan (1977) and Rotblat (1981).

[e] Detonation at which fireball comes in contact with the ground surface.

[f] Detonation assumed to occur at optimal height, $h = 1100\ W^{0.45}$ (Glasstone and Dolan, 1977); for a 1 MT detonation, this height is 3.35 km (Harwell, 1984).

and initial ionizing radiation, the Urabe model included the effects of local fallout from a surface burst, based on fallout patterns from Rotblat (1981) for an ambient wind of 3 m sec^{-1} from the southeast (the conditions on the day of the bombing in Hiroshima in 1945); a separate analysis was done for a wind from the south. Essentially no local fallout would occur after an air burst, so radiation exposure estimates from an air burst in the simulation were limited to that in the initial ionizing radiation.

The combination of effects was translated to human fatalities and injuries following relationships given in OTA (1979) for distance versus human health effects (as percentage killed and injuries from the exposed population). Exposure to thermal radiation was expected to occur for a range of 1%–25% of the total population within a specified distance; the remainder of the population was assumed to be shielded from the thermal rays at the time of the detonation. Account was kept of each individual effect for each location on a grid superimposed on the Hiroshima area map.Combined effects were done as proposed by the British Medical Association (1983), in which a sublethal effect from each of two or more factors was treated as a fatality for the affected individual. By evaluating each grid location for the combined human effects of the stresses at that location and by considering the population within that grid location based on 1980 Hiroshima population data, the total direct effects of a 1 MT detonation on the current population were estimated. This methodology is appropriate for any location and for surface or air bursts of different yields; however, the population distribution grid is specific to Hiroshima and would require adaptation to other cities.

The results from the Hiroshima attack scenarios are presented in Table 6.5. The human fatalities from an air burst are seen to be greater than from a surface burst because of the greater ranges to which the blast and thermal pulse are lethal. In partial compensation for this, the surface burst fatality estimates include deaths from radiation arriving from local fallout; this effect does not occur for the air burst. Further, unlike the situation from the actual 15 kT detonation that occurred over Hiroshima, initial ionizing radiation would not contribute to fatalities, since the distances to which lethal levels of initial ionizing radiation would be absorbed from a 1 MT detonation are well within the distances to which blast and the thermal pulse would be fatal (Table 6.6); the latter effects would result in much earlier deaths than would ensue from lethal doses of initial ionizing radiation, so the individuals lethally exposed would already be dead before radiation symptoms could be evident.

6.2.3.3 Other Concerns

From the results of the simulation model, the direct casualties from a 1 MT explosion are estimated to be about half of the total population. Even if it is assumed that other cities remain in an unharmed state, rescue activities in Hiroshima and areas similar to it would be hampered. Hiroshima is surrounded by mountains, and if the railway, airport, and road systems were destroyed, access to the city from the land and air would be difficult. In addition, the sea which Hiroshima faces is an inland sea, and the passage is usually crowded and could be blocked by a few destroyed ships.

Another significant point about rescue activities in Japan would be the extreme sensitivity of the Japanese people to the presence of radioactivity. After the end of the war, people came to understand that some of the medical effects in Hiroshima and Nagasaki were caused by radioactivity. Sensitivity to the subject of radioactivity was amplified by the Bikini accident, when Japanese fishermen were injured by fallout. Psychological sensitivity to the idea of radioactivity is still a national characteristic.

6.2.4 Additional Effects from Global Stresses

The discussion thus far in this section has focused on the effects on Hiroshima from a single 1 MT detonation in the context of no other nuclear detonations occurring elsewhere at the same time. In the more likely event of a nuclear detonation over Hiroshima during a modern nuclear war, other nuclear detonations would occur over cities and other targets. The qualitatively new effects from multiple detonations discussed throughout this report would be in addition to the direct effects calculated for Hiroshima. These additional effects include the following:

