SPECIAL REPORT

NEW PERSPECTIVES ON THE MEDICAL CONSEQUENCES OF NUCLEAR WAR

THE destructive capability of modern nuclear weapons should now be evident to everyone; in fact, our national security for the past 40 years has been based on the perception that nuclear war would be unhealthy. People's perceptions of how serious the health problems would be in the event of a nuclear war, however, vary surprisingly and must affect their attitudes toward the use of nuclear weapons. Therefore, understanding what the health consequences of a nuclear war would be, as best we can know them, is very important for informed opinions and actions by citizens and by government.

Studies performed primarily by physicians the world over have done much to make explicit what the health effects of a nuclear war would probably be. Physicians, together with scientists from different disciplines, have applied knowledge about the blast, thermal, and radiation effects of thermonuclear weapons to build on the tragic experiences of Hiroshima and Nagasaki and to estimate the damage to humanity that might result if nuclear weapons were ever used again.

In September 1985, an international symposium was held by the Institute of Medicine of the National Academy of Sciences in Washington to present and discuss new studies regarding the potential health effects of nuclear war. Entitled "Medical Implications of Nuclear War," the proceedings of this symposium are now being published.[1] Two weeks earlier, the Scientific Committee on Problems of the Environment of the International Council of Scientific Unions released the results of a three-year study, "Environmental Consequences of Nuclear War," which involved some 300 scientists from more than 30 countries and a wide range of disciplines. This study, which is the most ambitious and authoritative on the subject, has been published in two volumes.[2,3]

My purpose is to summarize some of the salient new information on the health effects of nuclear war that was presented in these reports. This information includes a new basis for estimating the numbers of expected casualties,[1,4] a reconsideration of the LD_{50} radiation dose in humans,[5] a description of the impairment of the immune system that would occur among the survivors of a nuclear war,[6] and predictions on hunger and starvation, which now seem likely to be the major health problems that a nuclear war would create. I will not attempt to discuss the psychological and sociological reports included in the Institute of Medicine symposium.

Each successive study[1,3,7-10] of the possible human destruction that would result from a nuclear war — either a limited exchange (were that possible) or a total exchange of existing stockpiles — draws a grimmer conclusion about what the human costs would be. Instead of speculating that the casualties might amount to only a few tens of millions,[7] recent studies have indicated that the casualties are likely to number a billion or more,[3,9] and even the survival of human beings on earth has been questioned.[10] There are clearly many untestable assumptions made in all such projections of outcomes. Nevertheless, the possibility of their occurrence cannot be denied; only the quantification cannot be stated, and this uncertainty has given license to policy makers to gamble with humanity's future. Thus, the entire world is now held hostage to double uncertainties — the unknown consequences of a nuclear war, should it occur, and the uncertain wisdom or folly of a few policy makers in the Soviet Union and the United States who have it in their power to determine its occurrence or prevention.

A NEW BASIS FOR ESTIMATING THE NUMBERS OF CASUALTIES

Nuclear bombs can be exploded in the air at an altitude calculated to maximize the area of damage. Table 1, based on data from Glasstone and Dolan,[11] shows the effects of a blast from an airburst at increasing distance from ground zero — the point on the ground directly below the explosion. For simplicity it has been assumed that with a uniform population density everyone within the area subjected to 5 psi of overpressure (pressure above the ambient atmospheric pressure) would be killed outright. This is of course an approximation since not everyone in that area would be killed. However, if one counted the number of people dying outside the 5-psi overpressure zone, it would about equal the number of survivors within the zone. This simplified "cookie-cutter" approximation

Table 1. Blast Effects of a 1.0-Mt Airburst at 2438 Meters (8000 Feet) above Ground.*

DISTANCE FROM GROUND ZERO		OVER-PRESSURE	WIND VELOCITY	TYPICAL BLAST EFFECTS
km	*miles*	*psi*	*mph*	
1.3	0.8	20	470	Reinforced concrete structures are leveled
4.8	3.0	10	290	Most factories and commercial buildings are collapsed. Small frame and brick residences are destroyed and distributed as debris
7.0	4.4	5	160	Lightly constructed buildings and residences are destroyed; heavier construction is badly damaged
9.5	5.9	3	95	Walls of steel-frame buildings are blown away; severe damage to residences occurs. Winds are sufficient to kill people in the open
18.6	11.6	1	35	Damage to structures occurs; people are endangered by flying glass and debris.

