

Arming Mother Nature

*The Birth of Catastrophic
Environmentalism*

JACOB DARWIN HAMBLIN

U.S.C.
Von KleinSmid
Library

OXFORD
UNIVERSITY PRESS

Contents

<i>Acknowledgments</i>	ix
------------------------	----

Introduction: Total War and Catastrophic Environmentalism	3
---	---

PART ONE: Pathways of Nature

1. The Natural Vulnerability of Civilizations	17
2. Bacteria, Radiation, and Crop Destruction in War Planning	37
3. Ecological Invasions and Convulsions	56

PART TWO: Forces of Nature

4. Earth under Surveillance	85
5. Acts of God and Acts of Man	108
6. Wildcat Ideas for Environmental Warfare	129

PART THREE: Gatekeepers of Nature

7. The Doomsday Men	151
8. Vietnam and the Seeds of Destruction	179

9. The Terroristic Science of Environmental Modification	197
10. Adjustment or Extinction	217
Conclusion: The Miracle of Survival	243
<i>Notes</i>	253
<i>Index</i>	287

Wildcat Ideas for Environmental Warfare

This kind of warfare has the peculiarity that it could look like our image of nuclear war, or could be so subtle that the "weapons" and "battles" are hard to identify.

—Weapons Group, NATO Von Kármán Committee (1961)

As one who has witnessed the horror and the lingering sadness of war, as one who knows that another war could utterly destroy this civilization which has been so slowly and painfully built over thousands of years, I wish I could say tonight that a lasting peace is in sight.

—PRESIDENT DWIGHT EISENHOWER, in his farewell speech, January 17, 1961

THE YEARS BETWEEN the first hydrogen bomb tests and the Limited Test Ban Treaty in 1963 saw more than just increased anxiety about the effects of nuclear testing on weather. They also saw increased interest in large-scale, purposeful environmental modification. Most climate modification enthusiasts spoke of increasing global temperatures, in the hopes that this would increase the quantity of cultivated land and make for fairer weather. Some suggested blackening deserts or snowy areas, to increase absorption of radiation. Covering large areas with carbon dust, so the theory went, would raise temperatures. Alternatively, if several hydrogen bombs were exploded underwater, they might evaporate seawater and create an ice cloud that would block the escape of radiation. Meteorologist Harry Wexler had little patience for those who wanted to add weather and climate modification to the set of tools in man's possession. But by 1958 even he acknowledged that serious proposals for massive changes, using nuclear weapons as tools, were inevitable. Like most professional meteorologists,

in the past he had dismissed the idea that hydrogen bombs had affected the weather. But with the prospect of determined experiments designed to bring about such changes, he warned of "the unhappy situation of the cure being worse than the ailment."¹

Whatever one might have thought about the wisdom of tinkering with the weather in peacetime, the manipulation of nature on a vast scale for military purposes seemed to be a perfectly legitimate application of scientific knowledge. While planning a total war against the Soviet Union, every avenue begged for exploration. This chapter explores how the scientific advisors of America's key allies in NATO saw the alliance fighting in the future. Numerous ideas for creating catastrophic events through natural processes were presented, especially using hydrogen bombs as triggers. In these discussions, held as early as 1960, top scientists debated the fundamental environmental question—can humans have a long-term effect on the global environment?

The desire for novel military technology seemed especially urgent by the early 1960s. Although officially part of the International Geophysical Year, the Soviet Union's launch of Sputnik in October 1957 had clear military ramifications. Not only did it begin the space race but it also took the arms race to a new stage that included communications satellites and intercontinental ballistic missiles. The launch of Sputnik made the world seem smaller and made the most far-fetched visions of the future seem possible. The gee-whiz, Buck Rogers feel of the immediate postwar years returned. But this wave of technological enthusiasm was darker, because instead of coming on the tide of a war victory, it came as a foreboding new competition. For years the Americans had been preparing for the missile age, gathering data on the atmosphere and on the earth's gravity over the poles. The Soviets clearly had kept the pace. Sputnik served as a justification for a vast array of projects to use scientific knowledge to tamper with nature on a large scale.

