A Nuclear Winter's Tale

Science and Politics in the 1980s

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1 Nuclear Peril

On Sunday, 30 October 1983, more than 20 million American families encountered an unfamiliar but ominous phrase in *Parade*, a magazine offered by many newspapers as a Sunday supplement. The phrase—"nuclear winter"—appeared in a story credited to Carl Sagan, a planetary astronomer and a renowned science popularizer.

Research on normal atmospheric phenomena had led Sagan and his colleagues to investigate the effects on Earth's climate of the explosion of numerous nuclear weapons. Computer simulations of various nuclear war scenarios suggested to Sagan and colleagues that so much dust, smoke, and soot would be lofted into the atmosphere by city fires that the midday sun would be almost entirely obscured across much of the Northern Hemisphere. Except along the coastlines, continental temperatures would fall to –25°C (–13°F), a decrease of about 38°C, and would remain below 0°C for months. (For comparison, the difference in average temperature between the last ice age and the present is estimated at somewhere between 5°C and 15°C.[1]) In this cold and dark environment, Sagan said, many biologists anticipated the extinction of numerous species of plants and animals. Human civilization—its social order, its economy, its intellectual achievements—would be destroyed. The human population would stabilize at prehistoric levels . . . or *Homo sapiens* might become extinct.

In the past, scientists, especially those who worked for various government agencies examining the consequences of nuclear explosions, had underestimated the seriousness of radioactive fallout. They also had not foreseen the crippling of electronic apparatus by the electromagnetic pulses that nuclear explosions caused. And they had failed to predict depletion of the ozone layer by fireballs caused by high-yield explosions. Now it seemed they also had failed to notice the potential of striking climatic effects from dust and smoke. "What else," Sagan asked, "have we overlooked?"

Sagan, a man with strong political feelings, nonetheless restricted the *Parade* article to the popularization of a scientific discovery, albeit one with tremendous implications. The antiwar position was not controversial; no one was *for* a nuclear war. Sagan proposed no solutions here; he merely noted the danger of the superpowers' arsenals and argued that by "concentrating always on the near future" we had "ignored the long-term consequences of our actions" and "placed our civilization and our species in jeopardy."[2]

The Reagan Context

The announcement that a nuclear winter might occur came as a shock to the public. Many felt frustrated by the Reagan administration's apparent hostility toward the arms-control process and appalled by the ongoing arms buildup and the increasingly frigid Cold War. With respect to radioactivity, these critics were weary of US government inaction, indifference, and even misbehavior under the cloak of national security. "Atomic veterans," the American GIs who were commanded to sit in trenches near ground zero at the Nevada Test Site in the days before atmospheric testing was banned in 1963, sought compensation in federal court for the cancers they associated with that experience. "Downwind people"—civilian residents of communities such as St. George, Utah, who were deliberately told by the Atomic Energy Commission (AEC) that hazardous levels of radioactivity from the tests were "safe" and who, like the atomic veterans, experienced uncommon rates of cancer—also fought an unsympathetic government.[3]

Arms-control measures—particularly the Strategic Arms Limitation Treaty (SALT II), signed in 1979 by Presidents Jimmy Carter and Leonid Brezhnev, were derided as "fatally flawed" by the American political right.[4] With little chance of ratification in the Senate, Carter used the pretext of the USSR's invasion of Afghanistan to withdraw SALT II from consideration.[5] Not that the American left thought highly of a treaty that merely enshrined existing arsenals instead of reducing them. (There were roughly 10,000 strategic weapons in each superpower, plus perhaps 30,000 tactical weapons in both countries; the numbers held by the United Kingdom, France, China, Israel, and India were relatively insignificant.) But negotiations, it was broadly felt on the left, were preferable to escalating tensions. Now, for the first time in years, the US and the USSR had no discussions under way on controlling strategic nuclear weapons.

Thirty-eight years into the arms race, it seemed that problems were compounding instead of being solved. Many people clearly were frightened by the program for arms expansion and harsh rhetoric of President Ronald Reagan's administration. Half of the American public believed that Reagan was playing nuclear "chicken" with the USSR.[6] The *Bulletin of the Atomic Scientists* moved the hands of the "doomsday clock" on its cover closer to midnight. Liberals, who normally had nothing good to say about Richard Nixon, recalled favorably the détente he maintained with the USSR. Under Nixon, "sufficiency" in nuclear weapons replaced unattainable "superiority"—if indeed superiority had any real meaning.

