



Nuclear winter

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Nuclear winter is the term for a theory describing the climatic effects of nuclear war. Smoke from the fires started by nuclear weapons, especially the black, sooty smoke from cities and industrial facilities, would be heated by the Sun, lofted into the upper stratosphere, and spread globally, lasting for years. The resulting cool, dark, dry conditions at Earth's surface would prevent crop growth for at least one growing season, resulting in mass starvation over most of the world. In addition, there would be massive ozone depletion, allowing enhanced ultraviolet radiation. More people could die in the noncombatant countries than in those where the bombs were dropped, because of these indirect effects. Nuclear proliferation is now expanding the threat. A nuclear war between India and Pakistan could produce so much smoke that it would produce global environmental change unprecedented in recorded human history. Although the number of nuclear weapons in the world has fallen from 70,000 at its peak in the 1980s to less than 10,000 currently deployed, a nuclear war between the United States and Russia could still produce nuclear winter. This theory cannot be tested in the real world. However, analogs can inform us about parts of the theory, and there are many that give support to the theory. They include the seasonal cycle, the diurnal cycle, forest, fires, volcanic eruptions, and dust storms on Mars. The only way to be sure to prevent the climatic effects of nuclear war is to rid the world of nuclear weapons. © 2010 John Wiley & Sons, Ltd. *WIREs Clim Change* 2010 1 418–427

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In the 1980s, after Crutzen and Birks¹ pointed out that smoke from fires following a nuclear war could have important climate effects, Turco et al.² used a radiative-convective climate model and calculated that surface air temperatures could fall below freezing in the middle of continents from the effects of smoke generated by a full-scale nuclear war between the United States and Soviet Union. They coined the term 'nuclear winter' to describe this result, which in two words succinctly captures the forcing and response. Other works soon thereafter, conducted jointly by Western and Soviet scientists,^{3–10} showed that for a full-scale nuclear war between the United States and the Soviet Union, smoke from the fires started by nuclear weapons, especially the black, sooty smoke from cities and industrial facilities, would block out sunlight over the entire planet. Badash¹¹ provides a detailed history of the 1980s work on nuclear winter.

The resulting cold, dark, and dry conditions at the surface would prevent agriculture for years. Mass starvations in Africa, but without any outside help,

now seemed more appropriate models for the world after nuclear war than Hiroshima or Nagasaki. More people could die in India or China from a nuclear war, even if no bombs were dropped there, than would die in the United States and Russia combined. That work was limited by existing climate models and computers, but the fundamental physics of the situation, that blocking out sunlight cools the surface, was unquestioned. The biggest unknown was how much smoke would be produced and how long it would remain in the atmosphere.

Based on some early experiments with a general circulation model that was limited in vertical extent and length of runs,¹² some (e.g., Ref 13) suggested that nuclear winter theory was disproved. But recent work with modern climate models and computers has shown that nuclear winter theory was correct, and that, in fact, the effects would last for many years, much longer than previously thought.¹⁴ The number of nuclear weapons in the world has decreased to 1/3 of the peak number of more than 70,000 in the 1980s, and current treaties call for the global arsenal to be less than 10% of that number by 2012. Yet, if used, even this arsenal could plunge the planet into nuclear winter. Furthermore, nuclear proliferation

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now presents the problem that a nuclear war between new nuclear states, say India and Pakistan, using much less than 1% of the current global arsenal, could produce so much smoke that, while it would not produce winter conditions in the summer, it could produce global environmental change unprecedented in recorded human history.¹⁵

This article first discusses the history of nuclear weapons arsenals and reviews the theory of nuclear winter. It then presents new climate model simulations of the effects of massive smoke input to the atmosphere from fires, and multiple analogs that give us confidence in the different parts of the theory. Next, the biological consequences of these climate changes are described. Finally, policy implications are discussed.

THE NUCLEAR ARSENAL

On August 6, 1945, a 15-kt nuclear bomb was dropped on Hiroshima, Japan, killing approximately 150,000 people. (1 kt means the explosive power of 1000 tons of TNT; 1 Mt = 1000 kt.) Many of these people died from the fires ignited by the bomb, which turned the city into a raging inferno, which pumped dense clouds of smoke high into the atmosphere. Figure 1 shows the remains of the city. Where did all the buildings go? A significant fraction of them went up in smoke.