Reinforcing the sense of urgency, President Eisenhower's special committee on weather modification submitted its final report in January 1958, just months after Sputnik's launch. The committee's chairman, retired Navy Captain Howard T. Orville, said at a press conference that he suspected that the Soviets already had begun a large, secret program on weather control. Despite routine dismissals of the idea throughout the decade by meteorologists, the high-level committee ranked weather control ahead of hydrogen bombs and satellites in military significance. Orville urged the government to support research on controlling large-scale

weather systems, not just rainmaking. He further suggested that finding ways to manipulate the heat balance between the sun and earth might be the key to weather and climate control. The earth already had been heated up by man's efforts, by introducing carbon dioxide into the atmosphere through the burning of fossil fuels. This carbon dioxide helped to trap the heat and create, as the *New York Times* put it, a "greenhouse effect." It might be possible to harness this greenhouse effect. "If such steps are feasible," journalist John Finney reported, "then New York City might be put under a few hundred feet of ice or a few hundred feet of water depending on whether the temperature was raised or lowered."²

Rumors spread quickly about scientists in the United States and Soviet Union experimenting with unprecedented tools for controlling nature. Were the Soviets planning to dam the Bering Strait? Were the Americans able to steer storms? Naysayers pointed out that meteorologists could not even predict naturally occurring weather, so how could anyone control it? One author opined in the *New York Times*, "For would it not be foolish for anyone to talk of controlling an intricate piece of apparatus until he knew precisely how it worked?"³ After the report of Eisenhower's special committee was made public, scientists in allied countries received strange, sheepish letters from their defense establishments, asking if the latest rumors about American research could be true. For example, a British Air Ministry scientific advisor, E. V. Truefitt, presented his countryman, oceanographer George Deacon, with "one or two questions which have come up in odd conversations." He called them "wild cat" ideas that he did not really take seriously, yet they appeared to be in discussion in the United States. Despite his instinct that they could not possibly be real, he felt obligated to run them by a competent man of science.

One of the ideas was to melt the polar ice cap by exploding nuclear weapons on it, thus raising the global sea level. The Soviets might be considering it, so the rumor went, to drown cities in the United States and Western Europe. Another idea was to change ocean currents or temperatures to interfere with an enemy's climate and food production. Truefitt had no idea how assess an ocean-initiated climate change, but he had made a rough calculation to determine what was needed to melt the polar ice cap. He believed that it would take about a million tons of fissile material to melt enough to raise sea level by 30 feet. "This is a large amount of fissile material whichever way you look at it," he wrote to Deacon, "and consequently my guess is that it is not the kind of project that even the Americans would embark on under the influence of Sputniks."⁴

The truth was that the immediate post-Sputnik years had a peculiar air, both of desperation and of opportunity. Doors were wide open to a range of technological possibilities. Nearly anything that was technically feasible made it to the highest levels of discussion. For starters, that meant revisiting the questions surrounding biological, chemical, and radiological weapons. But it also sparked discussion of the ambitious, the horrendous, and the quirky. Like wildcatters exploring for oil, American scientists grasped desperately around them, striving to find the next weapon of the future.

There were several post-Sputnik efforts to push the limits of the "possible," to explore exotic ideas that might prove decisive 5, 10, or 20 years into the future. Some actions to direct this scientific work were high profile and public. President Eisenhower created a science advisory committee to guide the course of American technology and ensure that the Americans did not fall behind the Soviet Union. This President's Science Advisory Committee (PSAC) also existed to rein in some of the wilder ideas, to avoid wasteful spending.⁵ Other brain trusts, often dominated by physicists with expertise in nuclear affairs, sprang up behind closed doors to advise military establishments. One of these was "JASON," an elite group of scientists who got together during the summer months to assess major scientific and technological problems of military significance. Paid by government contract through several different bodies throughout its existence, "the Jasons," as they called themselves, were drawn from the cream of civilian academic science. Despite their outsider status, the Jasons gained the respect and trust of officials in the Defense Department and the armed services, and their advice often revolutionized military thinking during the nuclear era.⁶

Sputnik did not just spark new scientific projects, however. It also revolutionized military strategy, making it grimmer than ever. The American and Soviet air forces realized they were going to have to rethink the basic notion of national vulnerability. No longer could the Air Force's Strategic Air Command count on scrambling bombers and flying them over the North Pole. Most of the war's damage would have been done before bombers left the Western Hemisphere.