But whether a valid concept or not, superiority seemed to be the goal of the Reagan administration. Secretary of State Alexander Haig spoke approvingly of firing a nuclear warning shot across the bow if the Soviet Union were to misbehave in Europe.[7] Secretary of Defense Caspar Weinberger sought to improve the nuclear-war-fighting capability of the United States in order to "prevail" in an encounter that, he felt, could be limited.[8] And the president, in word and deed, gave many people reason to debate whether he really subscribed to the inevitability of the Book of Revelation's "Armageddon prophecy."[9]

Just as the environmental movement was galvanized to action by the perceived determination of Secretary of the Interior James Watt to remove protection from natural resources, Reagan's view of national security energized the "Nuclear Freeze" movement and drove up the membership and contributor lists of numerous "peace" organizations. Not only general membership groups (e.g., the Committee for a Sane Nuclear Policy) but also associations with special expertise (among them the Union of Concerned Scientists, Physicians for Social Responsibility, and the Center for Defense Information) flourished.[10] Indeed, half of the American organizations that focused on peace, disarmament, defense, nuclear war, and weapons were founded during Reagan's first term.[11]

Jonathan Schell's enormously popular book *The Fate of the Earth* (1982) reflected public disenchantment with the casual attitude toward nuclear weapons displayed by government officials.[12] And such books and organizations fed and were fed by a growing popular recognition that nuclear war must not be fought, and that a limited nuclear conflict almost inevitably would escalate.[13] On television, the ABC network aired *The Day After*, a fictional account of a nuclear attack on Kansas. Hollywood produced the film *Testament*, a vision of the consequences of the destruction of San Francisco. It was during this turmoil that the concept of nuclear winter emerged.

Controversial nuclear issues abounded. These ranged from the US government's inability to find a transportation mode for the MX mobile intercontinental missile to the USSR's admittedly foolish and provocative placement of SS-20 mobile intermediate-range missiles in position to threaten Western Europe.[14] NATO's response was for the US to plant Pershing II ballistic missiles and ground-launched cruise missiles on European soil, where parts of the USSR were within their range. The Pershing IIs were regarded as especially destabilizing, since their flight times—and therefore the USSR's reaction times—were much less than those for intercontinental ballistic missiles. Hundreds of thousands of people rallied in European and American cities to oppose this escalation of the arms race.[15]

In 1981, when the retired American diplomat George F. Kennan suggested a 50 percent reduction in the strategic arsenals, his proposal was ridiculed as fanciful, but within a few years this idea became the basis of Strategic Arms Reduction Treaty negotiations, and START II achieved a two-thirds reduction.[16] In 1983, with the best of intentions and the worst of intelligence, Reagan advanced his concept of a Strategic Defense Initiative (SDI).[17] His desire to render nuclear weapons impotent and obsolete was commendable, but unfortunately it was impossible to achieve: ballistic-missile defense cannot be 100 percent effective, and the warheads that "leak" through will suffice to destroy the country.

Moreover, SDI (or "Star Wars," as it was popularly and derisively called) was not without its own problems. For example, it would be enormously expensive; the Soviets would respond to it by increasing the number of their ICBM warheads and/or building their own inadequate space shield, thus ratcheting up the arms race another notch; testing SDI components threatened to violate the agreement signed along with the 1972 SALT I Treaty, which limited anti-missile experimentation; and construction of SDI could be interpreted as provocative, for if the Soviet Union believed that the United States felt it was now safe from attack—and thus liable to be more belligerent in a crisis—it might attempt a preemptive strike.

In the early 1980s, political events and defense-policy controversies such as those recounted above set the stage for the whirl of science, military stonewalling, and public discourse that followed the announcement of the NW phenomenon to an American public that was rather sophisticated concerning nuclear weapons. Newspapers, newsmagazines, journals of opinion, radio, television, books of fiction and nonfiction, and films, in addition to the numerous "peace" organizations, had provided an enormous range of information about the arsenals, politics, and effects of these weapons of mass destruction. Since President Harry Truman's announcement of the atomic bombing of Hiroshima on 6 August 1945, few subjects had received as much media attention.[18] The high level of public "nuclear awareness" at the time of NW's debut did not, however, translate into a broad, vigorous, and sustained effort to change the superpowers' nuclear policies. The public did, nonetheless, observe a generally cordial and intelligent debate and a fine example of both the normal progress of science and the normal, though terribly haphazard, process of providing scientific advice to the government.

A Nuclear Winter's Tale focuses upon one of the effects of nuclear explosions: lowered temperature and illumination due to reduced sunlight. The development of nuclear arsenals and the history of nuclear weapons policies and politics are not major parts of this story and will be mentioned only in passing.[19] Among the effects of nuclear explosions, the best-known consequences are the immediate and relatively short-range ones (blast, heat, ionizing radiation)—but they are not central to the story. Nor are the societal factors of population loss and economic, industrial, political, social, and cultural devastation examined carefully in this study. Instead, attention is directed to long-range physical consequences to the environment.