Many more people would have died if help had not been available immediately from outside the city in the form of medical care, food, water, and shelter. Three days later a 20-kt bomb was dropped on Nagasaki, also killing tens of thousands, but since then nuclear bombs have not been used in warfare.

TABLE 1 | Nuclear Weapons Inventories, Using the Latest Available Data for the Nine Nuclear Nations

Country	Date of analysis	Number of Nuclear Warheads	Reference
United States	2009	2702 ^a	18
Russia	2009	4830 ^b	19
United Kingdom	2005	200	20
France	2008	300	21
China	2008	176	22
Israel	2006	115–190	16
India	2008	70	23
Pakistan	2007	60	24
North Korea	2006	5–15	16
Total		8458–8543	

^aAn estimated 6,700 additional warheads are in reserve or awaiting dismantlement.

^bAn estimated 8,150 additional warheads are in reserve or awaiting dismantlement.

When nuclear winter theory was first developed in the early 1980s, at the height of the nuclear arms race, the world had more than 50,000 nuclear weapons. Now, with the Cold War over, the US and Russia are reducing their nuclear arsenals. However, with about 8500 nuclear weapons still deployed in the world (as of the year 2009), there are still many more than would be necessary to produce nuclear winter (Table 1, Figure 2). The total explosive power of the current arsenal becomes more meaningful when considered in perspective. There is the equivalent explosive power of more than 1 ton of TNT for each human on the face of the Earth. The 15-kt Hiroshima bomb was only 0.00018% of the current global



FIGURE 1 | Hiroshima after a 15-kt bomb was dropped on August 6, 1945. The streets were cleaned before this picture was taken. Where have all the buildings gone? They burned in the resulting fire, pumping thick clouds of black smoke into the atmosphere. (Original picture copied by author from US Air Force Photo Library, Bolling Air Force Base, Washington, DC).

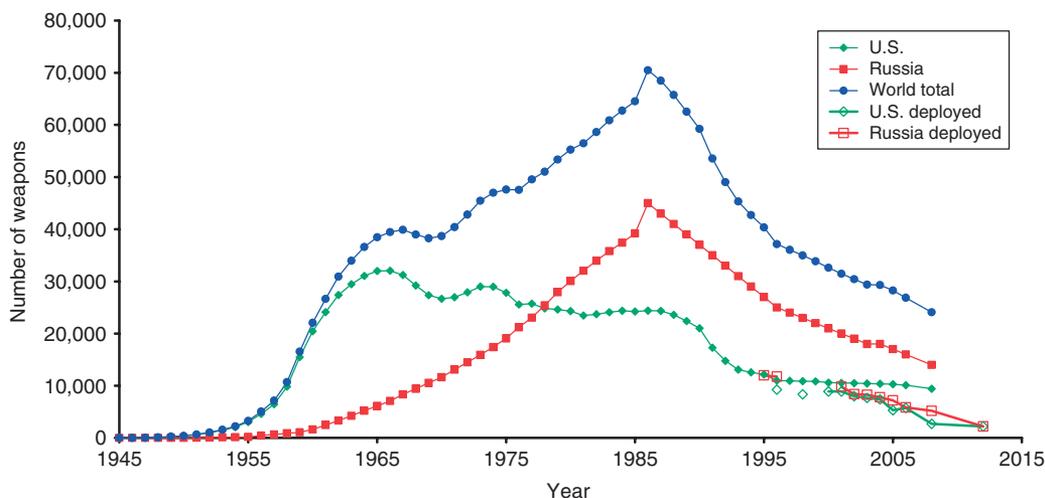


FIGURE 2 | Number of nuclear warheads in Russia (formerly USSR), the US, and the total for all the nuclear weapons states.¹⁶ Russia and the US have more than 95% of the warheads worldwide. The number of warheads began to fall after 1986 following the Intermediate-Range Nuclear Forces Treaty, and by 2005 it was about one-third of its value at the peak in 1986. Current treaties do not require a future reduction in the numbers of warheads, only a reduction in the numbers of warheads that are on strategic delivery systems. Weapons on strategic delivery systems should decline to 1700–2200 for each country by 2012 based on current treaties. (Updated from Figure 1 from Ref 17, used by permission).

arsenal. If one Hiroshima-sized bomb were dropped every day, it would take more than 1550 years to use up the current arsenal.