*Data are from Glasstone and Dolan.[11]

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has been a convenient way to estimate fatalities. It considers that everyone in an area of some 150 km^2 (radius, 7 km) below a 1-megaton (Mt) airburst would promptly die.

It was only after the atmospheric scientists had made their calculations on the possible amounts of smoke and soot that would be lofted into the atmosphere after a nuclear war that the effects of the postulated fires on human populations were carefully examined.[4,12] The temperature generated by a thermonuclear explosion is tens of millions of degrees centigrade — hotter than the interior of the sun. The surface of the sun is 6000°C, and it warms the earth's surface at a distance of 150 million km (94 million miles).[12] It is not surprising, therefore, that a 1.0-Mt airburst would simultaneously ignite fires over a large area. About 35 percent of the energy of an airburst is initially radiated as heat.[11]

At Hiroshima, a mass fire developed approximately 20 minutes after the explosion and created a firestorm similar to that produced by the innumerable incendiary bombs dropped on Dresden, Hamburg, and Tokyo. The energy necessary to ignite combustible material in U.S. or Soviet cities would be present anywhere from 4.5 to 14 km from ground zero after a 1-Mt airburst. Furthermore, fires ignited simultaneously over such large areas can be expected to coalesce and create mass fires. The air heated by such fires rises, and cool air is sucked in at the base of the fire, around its perimeter. This creates an intensely hot central core with temperatures rising to 1000°C and gale-force wind velocities fanning the flames moving radially from the periphery into the fire. The speed of these "fire winds" is predicted to average 55 to 65 km per hour in a lightly built-up city; in a heavily built-up city, average wind speeds of 100 km per hour are predicted. Such winds channeled down streets could create hurricane-force winds, trapping people within the fire zone. Postol,[12] in his development of this scenario, has calculated that air temperatures at ground level would exceed that of boiling water throughout the fire zone. Anyone caught in the fire zone would be promptly roasted, and those in underground shelters would be either suffocated from lack of oxygen or asphyxiated by carbon dioxide or carbon monoxide, as occurred in Hamburg and Dresden.

There are many uncertainties and assumptions in the conflagration model for estimating casualties. First of all, the distance that a given energy flux will travel through the air from an airburst is very much influenced by atmospheric conditions. With clear visibility, fires may be expected 10 to 14 km from ground zero after a 1.0-Mt airburst; with inclement weather, the range may extend only to 4 to 5 km from ground zero.

Secondly, it seems that the amount of combustible material in urban areas, even in residential districts, is sufficient to sustain a firestorm. Because of the strong concentration of fossil fuels and related products around cities and towns, such mass fires seem likely if urban centers are targeted. One hundred megatons would accomplish this.[10]

In addition, the intensity of the heat energy necessary to start fires can only be estimated. It is possible that the primary fires started by the initial heat pulse would be extinguished by the blast and winds following. The blast, however, by toppling buildings, would expose more combustible material, burst gas mains, break fuel-storage tanks, and ignite fires mechanically and by electric sparks.

With these considerations, Daugherty et al.[1,4] estimated that for a 1.0-Mt airburst, simultaneous fires would be ignited in an area with a radius of some 12 km under average clear weather conditions, and that the minimum and maximum radii would be 8 and 15 km, respectively. It was assumed in this conflagration model that deeper than about 2 km within the periphery of the fire zone, everyone would be killed, because the population would not have time to escape before the individual fires merged into a single inferno. Within the central zone with a radius of 10 km, therefore, everyone is assumed to be killed. In a 2-km penumbra surrounding this area, half are also assumed dead, one third are assumed to be severely injured, and the remainder are assumed to be intact.

This conflagration model makes a very important point: the area for fatalities is much larger with fires than with blasts. Thus, for a 1.0-Mt airburst, the lethal area predicted on the basis of overpressure would be some 150 km^2, as compared with the lethal area from fires estimated to be some 380 km^2. The difference in estimates of casualties based on these two approximations is shown in Table 2.