Global Incineration

During the summer of 1942, J. Robert Oppenheimer, a theoretical physicist with appointments at both the University of California at Berkeley and the California Institute of Technology, headed a study group whose task was to investigate the construction of nuclear weapons (also termed fission weapons and, less accurately, atomic bombs). The United States was at war and feared that Germany would build such weapons first. The US government's commitment to build this novel explosive was not formalized until the Manhattan Project cranked up its operations in the fall of 1942, but many scientists had been studying the possibility of such a bomb since early 1939, when the discovery of nuclear fission was announced. The US government had been apprised of the prospect in a famous letter from Albert Einstein to President Franklin D. Roosevelt in that same year.[20]

Oppenheimer and his colleagues were most concerned with a bomb made of fissionable uranium, yet the alternative concept of energy released from the fusion of hydrogen isotopes was raised by Edward Teller, who had left Europe in 1935 for a post at George Washington University. Teller wondered if the atmosphere could be set afire by the high temperatures reached in such fusion reactions. In alarm, Oppenheimer traveled east to consult with Arthur Compton, the director of experimental and theoretical work on the bomb. Before Oppenheimer returned to Berkeley, Hans Bethe, another mid-1930s refugee from Europe, checked Teller's calculations and concluded that the atmosphere could not be ignited. Teller was reasonably well convinced.[21]

By late 1944, however, when the major design questions about the first fission bombs had been settled at the Los Alamos Laboratory, some theorists had broached the concept that the atmosphere might be ignited even by a fission detonation. A variety of nuclear reactions, mostly by nitrogen but also by hydrogen, oxygen, and carbon in the atmosphere, might be triggered by the explosion and propagate throughout the atmosphere. Or would the large amounts of energy be dissipated too fast for this to occur? The physicists Emil Konopinski, Cloyd Marvin, and Edward Teller examined the problem, using "worst-case" choices when precise values were not available, and concluded that "no ignition point exists," though they were deferential enough to the uncertainties of the calculation to recommend further investigation.[22]

A question as monumental as global incineration was bound to arise again, as indeed it did before the 1946 Crossroads series of bomb tests at Bikini Atoll, which included an underwater test. Concern was expressed that hydrogen in the sea would join in a global fusion reaction. And before the first fusion detonation (in 1952), additional studies were made, once more concluding that no self-propagating nuclear reaction in the atmosphere was possible.[23]

Radioactive Fallout

Decades after World War II, accidents at the civilian nuclear power plants at Three Mile Island in Pennsylvania (1979) and Chernobyl in the Ukraine (1986) drew renewed attention to the danger of radioactive fallout. None of the residents downwind of Three Mile Island died as a result of the incident there.[24] The Chernobyl accident was far more serious, with 31 immediate radiation fatalities, unofficial reports of 300 deaths, and an ultimate cost of $416 billion.[25] Furthermore, there was a much greater likelihood of future radiation-induced illness for the population ranging from the vicinity of Kiev northwest across the former Soviet Union and other European countries, and especially for the people of Poland and Scandinavia, where the radioactive clouds released significant amounts of their deadly cargo.[26]

Radioactive fallout was well known before these events, however. It was, indeed, a predicted consequence of a nuclear explosion. In March 1940, two physicists who had recently fled Nazism, Otto Frisch and Rudolf Peierls, presented to the British government calculations which suggested that an atomic bomb could be made within a few years.[27] It also was certainly on the minds of those who organized the test of the very first atomic bomb, at Alamogordo, New Mexico, on 16 July 1945. Plans were made to monitor the cloud of radioactive debris and to evacuate the few ranchers who lived downwind. The evacuation proved unnecessary, although a number of range cattle in the vicinity suffered skin burns.[28] More pertinent to our concern about long-distance effects, radioactivity from the test was washed out of the air by a rainstorm 1,000 miles away in Illinois. This was detected, and its origin was deduced, when Eastman Kodak found that its x-ray film was fogged by cardboard packing material produced in the midwest.[29] Detection at an even greater distance—2,700 miles—occurred in April 1953, when radioactive debris from an air burst at the Nevada test site was propelled across the continent by the jet stream. A rainstorm washed it out of the air above Troy, New York, where it set Geiger counters at the Rensselaer Polytechnic Institute clicking rapidly.[30]

In the early postwar years, all US nuclear explosions were conducted in the atmosphere (atop a tower or dropped from an airplane), either in Nevada or at the Pacific proving grounds. Little attention was given to radioactive particles transported long distances, because their effect was considered too small to be harmful. This does not mean too small to be usefully measured and analyzed, however; the detonation of the first Soviet atomic bomb, in August 1949, was detected from the radioactivity of high-altitude dust samples collected by specially equipped US aircraft.[31]

The American reaction to this Soviet accomplishment was to consider a "crash" program to develop a hydrogen fusion "superbomb." In a report dated 30 October 1949, the General Advisory Committee of the Atomic Energy Commission urged the commissioners *not* to grant fusion research extraordinary priority. Indeed, a majority of the GAC recommended that the United States unilaterally renounce such weapons. Of course, we know that President Truman listened to other counsel, but the interest for us in this long-secret report lies in one of the reasons advanced by James B. Conant, Hartley Rowe, Cyril Stanley Smith, Lee A. DuBridge, Oliver E. Buckley, and GAC chairman J. Robert Oppenheimer: "We are alarmed as to the possible global effects of the radioactivity generated by the explosion of a few super bombs of conceivable magnitude."[32] The potential for global phenomena was recognized.