The total explosive power of all bombs dropped in all of World War II, during which 50,000,000 people died, including Hiroshima and Nagasaki, was 3 Mt.²⁵ The total explosive power of all bombs ever used in the history of the world in wars is 10 Mt, with 4 Mt of those dropped in the Vietnam war.²⁶ Yet we now have 850 times that explosive power in the world arsenals. And the number of nuclear weapons states is growing, increasing the danger that these weapons could be used (Figure 3). This illustrates the enormity of the current potential to start fires.

HOW COULD NUCLEAR WINTER BE PRODUCED?

A nuclear explosion is like bringing a piece of the Sun to Earth's surface for a fraction of a second. About one-third of the energy of a nuclear explosion is in the form of light or heat. Like a giant match, it causes cities and industrial areas to burn. The assumption made in many nuclear winter scenarios is that anything receiving more than 10 calories per square centimeter per minute (about 7000 W/m^2 —20 times the average amount of energy received at the top of Earth's atmosphere from the Sun) will burst into flames, and this was demonstrated in actual tests in Nevada before the atmospheric nuclear test ban. Megacities have developed in India and Pakistan and other developing countries, providing tremendous amounts of fuel for

potential fires. Following the flash of light comes the blast wave (like thunder following lightning) which will break apart many structures and blow out the flames, but crumpled structures burn more easily and fires would be reignited by burning embers and electrical sparks. Imagine how easily a house would burn with open gas lines or a filling station with gas pumps knocked over. In fact, there are many flammable sources of fuel for fires in cities, including buildings and their contents, trees, and even asphalt. Modern materials, such as plastics, not only burn with a sooty smoke, but also produce high levels of toxic chemicals.

The direct effects of the nuclear weapons, blast, radioactivity, fires, and extensive pollution would kill millions of people, but only those near the targets. However, the fires would have another effect. Massive amounts of dark smoke from the fires would be lofted into the upper troposphere, 10–15 km above Earth's surface in the tropics and 6–8 km above the surface in higher latitudes, and then absorption of sunlight would further heat the smoke, lifting it into the stratosphere, a layer where the smoke would persist for years, with no rain to wash it out.

The climatic effects of the use of nuclear weapons depend on the amount of smoke they would generate, and this depends on the targets. Nuclear targeting plans call for not only cities to be targeted, but also industrial facilities such as oil refineries and wells. Forests around military targets would also provide fuel. All these targets together would produce clouds of black sooty smoke, which rise into the atmosphere.

For 50 nuclear weapons dropped on two countries, on the targets that would produce the maximum amount of smoke, as much as 5 Tg of black smoke would be produced, accounting for the amount emitted from the fires and the amount immediately washed out in rain.²⁷ For a war between the US and Russia, even with total arsenals of about 4000 weapons planned for 2012 with current treaties, 150 Tg of smoke could be produced by the fires.²⁸ As the smoke is lofted into the stratosphere, it would be transported around the world by the prevailing winds, as illustrated in animations from Refs 14,15 at <http://climate.envsci.rutgers.edu/nuclear/BCabsopdaily.gif> and <http://climate.envsci.rutgers.edu/nuclear/BCdaily150tg.gif>.

CLIMATE MODEL CALCULATIONS

As discussed in detail by Robock et al.,¹⁴ earlier climate model simulations of the effect of massive smoke injections from nuclear fires were limited by the available computer time, available data, and the small number of people working on the problem. They used single-column radiative-convective models, energy balance models, or low-resolution atmospheric general circulation models that only considered the lower atmosphere, ignored ocean changes, and were run for

very short periods. This prevented them from calculating the lifetime of smoke or long-term responses. However, modern climate models have now been applied to this problem. These new climate model simulations, with the capability of including the entire atmosphere and oceans, find that the smoke would be lofted by solar heating to the upper stratosphere, where it would remain for years.¹⁵ The climatic effects of the smoke from burning cities and industrial areas would last for several years, much longer than we previously thought. And a nuclear war between India and Pakistan, with each country using 50 Hiroshima-sized atom bombs as airbursts on urban areas, could produce climate change unprecedented in recorded human history.¹⁵ This would be less than 0.02% of the explosive power of the current global arsenal. This same scenario would produce global ozone depletion, because the heating of the stratosphere would enhance the chemical reactions that destroy ozone.²⁹