Table 2. Predicted Numbers of Deaths and Injuries (in Millions) after an Attack Involving 100 1-Mt Airbursts at an Altitude of 2 Km (1.24 Miles) over 100 City Centers, According to Two Models.*

Model	No. Dead	No. Injured
Overpressure	14	22
Conflagration		
Medium radius 12 km	42	9
Maximum radius 15 km	56	5
Minimum radius 8 km	23	17

*Data are from Daugherty et al.[1-4]

Reconsideration of the LD_{50} Radiation Dose

The lethal dose from ionizing radiation is usually quantified as the amount of radiation that will kill 50 percent of a specified population. For humans the generally accepted whole-body $LD_{50/60}$ surface dose is taken as 450 rem (or rad) for an acute exposure, with deaths occurring within 60 days. For our purposes the amount of radiation in an "acute exposure" can be defined as the quantity accumulated over a period of one week. It is well known that mammals can survive larger cumulative doses of radiation if these doses are received over a longer period. The biologic repair processes after radiation-induced damage to cells account for this time-related tolerance. It is assumed that 90 percent of the damage from radiation is repaired with an exponential time constant of 30 days.

The figure of 450 rad for the $LD_{50/60}$ for humans has been rather arbitrarily selected from an uncertain range of 250 to 600 rad.[13] Cronkite and Bond[14] have estimated an LD_{50} of 350 rad in the absence of treatment with antibiotics and blood transfusions. Their estimates were based on information on the Japanese atom-bomb casualties, the accidental exposure of Marshall Islanders to fallout radiation, and experiments with dogs. Lushbaugh[13] suggested that the presence of widespread trauma, infections, malnutrition, and dependence on nursing care would shift the human sensitivity to radiation toward the low dose side of the range of LD_{50} exposures for a civilian population under austere environmental conditions.

Rotblat[5] has recently reexamined the question of the appropriate LD_{50} for the estimate of casualties from a nuclear war. His analysis used data from Hiroshima, which included a distribution of persons at known distances from ground zero who were shielded to various degrees from a known dose of radiation. Rotblat assumed that all deaths occurring within the first day were due to burns or blast. Death rates as a function of distance from ground zero on subsequent days were interpreted as representing primary radiation fatalities. From these calculations Rotblat derived a bone marrow LD_{50} radiation dose of 155 rad, or a body-surface LD_{50} of 220 rad.

Although this low value for the LD_{50} probably reflects synergistic effects of radiation with blast and burn injuries from the nuclear explosion, it indicates that radiation may be expected to be much more lethal under conditions of warfare than under peace-time conditions in which sophisticated medical care is now available to treat victims of accidents involving radiation (e.g., the disaster at Chernobyl in the U.S.S.R.). The debilitated state of the Hiroshima population after five years of war undoubtedly served to lower this value. Without a long conventional war preceding the use of nuclear weapons, the LD_{50} may not be so low, but the many civilian burn and traumatic injuries that would result from a nuclear attack would quickly lead to a state of debility in the exposed population.

The calculations of Daugherty and colleagues[1,4] for an attack limited to U.S. strategic nuclear targets illustrate the effects of different assumed values for the LD_{50} on the expected casualties (Table 3). The range of estimated casualties from radioactive fallout arises from the different average wind speeds and directions expected at different seasons of the year. The total casualties from such a "limited attack" would approximate the sum of the casualties from fire and radioactive fallout.

Table 3. Predicted Numbers of Deaths and Injuries (in Millions) after an Attack on U.S. Strategic Nuclear Targets with Air and Ground Bursts.*

	No. Dead	No. Injured
Effects of blast and fires		
By overpressure model	7	7
By conflagration model (medium radius)	16	3
Effects of radioactive fallout		
At a high LD_{50} (250 rad)	9–14	8–15
At a medium LD_{50} (350 rad)	7–8	4–8
At a low LD_{50} (450 rad)	5–6	2–3
Excess cancer	1–9	

*Data are from Daugherty et al.[14]

As targeting becomes more accurate, reduction in the size of warheads to maximize the destructive capacity per megaton of explosive power will result in increased radioactive fallout. When smaller bombs (e.g., those of a few hundred kilotons) are used as ground bursts, they inject radioactivity into the troposphere rather than higher into the stratosphere, as do megaton bombs. The result is that the radioactivity settles to the surface more quickly, with less time to decay. A heavier radioactive fallout dose is thus delivered at ground level. Finally, the effect on radioactive fallout doses of targeting nuclear power plants has received attention. In a situation in which a nuclear power industry of 500 gigawatts was attacked, the accumulated dose of fallout globally would be more than double that received from the weapons alone.[15]