More than that, as a secret National Academy of Sciences group advised the Air Force in 1958, the range of possible wars soon would expand exponentially. Conflicts were going to become both more total and more limited at the same time. On the one hand, the United States was losing its ability to incapacitate enemy forces. In practice that meant that the most attractive targets all over the world would be centers of population—cities—rather than armies or airfields. Making an effective attack against enemy military

forces seemed a dwindling prospect in an era when missiles could be put into hardened silos, mobile rocket units, or submarines patrolling the oceans. Cities, by contrast, would be ripe for plucking. "Weapon yields, delivery accuracies, and force level requirements for city destruction are modest," these scientists concluded, while attacking heavily fortified bunkers would require large and accurate payloads. That meant that finding ways of maximizing civilian death would assume an even greater importance than it already had.⁷

On the other hand, nuclear parity would make full-blown conflict less likely, meaning that all of the armed services would have to reorient themselves back to conventional warfare. As RAND Corporation game theorists had long feared, the atomic bomb was a wasting asset—and the window of opportunity to "win" decisively in a war against the Soviet Union had passed. By the late 1950s, the new orthodoxy in strategic thinking accepted that the Soviet Union was committed to avoiding a nuclear holocaust and that it intended to encourage "brushfire" wars instead. Small wars like those in Malaya and Korea would become more common. As the 1960s dawned, military strategists wondered about the fate of Vietnam, which the French had failed to hold. By treaty the country had split between North and South. Should the communist North Vietnamese invade, would the Americans consider using nuclear weapons? Some may have argued that nuclear bombs were America's answer to the human population imbalance against, say, people in China or Southeast Asia. But new studies at RAND had dismissed this possibility, showing that nuclear weapons would be ineffective against guerrilla forces in Southeast Asia and would visit enormous collateral damage upon friendly population centers. So the military would need to let go of President Eisenhower's preferred strategy of massive retaliation as America's basic posture.⁸

The Air Force would have to stop relying on aircraft designed purely to deliver nuclear weapons. Instead, it would need to find ways of fighting men, tanks, rockets, and airplanes—all without nuclear weapons. A decade earlier the Navy had bitterly opposed the Air Force's claims that the era of aircraft carriers and battleships had ended. Now it seemed that the Navy had been right. The new conventional wisdom, which President Kennedy (a former Navy man) soon would establish as the doctrine of "flexible response," was that the nations with the greatest range, flexibility, and cleverness in weapons systems would stand strongest. This meant conducting research on weapons at various levels of destruction up to and including nuclear bombs and being creative about their uses.⁹

It also meant combining modes of warfare across scientific disciplines. Geophysical and biological knowledge might be united, for example, in developing dispersal mechanisms for pathogens. In trying to achieve large area coverage, one might fall back on cloud-seeding techniques—with the important difference that the “seeds” would not be silver iodide to cause rain but pathogens to spread disease far and wide. For example, certain phenomena in air masses, such as “Polar Outbreaks” (thrusts of cold air from the poles toward the equator), seemed to have great potential for such seeding, especially given the Soviet Union’s meteorological vulnerability from the north.¹⁰

The post-Sputnik national pall of gloom encouraged American scientists to explore unorthodox weapons, and they left no stone unturned. The US military forged ahead with research on weapons using radiation, particle beams, nuclear energy, and kinetic energy. The Army Chemical Corps even investigated the use of lysergic acid diethylamide (LSD) and cannabis as non-lethal, incapacitating agents. The National Academy of Sciences noted this approvingly in 1958 and suggested that the Air Force begin administering LSD to airmen as soon as possible, to judge whether to add it to the arsenal of chemical weapons.¹¹

With so many wide-ranging ideas being vetted, NATO allies worried that the Americans were moving in too many directions at once. It was fine to support science in the United States and to speak grandly about possibly controlling forces of nature—but which ideas could be incorporated into actual NATO war plans? In 1960 NATO members agreed to convene a special group of scientists and military leaders to assess the long-term prospects of war. They wanted to know what would really be feasible by the 1970s, and what was just science fiction.

This kind of science forecasting was not just a matter of intelligent people guessing the future. By 1960 it had a distinguished history of shaping policy, particularly in some parts of the American military establishment. The Air Force, for example, understood in the 1950s that much of its strength relied on continuous research and development (R&D). Toward the end of World War II, General Henry “Hap” Arnold, commander of the then-Army Air Force, famously said that “for twenty years the Air Force was built around pilots, pilots, and more pilots. . . . The next twenty years is going to be built around scientists.”¹² Throughout the Cold War, such brain trusts—in think tanks like RAND, secret groups like JASON, and many others—exercised a remarkable influence on policies.