Figure 4 shows the global temperature changes following the injection of 5 Tg of smoke into the upper troposphere in the subtropics.¹⁵ Global average temperatures would rapidly plummet to values below those of the Little Ice Age (1500–1850). The global hydrological cycle would also weaken, reducing global average precipitation by 10%. While these

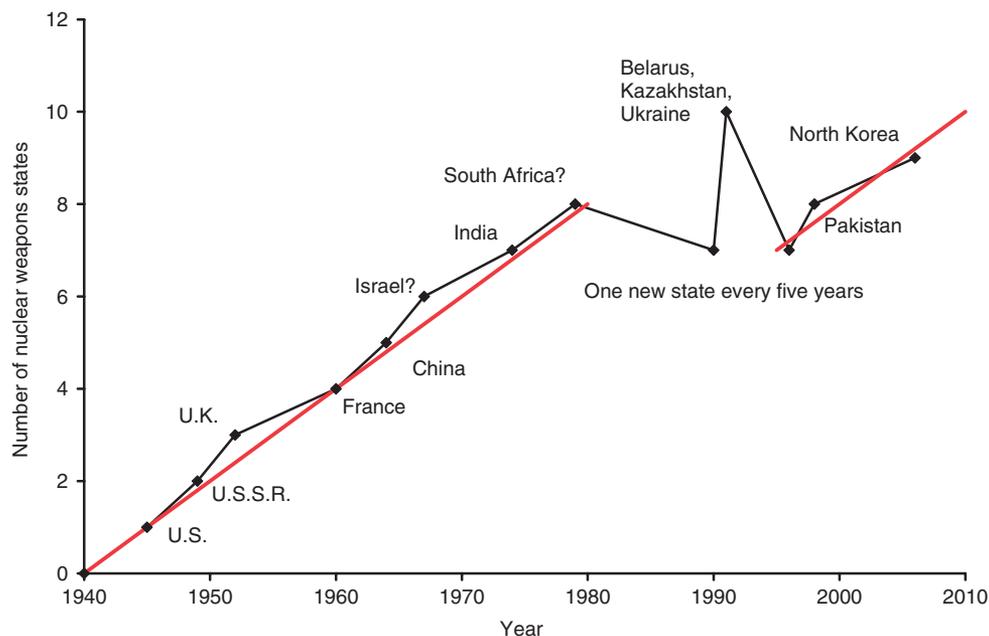


FIGURE 3 | New nuclear states have steadily appeared since the invention of nuclear weapons. In this graph the date of the first test, or the date when weapons were obtained, is noted. Israel and South Africa did not test weapons so their dates to obtain weapons are uncertain. South Africa abandoned its arsenal in the 1990s. Ukraine, Belarus, and Kazakhstan also abandoned the weapons they inherited after they left the Soviet Union. The red lines show growth in the number of nuclear weapons states at the rate of one new state each 5 years. Although the growth halted during the 1980s and 1990s, just after nuclear winter research was published and the Cold War ended, the recent resumption of growth is of great concern. (Modified from Ref 28, used by permission).