Reduced Immunity among Survivors of a Nuclear War

Greer and Rifkind[6] reviewed the potential effects of a nuclear war on the normal immune response. They indicated several features of nuclear warfare that would adversely affect the immune response: ionizing radiation, hard ultraviolet radiation (ultraviolet-B), burns and trauma, psychological factors, and malnutrition.

Ionizing Radiation

The ability of ionizing radiation to impair the functioning of the immune system is well substantiated from studies in animals and from clinical observations on the use of radiation therapy in humans. An increased incidence of viral infections (herpes zoster and varicella) is seen in patients with Hodgkin's disease who are subjected to extensive radiotherapy.[16] The antibody response to pneumococcal vaccine is markedly impaired by total lymphatic radiation, and the ability to respond to immunization may not return for several years.[17] Impaired T-cell function was noted 30 years after exposure in some Japanese atomic-bomb survivors.[18]

Greer and Rifkind[6] concluded from various studies that the vulnerability of the human immune system begins at about 150 to 200 rad of ionizing radiation. The combination of even low-dose radiation and other injuries may have synergistic and disastrous effects. This was shown experimentally by Brooks et al.,[19] who observed no mortality in dogs exposed to a whole-body radiation dose of 100 rad and only 12 percent mortality in dogs subjected to a second-degree burn on 20 percent of the body surface. When the two injuries were combined, however, the mortality rate increased to 75 percent. Death results from the inability of the irradiated animal to fight sepsis because of the impaired immune response. After a nuclear war with an exchange of 5000 to 10,000 Mt, millions of people in the Northern Hemisphere would be subjected to sublethal radiation from fallout and would have an increased susceptibility to the many infectious diseases likely to be rampant at just that time. Many radiation victims would also be suffering from associated burns and trauma.

The mechanism of the immune suppression from ionizing radiation appears to be a reduction in T-lymphocyte function — specifically, a reduced ratio of helper to suppressor T cells.

Hard Ultraviolet Radiation

The immunosuppressive effect of ultraviolet light has only recently been recognized. Studies in animals have shown that exposure to ultraviolet radiation, particularly to ultraviolet-B (wavelengths ranging from 290 to 320 nm) results in a T-cell–mediated immunosuppression characterized by a predominance of suppressor T cells.[20] The energy in ultraviolet electromagnetic waves is nonionizing, in contrast to the much higher energy in x-rays and gamma-rays. Nevertheless, like x-rays, ultraviolet rays will reduce the amount of helper T cells[21] and increase the activity of suppressor T cells, to impair defense against infections and tumors.[22,23]

Several studies[2,24-26] have indicated that the large amount of oxides of nitrogen that would be lofted up to the stratosphere after megaton-range thermonuclear explosions would destroy the ozone layer in the lower stratosphere that normally absorbs the incident hard ultraviolet radiation and prevents it from reaching the surface of the earth. The reduction in the protective ozone depends on the amount of nitrogen oxides formed, which is determined by the total megatons exploded and the height to which the nitrogen oxides are lofted. In general, maximum ozone depletions are found to range up to 50 percent for explosions of some 5000 Mt, including high-yield weapons[2]; the peak depletion is reached in 6 to 12 months, and a sustained depletion of 10 percent or more can persist for 3 to 6 years. On the other hand, with only low-yield weapons, the peak ozone depletion may never reach even 10 percent. The increases in ultraviolet radiation at the ground arising from reductions in total ozone depend on latitude and season, as well as on any absorption and scattering by intervening clouds of smoke, dust, and ice. Calculations indicate that the reduction in ozone following a 5000- to 10,000-Mt exchange would be sufficient to allow at least a fivefold increase in the amount of ultraviolet-B reaching the earth's surface.[10,26,27] This would be sufficient to impair the immune system, cause an increase in skin cancers, and damage eyes and plant life.