Soviet scientists too developed hydrogen bombs, and they too were concerned about their potential effects. In March 1954, the scientific leader of the USSR's work on nuclear weapons from its inception, Igor Kurchatov, and three senior colleagues sent a classified report to V. A. Malyshev, Minister of Medium Machine Building (the nuclear weapons ministry). Malyshev forwarded it to Nikita Khrushchev, first secretary of the Central Committee of the Communist Party. The scientists argued that fusion weapons created a new and perilous situation. Not only would the combatants be destroyed, but radioactive materials, carried by the wind, would contaminate Earth's surface. Whereas life on Earth might be extinguished by the explosion of thousands of fission bombs, they wrote, it would take only about 100 fusion explosions to produce the same result.[33]

As these examples show, a few scientists and government officials were occasionally prodded to consider the possibility that nuclear weapons might have both long-range and long-term effects. Yet the public remained ignorant of such dangers until the mid 1950s. They were not warned by the 1950 Department of Defense and Atomic Energy Commission volume *The Effects of Atomic Weapons*, which surveyed the global circulation of Krakatoa's (1883) volcanic debris and the continental transport of both dust from storms and radioactive matter from the Alamogordo test. That report concluded that "in most circumstances the fall-out from an air burst will not be a serious radiological hazard," that fallout from a low air burst "might be an inconvenience, but it would not in general represent a real danger," and that, although contamination from a surface blast might be harmful, it would be localized. Worldwide, long-term effects were not predicted, because explosive yields were as yet too small to pump large amounts of radioactive particles high into the atmosphere.[34]

Samuel Glasstone's *The Effects of Nuclear Weapons*, successor to the above book and immediately (and to the present time) recognized as the "bible" on the subject, was published in 1957 with a separate chapter titled "World-Wide Fallout and Long-Term Residual Radiation." By then, thermonuclear weapons had been developed and tested. As before, larger pieces of debris would fall in the vicinity of the explosion. But now fine particles could be carried far by the wind. Their radioactivity would have the potential to cause long-term bodily harm, such as cancer, and also genetic effects, such as deformities, in succeeding generations. Nuclear explosions in the kiloton range (a kiloton, abbreviated KT, being equivalent to 1,000 tons of TNT) produce the characteristic mushroom-shaped cloud, which usually stays within the troposphere. This lower portion of the atmosphere, whose ceiling ranges from 30,000 to 50,000 feet, contains the weather. Rain and snow frequently are the means by which radioactive particles are carried to the surface. Hydrogen fusion explosions, which generally are in the megaton (MT, meaning equivalent to 1 million tons of TNT) range, pump nearly all the bomb debris into the stratosphere. There strong winds circulate the fine particles globally, and gravity is the primary cause of their slow descent. The longer these particles stay aloft, the less radioactive they are. But the long half-lives of the most biologically dangerous isotopes—cesium-137 (30 years) and strontium-90 (28.5 years)—mean that they will be harmful even after a delayed return to the surface.[35]

In the United States, in Japan, in Western Europe, and even in the developing nations, this information became the subject of heated debate after the "Bravo" test at Bikini Atoll on 1 March 1954. This was the detonation of a 15-MT fusion device (not yet a deliverable weapon), the largest man-made explosion yet. Unanticipated winds caused lethal doses of radioactive ash to fall on Rongelap Atoll, 100 miles away, and forced the unscheduled evacuation of the islanders. Ash also fell on the open sea, where a Japanese fishing boat, the *Lucky Dragon*, lay outside the published danger zone. Crew members experienced varying degrees of radiation sickness, one death occurred, and the boat's catch was found to be radioactive upon its return to Japan.[36]

The global reach of fallout became more apparent over the next few years as both the US and the USSR built and tested hydrogen bombs. During the 1950s, the two superpowers conducted 222 announced nuclear explosions (both fission and fusion), only 18 of them underground or underwater.[37] More and more often, newspapers reported that scientists in one community or another had detected unusual levels of radioactivity in surface water, or milk, or children's teeth.[38]

In the 1956 presidential campaign, Democratic candidate Adlai Stevenson spoke out against atmospheric testing. Around the same time, the chemist Linus Pauling became a leading advocate for an end to nuclear explosions; he was both accused of Communist support by the Senate Internal Security Subcommittee and awarded the Nobel Peace Prize.[39] Groups were formed to oppose radioactive "contamination without representation." These included the Committee for a Sane Nuclear Policy in the United States and the Campaign for Nuclear Disarmament in Great Britain.[40] This public protest led first to a moratorium on testing (in 1958), then (in 1963) to the Limited Test Ban Treaty, which prohibited nuclear explosions in the atmosphere, under water, and in space, but allowed them underground.[41] Out of sight meant out of mind. Although the pace of nuclear weapon testing actually increased when the superpowers took it underground,[42] and the arms race was not hampered, global levels of fallout decreased, and the dangers of radioactivity ceased to be a prominent public issue.