- direct effects from other detonations on the same city: Other detonations would initiate some additive factors, such as doses from local fallout originating from several different sources, but most of the direct effects would interact in nonlinear ways. For instance, a blast wave passing through an area from one detonation could make the area more vulnerable to the effects of blast from a second detonation.
- local fallout: In addition to proximally originated fallout, a large number of cities would experience additional local fallout from surface detonations over other targets upwind of the city.
- lack of outside assistance: Outside assistance was an important factor in the early response at Hiroshima and Nagasaki, as discussed above, particularly in providing food, medical expertise, medical supplies, and social order. It also was key to the long-term recovery of the city. The processes that were seen in the redevelopment of a modern, thriving post-war Hiroshima could not be repeated in the aftermath of a large-scale nuclear war.
- disruption of communications: The effects of an electromagnetic pulse on modern communications and electrical power systems would interfere with transfer of information about what had happened and would hamper efforts for post-nuclear war response.
- psychological effects: The knowledge of the essential disruption of the Earth's civilization would be a totally new experience far beyond that felt at Hiroshima and Nagasaki. For those with prior knowledge of the possibility of nuclear war-induced climatic alterations, the prospects of facing the long-term consequences of nuclear war would likely have a considerable impact on their reactions.
- economic effects: The disruption of the world's economic base and associated international exchange of goods would lead to the loss of food imports. Food availability would be insufficient within a short time, and many of the survivors would starve to death (see Chapter 5 for discussion of loss of food imports). The loss of fossil fuel energy sources and prod-

ucts would reduce potential agricultural productivity. Post-nuclear war life would also be affected by the reduced capabilities of survivors to migrate to areas less affected by direct perturbations; the reduced capability to manufacture essential goods such as pharmaceuticals; the difficulty in acquiring uncontaminated water from deep aquifers; and a host of other similar effects.

- direct effects from climatic disturbances: The people surviving the direct effects of the nuclear detonation might be subject to greatly reduced temperatures and near darkness within a few days of the detonation. Many of those injured and left homeless would die from exposure.
- indirect effects from climatic disturbances: The loss of agricultural productivity that would follow the acute effects of significant nuclear war-induced climatic disturbances occurring during the spring or summer, and chronic effects occurring during the growing season, would result in reduced food for the survivors of a detonation, and many would die of starvation, as discussed in Chapters 4 and 5. Over the long term, reduced levels of precipitation could lead to insufficient water availability for the survivors.
- ecosystem-mediated effects: The longer term responses of ecological systems could include the outbreak of pests that could transmit disease to surviving humans. Other adverse environmental conditions could include increased air and water pollution; pathways for radioactivity to contribute to internal doses to humans; incidents of flooding as climatic extremes abated and snow and ice melted, and increased flooding because of loss of vegetation cover over watersheds; increased levels of ultraviolet radiation, leading perhaps to increased blindness and skin cancers; and other environmental disruptions.

6.2.4.1 Estimating Effects on Social Structure and Processes

To determine the total consequences of nuclear war, it is critical to consider the physical effects within the framework of their implications for the functioning of complex technical–industrial national systems and the world economy. Based on the experiences at Hiroshima and Nagasaki, the likely impacts of individual detonations on humans can be objectively estimated, such as the losses sustained in the medical care system; educational facilities and infrastructure; industrial base; energy supply, production, and distribution systems; and food production, processing, and distribution systems. Additional questions arise about the human management of these systems under stress and the flexibility and improvisational capabilities of highly integrated systems in circumstances where key elements may be destroyed.

One detonation of a modern nuclear warhead would cause horrendous and unprecedented human distress, but experience from other large disasters suggests the dimensions of possible social consequences. Studies by economists, geographers, psychologists, sociologists, and political scientists have examined the ways in which people respond in disaster situations. Those responses include immediate relief, rescue, emergency aid, evacuation, and reconstruction. Such activities take place within societies that maintain their organization, are able to accept evacuees, albeit with distress, and can provide some assistance from within or outside the country.

For a large-scale nuclear war, the immediate and direct environmental effects within the range of each detonation would be of the same nature as described for the single detonations over Hiroshima and Nagasaki. Social responses to a large-scale nuclear war, however, would be different than those expected from a simple increase in the number of areas destroyed. To the extent that neighboring areas and transportation facilities were destroyed, the opportunities for either evacuation or outside aid would be reduced. Conditions would be altered drastically in the event of multiple nuclear explosions. The prospects for aid from nearby areas would be greatly reduced or in many instances eliminated, so that the opportunities for direct relief would be curtailed, as described for the availability of health services in the WHO report (Bergstrom et al., 1983; see also Abrams and von Kaenal, 1981). Capability in fighting fires would be minimal. Rescue and reconstruction activities in areas suspected of contamination by radiation would be impeded. The capacity of local and national governments to continue to provide elementary security, transportation, and food distribution would be undermined.