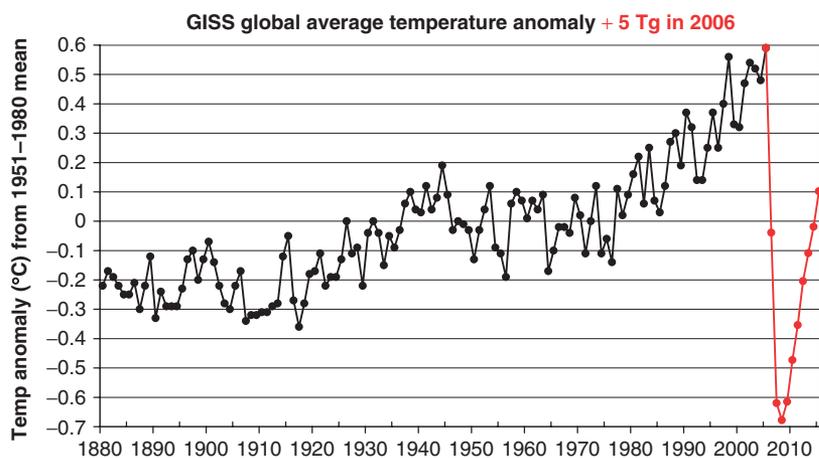


FIGURE 4 | Global average surface air temperature change from the 5 Tg standard case (red) in the context of the climate change of the past 125 years. Observations are from the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies analysis.³² The large global warming we have experienced in the past century would more than be erased, but with 20,000,000 dead immediately, many more injured from the effects of blast, fire, and radioactivity, cities rendered uninhabitable for long periods, and the effects on the global food supply, this should not ever be considered as a solution for global warming. (Figure 9 from Ref 15, copyright 2007 Alan Robock, used by permission).

temperatures would not be winter-like, growing seasons in midlatitudes of both hemispheres would be shortened by up to a few weeks, with potentially large impacts on agricultural production.¹⁵ The global average cooling, of about 1.25°C, would last for several years and even after 10 years the temperature would still be 0.5°C colder than normal. These numbers might not seem like much, but even during the Little Ice Age, global temperatures were only about 0.5°C below normal. Every once in a while large volcanic eruptions produce temporary cooling for a year or two. The largest of the past 500 years, the 1815 Tambora eruption in Indonesia, produced global cooling of about 0.5°C for a year. Year 1816 became known as the ‘Year Without a Summer’ or ‘18 hundred and froze to death’.^{30,31} There were crop-killing frosts every month of the summer in New England. The price of grain skyrocketed, the price of livestock plummeted as farmers sold the animals they could not feed, and a mass migration westward from the US East Coast across the Appalachians to the Midwest began. In Europe, widespread famines occurred

and the weather was so cold, dark, and gloomy that Mary Shelley was inspired to write *Frankenstein* in 1816. A nuclear war could trigger declines in yield nearly everywhere at once, with strong impacts on the global agricultural trading system.

Figure 5 repeats the curve from Figure 4, but adds temperature changes from injections of 50 and 150 Tg of smoke in the Northern Hemisphere midlatitudes.¹⁴ Even with Russian and American arsenals reduced to 6% of the 1980s levels by 2012, a nuclear war between the United States and Russia could produce 150 Tg of smoke and nuclear winter, with temperatures plunging below freezing in the summer in major agricultural regions, threatening the food supply for most of the planet.^{28,33}

ANALOGS SUPPORT THE THEORY

The climatic effects of a nuclear war between emerging nuclear powers or between Russia and the US are theories based on computer model calculations. Normally, scientists test theories by doing experiments, but we never want to do these experiments in the real world.

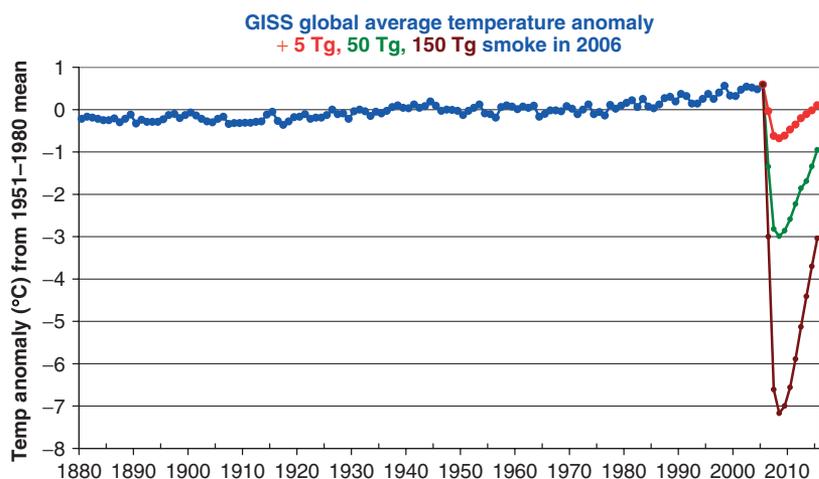


FIGURE 5 | Global average surface air temperature change from the 5 Tg (red), 50 Tg (green), and 150 Tg (brown) cases in the context of the climate change of the past 125 years. Observations are from the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies analysis.³² (Figure 8 from Ref 14, copyright 2007 American Geophysical Union, used by permission).