Burns and Trauma

Major burns and trauma can result in severe immunosuppression. Burns and wounds also serve as obvious portals for entry of infections. Serious infections are all-too-common accompaniments of burns and wounds, and gram-negative sepsis is the most common cause of death following these injuries after the initial shock phase is survived.

Reduced T-lymphocyte activity, which is thought to be largely responsible for the immunosuppression induced by burns,[28,29] results from a shift in the balance of helper and suppressor T-cell subpopulations. A low ratio of helper to suppressor T cells has been noted in patients soon after burn injuries of more than 30 percent of body-surface area. Sepsis is most likely to occur when suppressor T-cell levels are at a maximum, 7 to 14 days after the injury,[30] and a reduced ratio of helper to suppressor T cells in this setting predicts a low survival.[31]

Psychological Factors

Stress, depression, and bereavement would be widespread among the survivors of a nuclear war. Clinical studies suggest that psychological factors may influence susceptibility to infections and delay recovery from upper respiratory tract diseases, influenza, herpes simplex lesions, and tuberculosis.[32] Bereaved spouses and patients with primary depressive disorders have been shown to have reduced T-cell function.[33-35] Furthermore, there are some clinical suggestions that depressed patients have an increased mortality rate, cancer incidence, and frequency of certain viral infections.[35,36] Again, T-cell disturbances appear to mediate the abnormal immunologic state.

Malnutrition

Food shortages, malnutrition, and starvation are highly probable outcomes of a major nuclear war. Studies in animals have shown impaired immune functions associated with specific dietary deficiencies. Deficiencies of vitamin A, vitamin B_{12}, riboflavin, and iron have all been associated with reduced T-lymphocyte function or increased susceptibility to infections.[37,38] Abnormalities of T-cell function have also been noted in deficiencies of pyridoxine and zinc.[39]

It is well known that patients with protein-calorie malnutrition have a high incidence of many infections, notably with mycobacteria, viruses, and fungi. They are likely to have lymphopenia and reduced cutaneous hypersensitivity in response to antigenic challenge.[40] Among populations with protein-calorie malnutrition, there is a high mortality from infections that would cause only minor illness in well-nourished persons.[41]

Each of the problems just discussed — ionizing radiation, increased ultraviolet radiation, burns and trauma, psychological disturbances, and malnutrition — would be prevalent after a major nuclear war. As Greer and Rifkind indicated,[6] each affects the immune system so as to increase the incidence and severity of infectious diseases.

Food Supplies and Nutrition in the Aftermath of a Nuclear War

Hunger and starvation would plague the survivors of a nuclear war. Millions would probably starve to death in the first few years after an all-out nuclear war, as indicated by the following considerations.

World food reserves, as measured by total cereal stores at any given time, would be frighteningly small if production should fail. They have amounted in recent years to about a two-month supply of cereal at present consumption rates.[42] The stores fluctuate seasonally; they are largest immediately after harvesting and then gradually decline, reaching a nadir just before the next harvest. In the United States, food stores would feed the population for about a year.[43] Portions of the stores, however, would be destroyed by blasts or fire or would be contaminated by radioactivity.[44,45] Crops in the field would be damaged to an unpredictable extent.[45,46]

More important, the means to transport the food from sites of harvesting or storage to consumers would no longer exist. Transportation centers would be prime targets of an aggressor intent on destroying the industrial competence of an opponent in order to sustain a war. Roads, bridges, and rail and port facilities would be likely targets. Furthermore, in a nuclear attack, most of the food supplies in urban areas would be destroyed.

In the United States and other developed countries, food is no longer carried by farmers to nearby markets. The northeastern United States is particularly vulnerable to a breakdown in transportation of foods, since some 80 percent of its food is imported, but other sections of the country would fare only a little better. Eighty-five percent of the corn in the United States is grown in 11 midwestern states; one sixth of the wheat is grown in Kansas alone, and most of the rest is grown in Texas, Minnesota, North Dakota, and Montana. Two thirds of the soybeans are grown in the Great Lake states and the Corn Belt; rice is grown mainly in Arkansas, Louisiana, Texas, Mississippi, and California; and fruit and vegetable production is nearly as regionally concentrated.[43] With key railway links and highways destroyed and gasoline and diesel fuels unavailable, what crops survived could not be moved to the places where they were needed.