When NATO tried, in 1960, to estimate the next 10 to 15 years of weapons, it enlisted the leadership of Theodore von Kármán, the grand old man of science forecasting. By then he was 79 years old. Born in Hungary, von Kármán had been one of the world’s foremost experts in aerodynamics. He even had helped the Austrian military design aircraft during the First World War. In 1929 he came to the United States to head up an aeronautical laboratory at Caltech, helping to kick-start the aviation industry in southern California. Acting as scientific advisor to United States air forces during World War II, von Kármán had initiated a long-term study of air power that amassed some of the best brains in physics and aeronautics. The resultant report, *Where We Stand*, became a road map for postwar air power research. In subsequent years, von Kármán repeated this process with other studies, and in fact he chaired the 1958 secret committee advising the Air Force, under the auspices of the National Academy of Sciences. In 1960 he embarked on a study that would be the capstone of his long career: NATO’s attempt to grasp the future face of battle over the entire earth.¹³

Known simply as the Von Kármán Committee, the new group included the chief scientific advisor of each national defense organization in the United States, Britain, Canada, France, and West Germany.¹⁴ With several working groups of scientists under them, they ran the gamut of new weapons in an era of “total war.” They included the typical range of military subjects, including aircraft, weaponry, and ships. But they also delved deeply into the implications of the global physical environment, particularly in light of the extraordinary size of thermonuclear weapons, the global reach of ballistic missiles, and the extent of global monitoring begun during the International Geophysical Year.

The buzzword of the IGY had been “synoptic.” Taken literally, it meant observing more than one place at the same time—viewing together. The IGY’s concept was to take a huge number of observations, spread out over a variety of geophysical disciplines and geographic areas, all within an 18-month period. Doing so would provide a portrait of the earth that was more true and comprehensive than anything ever attempted.

The Von Kármán Committee adopted the word “synoptic” too, but applied it to weapons. Weapons of a “synoptic scale” meant control and domination of whole physical systems. In military shorthand, the word synoptic called to mind vastness, encompassing large portions of the earth—or perhaps all of it. The IGY had brought this idea into military planners’ field of vision. But while the IGY was concerned with synoptic-scale measurement, NATO was concerned with synoptic-scale manipulation.

Once they began to meet, the members of the Von Kármán Committee realized that they all agreed on at least one thing: the global observations initiated in the IGY would have to continue indefinitely. The geophysical factors of modern war involved knowledge of an operational environment—in other words, how would the sea, land, or air affect troops and ships? NATO forces needed to be able to operate in any kind of environment. If it was on planet Earth, NATO should be prepared to fight there and win.

In fact the US armed services already were developing environment-specific training centers to give American forces mastery of three classes of extreme conditions: polar, desert, and jungle. Given that the northern polar region was "the only large uncommitted area lying between the world's strongest antagonists," polar operations weighed heavily on defense planners' minds. Already polar and Arctic training centers existed at locations in Greenland, Canada, and in the state of Alaska. The United States also operated a desert warfare center in Yuma, Arizona. Still needed were centers approximating Mediterranean conditions and tropical ones.¹⁵

To take advantage of the apparent shrinkage of the earth due to ballistic missiles, NATO advisors also pointed out the need to revolutionize the field of geodesy—earth measurement. Mapmakers relied on data taken from a variety of oceanic or terrestrial expeditions, sometimes decades or more old. No one had seen the earth from space, much less taken accurate measurements based on satellites. Intercontinental ballistic missiles would require precision. But NATO literally did not know where the Soviet Union was. "On a world wide scale, we are not sure of the position of North America in relation to the Eurasian continent." Knowledge of anything in the Southern Hemisphere was even less accurate. The only decent data came from the Americas, Western Europe, Japan, and some of the former and current European colonial territories. The Soviets could target the West with accuracy, but the West could not do the same. Any kind of exact targeting of the Soviet Union would prove impossible before satellites could take comprehensive measurements. In the meantime, constant earth measurement from the air would prove essential. Fortunately, international scientific projects were providing that data.¹⁶

The IGY had convinced scientists and military planners of the usefulness of synoptic data collection. If done in real time, or close to it, data collection could be automated and collected over a large territory, perhaps even globally. Individual scientists might never analyze the vast amounts of data, but the data could be fed into computers in order to monitor and

predict environmental conditions. Already the Americans were working on an anti-submarine warfare "environmental prediction system." It collected oceanographic information—to estimate sonar performance—and combined it with meteorological information to predict future oceanographic conditions.