Thus we look for analogs that can inform us of parts of the theory. And there are many such analogs that convince us that the theory is correct:

1. *Cities burning.* Unfortunately, we have several examples of cities burning, firestorms created by the intense release of energy, and smoke being pumped into the upper atmosphere. These include San Francisco as a result of the earthquake in 1906, and cities bombed in World War II, including Tokyo, Dresden, Hamburg, Darmstadt, Hiroshima, and Nagasaki. At the end of the 1991 Gulf War, Iraqi troops set fire to about 700 oil wells in Kuwait. The resulting climatic effects were small, as the smoke did not get into the stratosphere and was only thick in the immediate region. The total amount of smoke from them, however, was much less than that would be generated from fires on targets with much more fuel, such as cities or refineries, with their above ground oil tanks. Therefore, the small climatic response to this smoke does not negate the nuclear winter theory.
2. *The seasonal cycle.* This analog gave nuclear winter its name. In the winter, the climate is cooler, because the days are shorter and sunlight is less intense. Again, this helps us to quantify the effects of reduction of solar radiation.
3. *The diurnal cycle.* At night the Sun sets and it gets cold at the surface. If the Sun did not rise tomorrow, we already have an intuitive feel for how much cooling would take place and how fast it would cool.
4. *Volcanic eruptions.* Explosive volcanic eruptions, such as those of Tambora in 1815, Krakatau in 1883, and Pinatubo in 1991, provide several lessons. The resulting sulfate aerosol cloud in the stratosphere was transported around the world by winds, thus supporting the results from the climate model simulations.³⁴ The surface temperature plummets after each large eruption, in proportion to the thickness of the stratospheric cloud. Following the Pinatubo eruption, global precipitation, river flow, and soil moisture all reduced, since cooling the planet by blocking sunlight has a strong effect on reducing evaporation and weakening the hydrologic cycle.³⁵ This is also what the nuclear winter simulations show.
5. *Forest fires.* Smoke from large forest fires sometimes is injected into the lower stratosphere. And smoke from large forest fires is transported

to large distances, producing cooling under the smoke.^{36,37}

6. *Dust storms on Mars.* Occasionally, dust storms start in one region of Mars, but the dust is heated by the Sun, lofted into the upper atmosphere, and transported around the planet to completely enshroud it in a dust blanket where it reduces daytime temperatures by tens of degree Celsius depending on how much dust is present. The spread of dust around the planet takes a couple weeks, just like our computer simulations for the nuclear winter smoke.
7. *Extinction of the dinosaurs.* About 65,000,000 years ago, an asteroid smashed into Earth in Mexico's Yucatan peninsula. The resulting dust cloud, mixed with smoke from fires, blocked out the Sun, killing the dinosaurs, and starting the age of mammals. This Cretaceous-Tertiary (K-T) extinction may have been exacerbated by massive volcanism in India at the same time. This teaches us that large amounts of aerosols in Earth's atmosphere have caused massive climate change and extinction of species. The difference with nuclear winter is that the dinosaurs could not have prevented the K-T extinction.

BIOLOGICAL CONSEQUENCES

The most important consequence of nuclear winter for humans is the disruption of food supplies.⁸ This comes from environmental disruptions that reduce or completely wipe out agricultural production and the disruption of the distribution mechanisms. However, there has been no new work on this subject since the 1980s. This is an area where new research, using scenarios of climate change from recent simulations,^{14,15} would provide more specific information on impacts, so the following conclusions are rather general. Not only would it be virtually impossible to grow food for 4–5 years after a 150-Mt nuclear holocaust, but it would also be impossible to obtain food from other countries. In addition to the disruption of food, there would be many other stresses for any surviving people. These would include the lack of medical supplies and personnel, high levels of pollution and radioactivity, psychological stress, rampant diseases and epidemics, and enhanced UV-B.