Food is now supplied in the United States and developed countries by a complex network of enterprises that involves not only farming, animal husbandry, and fishing but also farm machinery, pesticides, fertilizers, petroleum products, and commercial seeds. The sophisticated techniques and technology used to handle the food that is produced include grain elevators, slaughterhouses, cold-storage plants, flour mills, canning factories, and other packaging plants. The network also includes the transportation, storage, marketing, and distribution of foods through both wholesale and retail outlets. A breakdown in this vast agroindustry would be an inevitable consequence of a nuclear war. Without the means to harvest, process, and distribute the crops that survived, there would be much spoilage.

So much of the social and economic structure of society as we know it would be destroyed that relationships that we take for granted would disappear. Money would have little or no value. Food and other necessities, when available, would be obtained by bartering. More likely, as people became desperate with hunger, survival instincts would take over, and armed individuals or marauding bands would raid and pilfer what supplies and stores existed.

The early death of millions of humans and animals would not sufficiently compensate for the reduction in available food supplies. Stocks of fuel, fertilizers, agricultural chemicals, and seed would soon be exhausted. Not only functioning tractors but also beasts of burden would be in short supply, and food production would become very labor-intensive — a throwback to primitive farming methods. The doubling of crop yields per hectare that has occurred over the past 30 years is partly the result of improved seeds but also a result of the energy subsidies to agricultural production in the form of fossil-fuel products.[3] The amount of diesel fuel currently consumed in raising crops in developed countries is approximately 100 liters per hectare. In developing countries, this figure may be 0 to 10 liters. Once local centers of supply became depleted, it would be difficult to obtain fuel for agricultural or other purposes. In addition to the direct energy subsidies to operate and manufacture farm machinery, fertilizers are extremely important in determining high levels of crop productivity, largely in the developed countries. For example, in 1983 in the United States, nitrogen applications for maize had reached a level of 152 kg per hectare -- typical for developed countries.[3] Wheat and rice also received relatively heavy applications of fertilizers.

The resistance of insects to radiation and the lack of pesticides would further reduce the yield of crops. Radioactive fallout would probably make fields downwind from targeted sites unusable for weeks to years.

There would probably be a deterioration in the quality of the soil after a nuclear war. The death of plant and forest coverage due to fire, radiation, lack of fertilizers, and the probable primitive slash-and-burn agricultural practices of survivors would leave the soil vulnerable to erosion by wind and rain.[47] The creation of deserts and coarse grasses and shrubs would render agriculture and animal husbandry less productive.

Water supplies would be seriously reduced. Dams and large irrigation projects could well be targeted. Reduced rainfall in noncoastal areas, predicted in most models of the climatic effects of a nuclear war, would interfere with agricultural productivity.[3] Radioactive fallout would contaminate reservoirs and surface waters with long-lived radioactive isotopes, primarily strontium-90 with a half-life of 28 years and cesium-137 with a half-life of 33 years. These elements in the ground water would soon be taken up by plants, thus entering the food chain. Eventually they would concentrate in humans, the strontium accumulating in bone and the cesium within the cytoplasm, where they would contribute to the long-term burden of radioactivity in survivors.

Not only would food be scarce, but it would probably be unsanitary as well. The destruction of sanitation, refrigeration, and food-processing methods, especially in the remaining urban areas or population centers, would result in contamination of food with bacteria, particularly with enteric pathogens. Spoiled meat, the carrion of domestic animals and even of human corpses, would probably be eaten by starving persons, as has happened in major famines in the past.[43] Pathogens to which civilized humans have lost resistance would be acquired from foods and water contaminated by excreta and by flies, other insects, and rodents, which would be likely to proliferate in the aftermath of a nuclear war.

A reduction in the average temperature at the earth's surface, by even a single degree, due to soot and dust in the atmosphere absorbing solar infrared energy would shorten the growing season in northern latitudes and markedly reduce or prevent the maturation and ripening of grains that are the staple of our diets.[3] But we have been hearing debates, not about whether a "nuclear winter" would occur, but about how many tens of degrees the temperature would fall and for how long. During most of the growing season a sharp decline in temperature for only a few days may be sufficient to destroy crops.