Had the members of the Von Kármán Committee been military historians, there is little doubt about what they would have cast as the "decisive moment" in the history of global strategy. Time and again they called to mind the changes brought about by the advent of earth-orbiting satellites. It would prove to be, they believed, a dividing line between military eras. It promised total monitoring of the global environment, a vision of the future that was pervasive across the range of sciences and military operations. By 1970, these NATO advisors predicted, scientists would be able to identify and track thunderstorms as they occurred all over the entire earth and to keep the earth's radiation under constant surveillance. Old charts would be discarded, in favor of a constantly refreshing set of data beamed down from the heavens. Automated data systems would be necessary to achieve accuracy of measurement and improved forecasting. As the committee put it: "The concept of inaccessible geographical areas is no longer valid—observations over enemy-held, oceanic and uninhabited areas are as easily made as elsewhere." Reliance on existing charts and data, collected laboriously by error-prone humans, rarely uniform from country to country, seemed archaic. New methods of continuous, uniform data collection of the oceans, land, and space would provide the kind of mastery of the global environment that the Von Kármán committee envisioned.¹⁷

Aside from this unprecedented ability to forecast conditions and improve global accuracy, the NATO science advisors also predicted ambitious, large-scale manipulation of the environment. The brass ring of military geophysics was weather control. Scientists already had achieved modest results in increasing rainfall or dissipating fogs. But these successes required optimal conditions and certainly could not be projected over a large area or from a long distance.¹⁸ But what about climate control?

In a 1956 *Fortune* article, mathematician John von Neumann had suggested that militaries would be able to make large-scale changes to climate. He pointed out various ways to alter oceans and seas. One was to blanket ice sheets with blackening agents, to absorb more light and melt them. If it could be done to Greenland, its ice sheet alone would raise sea levels by about 10 feet "and cause great discomfort to most world ports." Another scheme was to divert the Gulf Stream, which would severely

change the climate of Northern Europe. Still another idea was to dam the Bering Strait. Such alterations would have clear, long-term effects on world climate. And these changes seemed possible.¹⁹ Reflecting on von Neumann's predictions, the NATO group believed that an extraordinary tool lay in the hands of military planners: the hydrogen bomb. "It is perhaps true," the committee concluded, "that means presently within man's reach could be employed so as to alter global climate for long periods."²⁰

Given the later controversy about the role of carbon dioxide in inducing global climate change, the focus on the hydrogen bomb might seem surprising. But the reason for this was simple. Advised by physicists, the defense establishments of NATO's strongest members believed that in order for "synoptic scale" weapons to be feasible, man had to achieve physical power that was comparable to nature's power. The only tool that seemed likely to provide that was the hydrogen bomb. Although professional meteorologists had insisted that hydrogen bomb tests had not created the extreme winters of 1954, 1958, and 1962, these military advisors were less adamant. They knew that the energies of nature were vast, but felt they might be shaped by man. It seemed that the Soviets were working hard on the problem. Canadian scientists repeated the oft-heard rumor that the Soviets were planning large-scale manipulation of the oceans, along with drastic modification of climate, by damming up the Bering Strait. The Canadians reasoned: surely the Russians had in mind the use of nuclear bombs?²¹

NATO scientists found the prospects of such power over nature intriguing. They called it *environmental warfare*. "This kind of warfare has the peculiarity that it could look like our image of nuclear war, or could be so subtle that the 'weapons' and 'battles' are hard to identify." The enemy might undertake a vast engineering project to change the climate of a whole region, "leading gradually to economic ruin and loss of strength." This could be done even without declaring war.²²

Once again ecological vulnerability emerged as a crucial area in need of study for military purposes. The NATO science advisors did not yet understand their true vulnerability to what they called "living weapons." But new data were coming in. Since the late 1950s, American engineers had planned to use thermonuclear explosions to excavate a harbor in Alaska—a project dubbed "Plowshare." Beforehand they put together what today might be called an environmental impact statement and discovered that the effect on the Eskimos' diet might not be as negligible as originally assumed. For this and other reasons, the project was scrapped.²³

But that knowledge had been useful for military thinking. Scientists had traced the pathway of radioactivity through the food chain. NATO scientists now used the example of the Eskimos' ecosystem to argue for more advanced knowledge of ecological warfare. Within that ecosystem, Eskimos lived interdependently with seals, otter, fish, caribou, and plankton. If the plankton were all killed, an Eskimo's ecological community would be utterly destroyed. "At best he would have to move," the group pointed out. "At worst he would die." This kind of thinking could be tailored to particular regions: "The people of Asia depend on rice and a very few other crops. Something like a lethal rice-rust or blight could make life in Asia much more difficult and perhaps untenable."²⁴