Destruction of electronic capacities and power transmission systems by EMP would cut off many lines of communication on which intricate public and individual activities depend, particularly following a catastrophe. No modern society has been subjected to this kind of disaster, and there is no precedent for estimating how the ordinary processes of social organization would respond.

If weather disturbances of the type and magnitude suggested in Volume I were introduced, projections of likely social responses become far more difficult. All of the impacts noted above would prevail, but they would be exacerbated by the additional physical and biological impacts outlined in Volume I and preceding chapters of this volume. The reductions in temperature, sunlight, and precipitation, and the accompanying impacts on entire ecosystems and especially on the agricultural productivity of the world would stress the social structure and process in fundamentally unique ways. How the components of social processes might be altered by experience of the physical and biological impacts, and by perception of their possible results, is an area of investigation requiring future attention.

A little is known of how some populations perceive the hazard of nuclear war in comparison with other, more familiar hazards such as airplane accidents or earthquakes (Slovic et al., 1980). Nuclear war is seen by many as being in a different category than the others. The reality of nuclear war, if it ever were to occur, would confront people already disposed to view it as something different and more horrifying than anything they had ever known, with stress unlike that borne initially by the residents of Hiroshima and Nagasaki, who did not learn the nature of the bomb until later. These initial experiences would affect immediate survivors who would have little or no information about the global nature and extent of the nuclear war. There would be extreme uncertainty about the future course of events in the minds of those survivors, who would begin to contend with the prospects for delayed, global consequences.

Ecosystem changes are mediated by perturbations induced by changes in the physical environment, such as climatic alterations, fallout, increased UV-B, air pollutants, and a host of other stresses. These would lead to much more complex alterations in human social and economic systems. These influence and in turn are influenced by human perceptions of the threat of war and, in the event of war, of its effects on natural and social environments.

Earlier discussion outlined ways in which the impacts of nuclear detonations would be different from those induced by the natural and technological disasters with which there has been some experience.Those differences are so important that it seems unwise at this time to venture any but the most general quantitative estimates of the societal consequences of widespread nuclear war. It seems more prudent to indicate the kinds of analyses that might be used in making such estimates with more time and resources, a few of the problems that would be encountered, and some of the directions in which further research might lend accuracy and validity to the results.

6.2.4.2 Estimating Effects on Economic Systems

The effects of a nuclear war on economic systems would occur at several levels. First, there would be the direct destruction of physical structures and effects on the labor force. As significant would be the disruption of surviving industry by the loss of raw materials or critical manufactured goods.

Beginning with the range of large-scale physical and biological perturbations discussed in previous sections of this volume and of Volume I, a few methods of studying possible impacts on production of goods and services present themselves. Some of these have been appraised in the SCOPE examination of climate impact assessment (Kates et al., 1985), and several might be based upon models of global interrelationships. None commends itself to direct and immediate application, but all suggest directions in which further research might proceed.

One assessment of the possible effects of nuclear detonations on the economy of a region examined the impacts on the State of Massachusetts and the United States from a limited and a large-scale nuclear war (Katz, 1982). Casualties, economic impacts, food supply and distribution, electricity and fuel oil, medical care, and other social impacts were considered. The complications entailed in emergency relocation of populations during a pre-war period were discussed. These latter issues were examined in more depth in Leaning and Keyes (1983). Examination was also made in Katz (1982) of the implications for the global economy and political system of massive destruction in the U.S. and U.S.S.R. No consideration was given to local environmental changes or to climatic alterations.

The early 1970's saw the design and application of a number of global simulation models of resource–environment–economic interactions, including World 3, the World Integrated Model, the Bariloche Model, and the United Nations World Model by Leontiev. These models have been used to investigate global issues, such as the relationship between resources and population, developed–developing world interdependence, and energy forecasts and impacts. These and others have been reviewed and appraised in recent years (Hughes, 1980; Meadows et al., 1982; US Congress, 1982). A key problem with all, whatever their applications, is that they have not been sufficiently tested or validated.