During the growing season, long-term reductions in average temperature of slightly more than 2°C for spring wheat and 4°C for barley would result in total elimination of these crops from production in western Canada, irrespective of any change in light or precipitation. Only slightly greater temperature reductions would eliminate these grains from any mid-latitude growing areas. The growing season would decrease at a rate of about 10 days per degree (centigrade) of decrease in average temperature, at the same time that the maturity requirements for wheat and barley would be increased by 4 to 6 days. These two opposing factors would lead to a shorter growing season than crops require, and total crop loss would result. Furthermore, reductions in both temperature and light would act synergistically in stunting plant growth and maturation.[3]

Since most wheat and coarse grains are grown in the temperate regions of the Northern Hemisphere, which would be the zones most affected by a "nuclear winter," it is evident that a nuclear war, especially during the spring or summer, would have a devastating effect on crop production and food supplies for at least the year in which it occurred. The United States and Canada are the breadbasket for the world; total cereal production in North America in 1982 was 387 million metric tons, of which 123 million metric tons, or nearly one third, were exported.[42]

After the atmospheric soot and dust finally cleared after a large nuclear exchange, destruction of the stratospheric ozone would allow an increase in hard ultraviolet-B rays to reach the earth's surface. In addition to having direct harmful effects on the skin and eyes of humans and animals, these hard ultraviolet rays would damage plant life and interfere with agricultural production. If the oxides of nitrogen increased in the troposphere, an actual increase in ozone might occur at low levels of the atmosphere.[26] Such an increase in tropospheric ozone is anticipated as nuclear bombs become smaller — that is, as they decrease from megaton to kiloton size. Ozone is directly toxic to plants.

If temperatures fell to freezing or nearly freezing as postulated in some scenarios, the direct effects of the cold could have serious consequences in terms of human survival, especially if the low temperatures affected regions that were not normally cold. Furthermore, the effect of the cold, even if not directly lethal, might still increase caloric needs just at a time when food supplies were very constrained.

Hunger and starvation would not be limited to the combatant countries or even to the Northern Hemisphere. It would be truly a global occurrence. Even if the possible climatic effects of a "nuclear winter" did not spread to the Southern Hemisphere, millions of people in noncombatant countries would die of starvation. Today a large portion of food exports goes to parts of the world where even with grain imports, millions of people are suffering from undernutrition and hunger.[43,44,48]

The number of undernourished persons in developing countries is staggering, approaching one quarter of all humankind.[43] On the basis of 1980 data, the World Bank has estimated that some 800 million persons in developing countries — from 61 to 71 percent of the populations — have deficient diets.[48] The Food and Agriculture Organization of the United Nations, using slightly more stringent criteria, has estimated that some 16 to 23 percent of the global population, or 436 million persons, has food-intake levels that permit little more than survival (1.2 times the basal metabolic rate, a level of caloric intake below which survival is not possible and which is incompatible with productive work[49,50]). In addition, the World Health Organization has reported that at least 450 million children suffer from varying degrees of protein-calorie malnutrition.[51] A large number of these persons are dependent on the food supply and price structure made possible by the food exports of North America; a disruption of these supplies would have grave consequences for most of the populations of developing countries.[43]

In the past decade an increasing dependence of countries on the food supplies of other countries has occurred.[52-54] In 1982, the major grain-exporting regions — the United States, Canada, the countries in the European Economic Community, and Australia — exported 170 million metric tons of cereals, more than half of which came from the United States alone.[42] The developing countries were the major recipients of these exports. Africa imported 24 million tons of cereals in 1982 — equal to a third of its own total grain production for that year. In South America cereal imports equaled 14 percent of total cereal production, and in Asia (excluding China) the corresponding figure was 18 percent. By 1990 the situation in the countries with food deficits will worsen and their food shortages will increase, despite their efforts to increase production and contain their populations.[50,55] Loss of their food imports from North America and Europe would be calamitous for these countries.

It is evident from the above considerations that hunger and starvation would decimate the survivors of a major nuclear war. Millions of deaths would result not only among the survivors in combatant countries but throughout the world. The developing countries, in fact, might be the principal victims of this famine, since their populations might not be as immediately reduced as would certainly be the case in the combatant countries. Starvation would be essentially global — an effect that would probably cause more deaths in the long run than all the direct effects of nuclear war combined.[3,9]

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