Electromagnetic Pulse

In Hawaii, on the evening of 8 July 1962, many street lights and power lines suddenly failed, and burglar alarms began to ring. The atmospheric testing moratorium of 1958 had ended, and the subsequent "gentleman's agreement" not to test had been violated by the USSR in 1961, followed by resumption of the US program. Hawaiians had grounds to suspect a connection between their curious experience and the detonation of a 1.4-MT hydrogen bomb that had been fired 248 miles into space atop a Thor rocket, but the mechanism baffled scientists. More than a year later, they had an answer. The rocket had been launched from Johnston Island, about 800 miles southwest of Honolulu. Gamma rays from the explosion had stripped electrons from air molecules in the upper atmosphere, and these electrons had moved in conformity with Earth's magnetic field, creating an electromagnetic pulse (EMP) with a range of hundreds or even thousands of miles.[43]

EMP may be compared roughly with the electromagnetic fields generated in the vicinity of a lightning stroke. But while lightning may merely cause static in radio receivers, EMP would likely burn out radios connected to long antennas. The potential of a high-altitude nuclear explosion to destroy electronic equipment operating on AM, short-wave, VHF, and UHF frequencies came as a shock. If these communication links were impaired, battle management would be impossible.[44]

In addition to the disruption of coast-to-coast communications, EMP would, as one writer put it, perform "an electromagnetic lobotomy on computer memories."[45] Unfortunately, this could be accomplished easily. A single warhead exploded 200 miles over Nebraska would bathe all of the contiguous United States in a powerful and disabling EMP. The reason this phenomenon had not been detected earlier was that most of the electronic equipment used during the 1950s contained vacuum tubes. By the early 1960s, the semiconductor revolution was well under way, leading to miniaturized electronics, microscopic circuitry, and tiny chips in both military and civilian equipment. Unhappily, this new solid-state technology was 10 million times as vulnerable to EMP as vacuum-tube devices.[46]

When the Safeguard anti-ballistic-missile site at Grand Forks, North Dakota, went operational in April 1975, there were fears that detonation of one of its Spartan interceptors about 150 miles above the United States would destroy not only the hostile incoming reentry vehicle but also communication and power equipment across the country. In another scenario, defense planners contemplated a president unable to issue emergency messages, regardless of the 43 or more different ways available to the commander-in-chief to communicate. Not only war-fighting, but war-termination orders could be casualties of an EMP-induced loss of electronic command, control, communications, and intelligence (C^3I) functions. Since then, millions if not billions of dollars have been spent on hardening electronic equipment. An EMP simulator, with a B-52 bomber sitting atop a twelve-story-high wooden scaffold, has been built at Kirtland Air Force Base in Albuquerque to test the shielding of aircraft electronics. And EMP-resistant fiber optics are increasingly employed for communications. Still, one cannot be confident that catastrophic failure of computers and communication due to EMP can be avoided. Though EMP occurs only at the time of a high-altitude nuclear explosion and thus is not long-term, it does qualify as long-range, and its unanticipated occurrence justifies its inclusion in this focused survey of nuclear weapons' effects.[47]

Ozone Depletion

Ozone, a molecule consisting of three oxygen atoms (O_3), was a novelty at the end of the nineteenth century. People went to the seashore to "take in the ozone." In 1894, to entice enthusiasts of this "health" craze, a "penny-in-the-slot galvanic battery" was installed on the new pier in Brighton, England.[48] Scientifically, ozone has been known since 1930 or earlier to engage in chemical reactions in the upper atmosphere, where it is formed by the action of sunlight on ordinary molecules of oxygen (O_2).[49] Although it is only a trace gas—no more than 10 parts by volume per million parts of air—its existence in the stratosphere is crucial because it acts as a natural sunscreen, blocking most of the solar ultraviolet (UV) radiation heading for Earth's surface. (In the troposphere, where it contributes to smog, ozone is harmful.)[50]

If all the stratospheric ozone were brought to Earth's surface, atmospheric pressure would squeeze it into a film only 3 millimeters thick.[51] Yet without ozone's filtering action in the stratosphere, humans would experience an increase in skin cancer and agriculture would be seriously affected. Indeed, it is believed that life on Earth's surface had to await the buildup of ozone that occurred during the Pre-Cambrian period. Ozone decomposes when it interacts with UV radiation and with various trace chemicals in the atmosphere. In addition, ozone's formation and removal involve heat changes in the stratosphere, and these variations affect atmospheric circulation. More will be said in chapter 3 about other hazards to the ozone layer; here it is appropriate to discuss the threat caused by nuclear explosions.[52]