There are many ways that agriculture is vulnerable to nuclear winter. The cold and the dark alone are sufficient to kill many crops. Superimposed on the average cooling would be large variations. During the summer of 1816 in New England, there were killing frosts in each summer month.³⁰ Only

1 day with the temperatures below freezing is enough to kill rice crops. Colder temperatures mean shorter growing seasons, and also slower maturation of crops; the combination results in much lower yields. Most of the grains that are grown in midlatitudes, such as corn, are actually of tropical origin, and will only grow in summer-like conditions. For example, a study done in Canada shows that with summer temperatures only 3°C below normal, spring wheat production would halt.⁸ Insufficient precipitation would also make agriculture difficult.

The tremendous productivity of the grain belt of the US and Canada feeds not only those countries but also many in the rest of the world where normal climate variability often results in reduced harvests. This productivity is the result of modern farming techniques that allow a tiny percentage of the population to produce more than enough for the rest. To do this, tremendous energy subsidies are needed. Farmers depend on fuel for their machinery, fertilizer, and pesticides, none of which would be available or distributed in the aftermath of a war. Furthermore, insects have a higher tolerance for radiation and the stresses that would follow than do their predators, such as birds. Whatever might grow would be eaten by pests, already a significant problem in today's production. Also, the seeds that are in use were designed to yield high productivity assuming the current climate and inputs of chemicals and energy as discussed above. These seeds would not grow well in a radically altered growing environment. Our dependence on technology is such that if every human in the US went out to the fields to try to raise crops with manual labor, and if they knew what they were doing, and if they had enough food to eat, and if they were healthy, they still could not produce what is produced today.

Thus, most of the world's people are threatened with starvation following a full-scale nuclear war. The number that would survive depends on how much food is in storage and how much could be produced locally. Earlier studies of various countries around the world conclude that even with extremely optimistic assumptions of perfect distribution systems within countries,⁸ that each person who will survive becomes a vegetarian and eats the minimum needed for survival, and the others waste none of the food, that nations in Asia, Africa and South America could only last 1–2 months. In many nations, people would be reduced to a hunter/gatherer existence with nothing to hunt and precious little to gather.

The effects on health would add to the misery. Immune deficiencies can be produced by any of the following: burns and trauma, radioactivity, malnutrition, psychological stress, and UV-B radiation. All of

these would be present for the survivors in the target nations.

Pollution from dioxins, PCBs, asbestos, and other chemicals will make the air unhealthy to breath. Severe psychological stress will prevent the survivors from making the efforts to continue to exist.

One might think that the ocean shore would be a good place to survive because the temperatures would not fall as much, and there would be plenty of food to catch. Although the ocean would not cool very fast, the darkness would decimate the phytoplankton, which are at the base of the oceanic food chain. That, combined with toxic and radioactive pollution, would severely limit the food sources in the oceans. Furthermore, the large temperature contrasts between the oceans and the land would produce strong storms that would make fishing difficult at best.

While it is important to point out the consequences of nuclear winter, it is also important to point out what will not be the consequences. Although extinction of our species was not ruled out in initial studies by biologists, it now seems that this would not take place. Especially in Australia and New Zealand, humans would have a better chance to survive. Also, Earth will not be plunged into an ice age. Ice sheets, which covered North America and Europe only 18,000 years ago and were more than 3-km thick, take many thousands of years to build up from annual snow layers, and the climatic disruptions would not last long enough to produce them. The oxygen consumption by the fires would be inconsequential, as would the effect on the atmospheric greenhouse by carbon dioxide production. The consequences of nuclear winter are extreme enough without these additional effects, however.