The models have a number of problems for use in assessing the possible economic impacts of climate change, including:

1.) aggregation based on economic criteria but which is inappropriate for considering nuclear war stresses, e.g., the Mesarovic–Pestel model lumps Canada, Australia, Israel, South Africa, and Japan together;

2.) simplicity of the agricultural components of the models, with little differentiation among crop types; inputs such as irrigation, fertilizer, and pesticides are combined into a surrogate capital investment term; and very simple functions relate production to capital and labor;

3.) oversensitivity to sudden changes and extreme variability in climate-related variables like crop yields; and

4.) inability to replicate actual events such as historical climate–food relationships.

Other models that do not have these limitations are dependent on economic variables, such as the price for a commodity, which would be exceedingly sensitive to the perturbations on the agricultural and economic systems following a nuclear war.

One type of model that could be used for a localized post-nuclear war economic assessment is a static input–output model of the world economy such as the Leontiev model. Here the inputs (e.g., labor and crop yields) could be changed to reflect production in the aftermath of a nuclear war and linked linearly to changes in output. avoiding instability problems of the dynamical behavior of systems models. However, input-output models could not be used to examine longer term impacts because the coefficients would not be valid for a global economy in the aftermath of a nuclear war.

In summary, the current global models were constructed to monitor slow trends and interactions, based on an understanding of existing structures and resources. They were not designed to investigate a global catastrophe like nuclear war, and different models need to be developed for that purpose.

6.3 SUMMARY

The survivors of the immediate aftermath of a modern nuclear war would experience some situations for which there are historical precedents, but many other factors would be unique in human history. This summary section recapitulates those factors in the context of what life would be like for persons living in combatant areas and for those who would not directly experience nuclear detonations.

For those who actually experienced a nuclear detonation, but who were far enough removed or somehow protected from the direct lethal effects, the environment they would initially experience would seem much like the early period after the detonations over Hiroshima and Nagasaki.Precedent experiences from Hiroshima and Nagasaki would include the almost instantaneous disruption of the physical system; the initiation and spread of fires; the loss of communications and an understanding of what had happened; the psychological shocks of experiencing the suddenness and overwhelming nature of the devastation surrounding the survivors; mass migration from the scene of destruction; disruption or elimination of fire-fighting capabilities; disruption or elimination of medical systems; extremely large numbers of civilian injured, primarily suffering from the effects of blast and burns; disruption or elimination of social infrastructure, including modes of public order, energy supply, and transportation; and early exposure to radiation, with symptoms appearing within a few days or weeks. In addition, there would soon be some effects for the survivors of a nuclear detonation associated with global phenomena for which there are some precedents among past natural disaster experiences, including lack of food; insufficient supplies of uncontaminated water; and threat of outbreaks of epidemics.

A few of the experiences of those not in combatant areas would have been observed before; particularly instructive would be experiences of wartime sieges, famines, and disease epidemics. But by far most of the post-nuclear war experiences of those not directly affected by detonations, as well as of the survivors of direct detonation, would have no historical precedent. These factors include:

- the scale of devastation, precluding outside assistance and precluding a refugia for exodus of the afflicted population;
- the onset of extreme climatic events on a global scale;
- the insufficiency of food, energy, and other subsistence factors both locally and over large areas of the world;
- the presence of a radioactively contaminated landscape of unknown extent or hazard;
- the impairment or destruction of the economic and social systems on a global scale;
- the psychological challenges to order and stability among survivors in a world undergoing rapid readjustment;
- other global-scale disruptions of the natural environment, including pollution, pest outbreaks, habitat destruction, and loss of species;
- synergistic combinations of the various perturbations; having these extreme perturbations occur simultaneously and on such a scale would likely result in even greater impacts than would be projected from the effects of individual stresses alone.

The ability to predict the responses of humans and societal systems to any of these factors, individually or in combination, is limited by the totally unprecedented nature of these situations. Mere extrapolation from the experiences of the localized atomic bombings of Hiroshima and Nagasaki has consistently led to a gross underestimation of what the consequences of the next nuclear war would be for the global human population.

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