For each megaton of explosive yield, the fireball of an air burst creates about 10^{32} molecules of nitrogen oxides. The fireball of a megaton-size warhead rises into the stratosphere, where about 90 percent of atmospheric ozone resides.[53] Thus, these nitrogen compounds, which are prodigious catalysts for the consumption of ozone, are placed where they can do the most damage.[54]

In 1970, attention was called to the connection between nitrogen oxides and ozone photochemistry by Paul Crutzen, a Dutch atmospheric chemist. Crutzen was a European Space Research Organization postdoctoral fellow at Oxford University's famous Clarendon Physics Laboratory.[55] He found that nitrogen oxide combined with ozone to form nitrogen dioxide and ordinary molecular oxygen ($NO + O_3 \rightarrow NO_2 + O_2$). The nitrogen dioxide then combined with monatomic oxygen to re-create the ozone-destroying nitrogen oxide and more molecular oxygen ($NO_2 + O \rightarrow NO + O_2$). In these reactions, the NO was recycled.

Where did the monatomic oxygen come from? It was produced in the ordinary photochemical reaction of light energy with ozone (O_3 + energy $\rightarrow O + O_2$). The ozone layer apparently was far more vulnerable to chemical attack than anyone had believed. However, it was not nuclear explosions but the effect of exhaust from supersonic transport (SST) aircraft on the ozone that lay behind this interest in the "chemosphere" in the early 1970s. In 1971, also with the SST as a stimulus, Harold Johnston, a chemist at the University of California's Berkeley campus, showed that nitrogen oxides were indeed a threat to stratospheric ozone, far more so in fact than the widely feared water in SST exhaust.[56] Two years later, Henry Foley and Malvin Ruderman, both of Columbia University's physics department, made the connection between nuclear explosions and ozone depletion by nitrogen oxides. Yet their imaginative examination of surface ozone measurements, recorded at a global network of meteorological stations, showed no rapid changes during the hectic period of atmospheric testing just before the 1963 Limited Test Ban Treaty.[57] Only 2 months after this paper was published, however, Harold Johnston described his longer-time-span study, which extracted a real effect from the background noise. There was, he claimed, a 5 percent increase in ozone over the period 1963–1970, which could be attributed to the atmosphere's recovery following the test ban.[58] The rapidity with which work on this "hot" topic was published was repeated with the NW phenomenon. Also similar were several of the personnel involved, for the subject remained atmospheric chemistry to them. Johnston shared the authorship of his paper with two other scientists, one of whom (John W. Birks) would join with Paul Crutzen a decade later to set the problem that resulted in the conceptualization of NW.

To John Hampson, nuclear explosions were a potential "photochemical war on the atmosphere." Hampson, at Laval University in Quebec, speculated in 1974 that the amount of explosive energy needed to degrade the atmosphere might be much less than already existed in the arsenals maintained for purposes of deterrence. If this was true, he suggested, the knowledge "could be used as a lever to cajole the nuclear powers to move towards a more positive view of the need for arms control."[59]

As if in response to Hampson's call, investigations did occur. At the Lawrence Livermore Laboratory in California (now the Lawrence Livermore National Laboratory, or LLNL; it and Los Alamos are the nation's only nuclear weapons design facilities), Michael MacCracken and Julius Chang used a one-dimensional computer model of the stratosphere to examine chemical and photochemical reactions and the movement of matter vertically. They concluded in 1975 that past atmospheric nuclear testing could have caused an ozone reduction of no more than a few percent, an amount almost indiscernible against normal variations. But a large war might deplete 25–50 percent of the global ozone, and even incomplete recovery would take several years.[60]

Throughout their report, MacCracken and Chang emphasized the tentative nature of their findings, for their model was only an approximation of three-dimensional reality. Models of two and three dimensions would involve an enormous increase in complexity, and would still rarely match the richness of nature's intricacies and feedback mechanisms. Models, further, are constructed to describe "normal" processes of nature. The sudden injection into the stratosphere of nitrogen oxides from a 10,000-MT war, MacCracken and Chang observed, pushed their model to the limit of credibility. Although the chemistry would be reasonably represented, the validity of vertical transport was not clear. Such reservations are characteristic of an advancing science, and uncertainty is not cause for embarrassment. The research front is a place of constant change, as scientists build on the work of their colleagues and competitors, sometimes incorporating previous concepts and sometimes rejecting them. Similar concerns about models would be expressed when NW was studied.

While these Livermore scientists were occupied with the ozone problem, the director of the US Arms Control and Disarmament Agency (ACDA), Fred Iklé, grew concerned enough to commission a study by the National Academy of Sciences (NAS) published as *Long-Term Worldwide Effects of Multiple Nuclear-Weapons Detonations* (1975).[61] As is true of most NAS investigations, the procedure was not to undertake new experiments but to review the existing literature. The panel examined the consequences of a 10,000-MT exchange of nuclear weapons and concentrated on long-term worldwide effects.