As a weapon system, ecological links went further than killing—they also promised biological coercion. Destruction of the enemy need not be the goal. Getting rid of plankton, for example, would make the Eskimos' entire food system collapse and force them to be entirely dependent on food supplied from outside the region. To achieve this, toxic agents "may be developed to attack essential links in various ecological chains." The aim would be to shape an existing interdependent web along new lines, "to force the ecology to accept dependence on some crop or animal which cannot live at all in the homeland." Doing this would put the victim in an extremely disadvantageous position, "leading to a gradual loss of power and position and inevitable vassalage."²⁵

Von Kármán died shortly after the first of his committee reports was completed. As colleagues remembered his contributions to aeronautics and to scientific advising, his death lent the committee's findings an extraordinary amount of authority within NATO. The reports had the air of a final act of service; the chairman's passing only augmented the committee's importance. With Von Kármán gone, the reports themselves were a foreboding, Cassandra-like vision of the future that military planners could ignore only at their peril. This was especially true of subjects that the committee felt it did not yet understand fully.

Environmental warfare had captured the imagination of the committee but the results had been unsatisfying. It seemed in keeping with the direction of science—toward global, synoptic-scale activities. Yet it was unclear how it might shape weaponry. The experience of the Von Kármán Committee established "environmental warfare" as a distinct concept, and it was not long before NATO reconvened the members to look into the subject more fully. They realized that there were commonalities between the work on geophysics and the ongoing work on radiological, biological, and

chemical weapons. Both involved alterations to the natural world with potentially devastating human consequences. Military technology seemed on the verge of an unprecedented ability to tap the forces of nature on a massive scale.²⁶

Thus in late 1962, NATO summoned scientists and military planners to Paris to hammer out what might legitimately come out of "environmental warfare" and what the long-term consequences might be. The man who tried to fill Von Kármán's shoes was another Hungarian, nuclear physicist Edward Teller, who joined the group as a "special advisor." Known widely as the father of the hydrogen bomb, Teller already was deeply committed to using nuclear explosions for massive earthmoving projects, such as the construction of harbors. He also saw great potential in developing novel uses of nuclear weapons in wartime. Along with Teller, committee members were drawn from national defense establishments and from the US Advanced Research Projects Agency (ARPA).

The central question almost always remained the same: were natural forces susceptible to human influence on a large, even global, scale? In methodical fashion, these military planners broke down environmental warfare into distinct spheres of possibility, corresponding with the layers of the earth and its atmosphere as it extended into space: lithosphere and hydrosphere (land and oceans), troposphere (lower atmosphere), stratosphere and ionosphere (upper atmosphere), and exosphere (outer space). Some of the earlier "wildcat" ideas were quickly dispensed with as impractical, such as using hydrogen bombs to melt the polar ice caps. But other wildcat ideas were feasible, particularly using nuclear weapons as triggers for tsunamis in the oceans, or for altering the weather.

One only had to open a newspaper to see what natural catastrophes could accomplish. In 1958, in Alaska's Lituya Bay, there was a landslide so powerful that it carried the energy equivalent to a one-kiloton explosion. In May 1960, a wall of water smashed the Chilean coast over a stretch of several hundred miles, with wave heights of 5.5 to 13.5 meters. The Chilean earthquake sent storm waves across a large area of the Pacific at speeds in excess of 400 miles per hour. Even as far away as Hawaii, low-lying areas were flooded. Thousands of Chileans were killed, and millions were left homeless. Reporters described the relentless devastation:

The quakes went on for all of the week, demolishing or damaging thousands of homes and other buildings, and burying some small communities under landslides. Whole villages were swept away by

tsunamis as high as twenty-four feet. The quakes were so violent that mountains disappeared, new lakes were formed and the earth's surface dropped as much as 1,000 feet in twenty-five miles. The worst quake, last Sunday, released energy of 240 megatons, equal to that of 1,200 atomic bombs of the type dropped on Hiroshima and far more than the 174 megatons released by all the nuclear explosions to date.²⁷

Noting deaths all over the Pacific Rim, the *New York Times* reported that the Chilean earthquake "gave tragic testimony that in this age of the conquest of the atom and of triumphs in outer space man is still helpless against the vast and still largely unpredictable forces that frequently go berserk in his immediate environment—hurricanes, volcanoes and earthquakes."²⁸