POLICY IMPLICATIONS

The suicidal nature of the use of nuclear weapons is one of the most important policy implications. If country A used enough weapons only against military targets to prevent country B from retaliating, in what is called a 'first strike', the climatic consequences could be such that everyone in country A could die. Nuclear weapons, therefore, become an instrument of suicide and not an instrument of defense.^{10,38}

Soon after the nuclear winter theory was established, Carl Sagan gave a briefing on the subject to Senators, Congressmen, and staff on Capitol Hill. He described how the smoke from burning cities and industrial areas after a nuclear war would be so thick as to block out so much sunlight that the Earth's surface would become so cold and dark for so long that agriculture would be impossible and most of

the people in the world would starve to death. After the presentation, one of them called him aside and said, 'Look, if you believe that the mere threat of the end of the world is enough to change thinking in Washington and Moscow, you haven't spent much time in those cities!' (Ref 10, p. 6). Albert Einstein said, after nuclear weapons were invented, 'Our world faces a crisis as yet unperceived by those possessing power to make great decisions for good or evil. The unleashed power of the atom has changed everything save our modes of thinking and we thus drift toward unparalleled catastrophe'.³⁹ Yet it does seem that nuclear winter has provided a context to reexamine all the existing policy assumptions about nuclear war. People are gradually changing the way they think. And it happened only because scientists have tried to warn the world of the dangers of current policies.

The world seems to be a much safer place now than it was in 1982 and 1983 when the first papers on nuclear winter were published. How much of this change was caused by the realization of the dangers of nuclear winter? Some historians of the future, assuming we learn enough to avoid nuclear winter and have a future, may be able to tell us. Discussion of this theory contributed to the lessening of tension between superpowers and the reversal of the nuclear arms race during the 1980s.^{38,40} The inclusion of the concept of nuclear winter in the speeches of Nobel Peace Prize-winner Mikhail S. Gorbachev, the prime architect of the current good East–West relations, argues for a role. Mikhail Gorbachev, then leader of the Soviet Union, described in an interview in 1994 how he felt when he got control of the Soviet nuclear arsenal, 'Perhaps there was an emotional side to it. . . . But it was rectified by my knowledge of the might that had been accumulated. One-thousandth of this might was enough to destroy all living things on earth. And I knew the report on "nuclear winter"'.⁴¹ And in 2000 he said, 'Models made by Russian and American scientists showed that a nuclear war would result in a nuclear winter that would be extremely destructive to all life on Earth; the knowledge of that was a great stimulus to us, to people of honor and morality, to act in that situation'.⁴⁰

The Cold War is over, but many of the nuclear weapons produced during that period remain. The US and Russia are very slowly reducing the numbers

of weapons, but each still maintains an arsenal far larger than necessary to produce nuclear winter. No current leader of the US or Russia would use nuclear weapons, but their existence alone makes the possibility of nuclear winter in the future possible if a crazy person or computer error or misunderstanding caused their use. The only solution is to reduce the number of weapons to a level that will still provide a deterrent, but will not create a nuclear winter should they ever be used. Reducing these numbers to a level below which they could produce a global climatic catastrophe, as Sagan was fond of saying, is a matter of elementary planetary hygiene. This number is around a few hundred, the same number of weapons that Britain, France, and China have had in each of their arsenals for decades, and a number they have deemed more than sufficient to maintain a credible defense of their countries. This is also the number Admiral Stansfield Turner,⁴² former Director of the US Central Intelligence Agency (CIA), argued for on other grounds, in 1997.

The United States dropped two atomic bombs on innocent people in Hiroshima and Nagasaki, Japan, in 1945 in the first nuclear war; since then, in spite of the massive buildup of these weapons, they have never been used in war again. Nuclear winter theory now shows not only that the superpowers still threaten the existence of the rest of the world, but also that the newly emergent nuclear powers now threaten the former superpowers, perhaps not with extinction, but with serious consequences including drought and famine. Eliminating the nuclear weapons will eliminate the possibility of this climatic catastrophe. If they exist, they can be used.^{17,43} Rapid reduction of the American and Russian nuclear arsenals will set an example for the rest of the world that nuclear weapons cannot be used and are not needed.

At the time of the writing of this article, Presidents Obama and Medvedev have stated their intentions to speed up reductions of their nuclear arsenals and even work toward complete nuclear disarmament. This is very encouraging, and I hope that nuclear winter theory will help to inform them on the potential effects of different numbers of weapons, as well as the serious potential dangers of continued nuclear proliferation.

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