Ozone depletion was the new actor in this drama. While admitting the uncertainties of the simplified model, the panel concluded that the concentration of stratospheric ozone might be reduced in the Northern Hemisphere by 30–70 percent. Natural processes would restore about 60 percent of this within 2–4 years, and most of the rest within 10–20 years. Ultraviolet damage to crops, micro-organisms, animals, and humans in the interim would likely be severe, but extinction—particularly in the nations not involved in the fighting—was unlikely.[62] Still, ozone depletion added a dimension of self-deterrence to nuclear strategy. Here was a phenomenon that could kick back at the aggressor. Within 10 years, the same concept would appear in the form of NW.

Climate Change

In the first edition of *The Effects of Nuclear Weapons* (1957), the physicist Samuel Glasstone examined speculation about weather changes caused by huge fusion reactions and concluded that they were not likely. The energy released, the quantity of debris injected into the atmosphere, and the intensity of the ionizing particles all were, he felt, not enough to affect the weather, let alone its more persistent manifestation, climate.[63] The question did not die, however, and in succeeding years a number of people returned to it.

In a popular book titled *Nuclear Disaster* (1964), Tom Stonier, a plant physiologist at Manhattan College, argued that, although radioactive fallout could inflict a great ecological catastrophe, it could not change the climate. Other debris injected into the atmosphere from explosions, however, did have the potential to do this. Indeed, in the extreme, Stonier forecast another ice age. Dust particles would serve as nuclei for water droplets, wringing more rain and snow from the sky, and cooling would come about as atmospheric dust prevented sunlight from reaching Earth. Stonier provided calculations of the amount of soil lofted by a 20-MT surface burst, and gathered data about temperature reductions due to both volcanic dust and forest fire smoke. Yet Stonier's circumstantial case was at bottom "hand-waving" (gesturing rather than proving).[64] He lacked much scientific information that would become available in the next two decades, such as the relationship between volcanic dust and solar radiation. In this period before the widespread use of computers, Stonier understandably could not even conceive of an interactive global circulation model.

Increasingly during the early 1970s, fear was expressed that a major nuclear war could alter the climate. "Major" meant somewhere around 10,000 MT of explosive yield, an amount about half the size of the superpowers' strategic arsenals. The novelty of the heightened concern lay in the emphasis on chemistry, physics, and computer modeling. Research was expanded. Current understanding was recognized as inadequate for many photochemical reactions, the circulation of particles, and the effects of large energy changes in the stratosphere. So-called defense intellectuals had calculated war scenarios on the basis of population, cities, or industry destroyed. Should the prime consideration now be chemical reactions initiated by sunlight?[65]

Research is not accomplished overnight, and informed conjecture continued to fill the information vacuum. The Stanford University biologists Paul and Anne Ehrlich maintained the tradition of speculation in their popular textbook *Population, Resources, Environment: Issues in Human Ecology* (1970). They pointed to explosive dust injections and smoke from huge fires as potential engines of regional and global climate change.[66] For the third edition, they added the UC Berkeley physicist John Holdren as a co-author, changed the title to *Ecoscience: Population, Resources, Environment* (1977), and adopted the then-novel phenomenon of ozone depletion as another important agent of change.[67] Increased photochemical activity involving the ozone molecule would store in the stratosphere solar energy that otherwise would heat the troposphere and the ground. Although the authors contributed nothing new to the scientific understanding of climate alteration (had they done so in a textbook, it would have been surprising), they certainly popularized the concept. In 1983, the Ehrlichs would be among the several authors of a paper on biological effects that was a companion to the sensational new report on the possible physical effects of nuclear war.

Another scientist who speculated about climate changes in this early period, and later was a prominent participant in the research and debate about NW, was Stephen Schneider, a climatologist at the National Center for Atmospheric Research in Boulder. While explicit that the data were still soft, in a book titled *The Genesis Strategy: Climate and Global Survival* (1976) he suggested that ozone depletion and dust injections into the stratosphere might cause Earth's surface to cool from a fraction of a degree to a few degrees Celsius. He thus echoed the now widespread recognition that this was a topic in need of greater attention. Schneider largely discounted the possibility of a new ice age, arguing that "the estimated changes in stratospheric composition were not anticipated to persist more than a decade or so."