NATO saw it differently. Environmental cataclysms could become part of the alliance's arsenal, with the help of a well-placed nuclear explosion. The cascading effects of energy release from the existing instabilities of nature could be, quite literally, earth shattering. The power over nature was tempting: "The large engineering capability which is provided by multi-megaton nuclear weapons might open up the possibility of changing the course of ocean streams which are known to affect climate and continents." Narrow straits could indeed be dammed up, as some feared the Soviets planned for the Bering Straits. Peninsulas could be turned into islands, changing the patterns of water flow and mixing. With enough nuclear bombs, the sea floor in some areas might be reconfigured entirely.²⁹

Even weather control seemed poised to make a quantum leap forward with the nuclear bomb as a tool. "Real weather control," NATO scientists argued, "would mean control of synoptic scale disturbances—the centers of high pressure and low pressure found on the daily weather maps." Such large-scale systems seemed inherently susceptible to influence, despite the huge energies required to do it. The sun imparted energy into the air masses constantly, but only some of it became kinetic energy. Most of the energy was stored, ready to be released. The results could be quite violent, as in the case of cyclones. A relatively small release of energy—say, a nuclear bomb—could trigger a much larger release of natural energy.³⁰

One reason that such widespread and even long-term changes in the earth's systems seemed feasible—at least in theory—was the growing realization of how serious an effect humans already were having upon the upper atmosphere. High in the sky, major effects seemed well within

NATO's grasp. Nuclear explosions could create electron clouds some 70–90 kilometers up, disrupting high-frequency communication. One of the leading researchers on electron cloud disruption, Jerome Pressman, had been advising the US Army Signal Corps, the Air Force, and ARPA on this subject for years.³¹ He told the rest of the environmental warfare committee that even a single nuclear burst could disrupt long-distance communication over a stretch of a thousand kilometers. If nuclear weapons were exploded in the atmosphere as a defense against incoming missiles, the range of this electron cloud would be vast indeed. High-frequency communication equipment and long-distance radar systems might be rendered useless.

Out in space—the exosphere—NATO saw great promise in the radiation belts that American and Soviet satellites had measured during the International Geophysical Year. The Van Allen belts were actually giant regions of charged particles trapped by the earth's magnetic field. They were sources of intense, persistent radiation that endangered any equipment or living thing in space. Although the Van Allen belts were natural phenomena, similar belts could be created artificially by exploding a nuclear weapon at an altitude of at least 400 kilometers. Large bombs at even higher altitudes would create an extraordinarily powerful radiation environment in space. The belts would cloak the earth, challenging any exit or entrance by missile, satellite, or spacecraft. Because the belts would be trapped by the earth's magnetic field, there would be holes in the radiation cloak at the north and south geomagnetic poles. Whoever controlled these entry points would have comparatively easy access to space. That would make the poles even more important as strategic regions.³²

In fact, manipulation of the Van Allen belts already had begun. In 1958 the United States discovered that its high-altitude tests of “small kilotonnage” had created electron shells around the earth, about 60 miles thick. Because the operation in which these tests occurred had been dubbed “ARGUS,” the creation of the shell became the “ARGUS effect.” Just a few months prior to these NATO meetings, the United States detonated an even larger explosion at high altitude—the “Starfish” experiment. As Edward Teller reported, “this is the first time that the Argus effect was demonstrated on a really big scale.” An immense number of electrons were caught in the earth's magnetic field and “are forming now a new Van Allen belt greater in electron density than any of the known Van Allen belts.” He confided that the electrons had damaged the solar cells in American satellites.³³

Despite their fascination with these weapons, the committee members struggled to overcome the possibilities that defied the logic of nuclear warfare. The military significance of triggering natural catastrophes was not readily obvious. “If the weapon can be exploded a few miles offshore, it can probably be delivered on, or close to, the target itself, and a far larger proportion of the energy available would be expended on the target and not on long lengths of unimportant coast line.”³⁴ The same argument could be made against any effort to influence the flow of ocean currents and thus modify the world's climate. Why not just drop a bomb on a city? It seemed more logical.

On the other hand, there might be great value in environmental devastation in a total war. NATO advisors had already moved beyond “cities” as targets and had begun to imagine much larger swathes of territory. Aside from the blast and radioactive contamination, thermonuclear bombs could have wide-ranging horrific consequences. Disruptions of dams and levees would lead to widespread flooding. Drowning and starvation would result, posing a serious threat to those who managed to survive the bombs.