One of the most interesting features of Schneider's commentary was his discussion of the climatic effects of industrialization, farming, deforestation, and other human activities. For example, it could well be assumed that after a nuclear war agriculture in the Northern Hemisphere would be severely disrupted. Fields that once were plowed would lie fallow, and the new, wild vegetation would have a different surface albedo (the fraction of sunlight that is reflected) and changed moisture-holding characteristics. Similarly, decreased deforestation and industrial activity would presumably lower the amount of dust in the atmosphere. Schneider's point was that changes in human social patterns could have climatic consequences just as real as those from the physical and chemical effects of nuclear explosions.[68] These "social assumptions" were excised from Schneider's contribution to the 1975 NAS study mentioned above. Hewing more closely to "fact," that report acknowledged that global temperatures might decline as much as several degrees, with disastrous consequences for agriculture. On the other hand, only negligible cooling or even a slight warming was also possible. The temperature decrease could result from the absorption, reflection, and scattering by dust of direct sunlight or light reflected from Earth. Ozone depletion could lead to a more significant effect, due to an altered pattern of stratospheric heating. This, in turn, would affect the tropospheric thermal structure, with a noticeable change in climate. But current understanding of climatological phenomena simply was inadequate to predict such effects with confidence. "They would probably lie within normal global climatic variability," the chair of the NAS panel, Alfred Nier, wrote, "but the possibility of climatic changes of a more dramatic nature cannot be ruled out."[69]

A final example of the assertion of widespread climate change appeared in a 1979 article by Kevin Lewis, a graduate student in political science at the Massachusetts Institute of Technology. It was published in *Scientific American*, a periodical known for its frequent stories on technical aspects of the arms race. In an excellent review titled "The prompt and delayed effects of nuclear war," Lewis, who had gained his expertise as a member of the congressional Office of Technology Assessment staff that composed *The Effects of Nuclear War* (1979), discussed urban firestorms, but only as a local phenomenon. Continental weather changes, however, appeared in his survey in connection with the burning of huge forests and grasslands in the US and the USSR. The resulting transfiguration in ground cover would alter the albedo of Earth's surface, a point also made by Stonier and Schneider. Additionally, Lewis said, the pall of smoke would obscure sunlight, while moisture would condense around particulate matter to increase cloud cover and precipitation.[70]

We see in these examples attempts to predict certain climatic consequences of nuclear war. They look to the obscuration of sunlight as the main mechanism, with ozone depletion and the altered reflection of sunlight, be it by abandoned farm land or scorched earth, as additional paths. That they failed to make many converts was not because they were unreasonable, but because they were more metaphor than science. The technical data and the comprehension of atmospheric processes were yet too unsophisticated. But this process by which new knowledge is generated is not by any means a true-or-false activity. The construction of experiments, the interpretation of data, and especially the forecast of complex phenomena carry with them a large dash of personal art, which is the spice of science. What is it, then, that determines when information convincingly supports predictions?

Summary

In this chapter I have surveyed a number of the effects of nuclear weapons. They were unanticipated before being detected (EMP, ozone depletion), initially known only in the local manifestation (fallout), postulated and then discounted (global incineration), and forecast but only in insufficiently quantitative terms (climate change). Seemingly a disparate assortment, they are nonetheless linked by the geographical extent of their consequences.

In a speech to the Chicago Council on Foreign Relations in 1975, Richard Nixon's ACDA director, Fred Iklé, expressed his awe about the discovery of ozone depletion in nuclear fireballs: "The more we know, the more we know how little we know." Surveying the other past surprises, he added: "Each of these discoveries tore a hole in the facile assumptions that screened the reality of nuclear war. Each brought a new glimpse into the cauldron of horrors. What unexpected discovery will be next?"[71]

Department of Defense spokesmen regarded this uncertainty as not necessarily bad, for it would deter a rational adversary from potential suicide. Secretary of Defense James Schlesinger, for example, when asked by the Senate Committee on Foreign Relations about Iklé's "cauldron of horrors," was sanguine about the predictability and controllability of nuclear war. He admitted that future discoveries might change attitudes, and hoped that merely one nuclear device would deter even the most irrational opponent. In the meanwhile, however, the United States must maintain great strength and flexibility.[72]

Schlesinger's remarks were condemned by the physicist J. Carson Mark, the long-time head of the Los Alamos Laboratory's Theoretical Division, as an example of the "stultifying effects of nuclear weapons on official thought." If currently known explosion effects are not awesome enough to stop plans for nuclear warfare, the experienced bomb designer asked, can we expect our leaders to possess any sensitivity to additional effects?[73] Several years earlier, the Soviet Union's most famous bomb designer, Andrei Sakharov, came to similar conclusions about the madness of believing that a nuclear war could be fought and "won."[74] Such concern in both superpowers was appropriate. In the United States, for example, the Department of Defense continued to believe that a full range of nuclear war options in the hands of the president was essential to deterrence.

Nearly a decade later, when the NW concept was postulated, Reagan administration officials would seek to employ it as justification for an arms buildup. Politicians and bureaucrats had learned little in the interim. But science progressed inexorably, and a new phenomenon was on the horizon. Much work had still to be accomplished, and the fortunate interaction of several scientific fields had to occur. Then NW would rise from the computer printout, and another powerful voice against nuclear warfare would emerge.