The most ghastly environmental threat was the prospect of large-scale fire. In *Whole World on Fire* (2004), Lynn Eden has written that military planners routinely ignored the consequences of huge firestorms caused by a nuclear explosion's thermal radiation. She suggests that this led nuclear strategists to underestimate the catastrophic effects of nuclear explosions throughout the Cold War. While war plans typically focused on blast effects,³⁵ not everyone ignored the totality of death and destruction from fires. Some military planners considered it part of environmental warfare. In the early 1960s, scientists and military planners at the highest levels of NATO faced a stomach-churning analysis that cast them as a way of arming the countryside against the enemy even when his cities were destroyed.

These fires would instantaneously ignite a huge area due to the explosion's initial thermal radiation, regardless of blast effects. Rather than just use bombs directly against cities, one could explode a large bomb of about 100 megatons high in the atmosphere, at about 80 kilometers. Doing so would maximize the amount of thermal radiation that would reach the earth. Such radiation would ignite flammable material instantly, over an area of nearly a million square kilometers. As a point of comparison, the largest recorded forest fire in the United States occurred in 1871 in Wisconsin and Michigan, which claimed 1,683 lives and spread over 15,000 square kilometers. Setting fire to forests, in an area of a million square kilometers, would pose intractable problems to an enemy. Outside the bombed-out

cities, the countryside would provide no shelter, no food, and no hope of survival.

A fire from thermal radiation would differ from a typical forest fire because it would not need to spread—instead, the whole area would go up in flames at the same time. Oxygen would rapidly deplete, leaving any survivors suffocating to death. It would be impossible to run from it. Rushes of air would create firestorms with “strong winds of up to hurricane force,” far more intense than the deadly firestorms created in German and Japanese cities during World War II. Edward Teller guessed that the energy released in a fire would exceed that of the nuclear explosion, roughly the equivalent of a thousand megatons. “This is the most violent and wide-spread environmental change which can be expected from a nuclear attack,” he said.³⁶ If total war were the goal, fires from thermal radiation could achieve it on a continental scale.

These discussions, recorded for posterity in NATO meeting minutes, have a surreal feel to them. Scientists argued about whether hydrogen bombs were more effective as triggers of vast environmental events, or if they should just be dropped directly on their targets. Scientists quibbled over the extent of damage from a fire-raising weapon. Some doubted, for example, that hurricane-force winds would ensue. It was difficult to argue with the conclusion, however: “The immediate result would be beyond all experience.” But some insisted that it would only “likely” be beyond all experience.

Such intellectualized detachment from human experience reached new heights when the long-term ecological consequences of nuclear weapons were imagined. The NATO group recognized that using nuclear weapons in this way might have severe consequences for the earth in the long run. But while acknowledging that the effect on weather and climate might be significant, scientists had little data with which to generate specific predictions. As for the devastation of the land, NATO was confident that a succession of vegetation “would sooner or later re-establish itself, and over a few decades there would be some ecological recovery.”³⁷

The only thing not in doubt in these discussions was that maximizing human death was the principal goal. Which was better, Teller and his colleagues asked—drowning villages along the coast, igniting the countryside with thermal radiation, or simply laying waste a city? Should humans be contaminated through the food chain, or beat into submission through ecological dependence? While praising the ingenuity of these wildcat ideas, Teller’s own preference was to bomb cities. If death and devastation

were the goals, he reasoned, why not keep it simple? Mammals, including humans, were more sensitive to radioactivity than insects, seed plants, or bacteria. It made little sense to attempt to contaminate man through these less susceptible organisms when the bomb would do the trick. “Thus the most economic way to attack populations with nuclear radiation,” the committee concluded, “is to do so directly rather than through some element of their surroundings.”³⁸

For many in NATO, looking at the world as a zero-sum game between the nuclear-armed United States and the Soviet Union, environmental warfare seemed like an inefficient sideshow. As interesting as ocean manipulation and weather control might be, nuclear explosions would be required to produce them. In that case, presumably a real war would have begun, and the enemy could be bombed directly without resorting to exotic methods such as these. Even in the case of biological, radiological, and chemical weapons, changing the environment would be a more circuitous route than attacking directly.

In trying to imagine uses of environmental weapons, military analysts working with NATO confronted the same question that has stood at the center of environmental issues ever since: can human actions have long-lasting, detrimental consequences upon the earth? As an advocate of peacetime nuclear testing, Teller had reason to minimize the long-term impacts of human action, particularly nuclear fallout. He spoke at length to the committee about how some scientists had exaggerated these effects, and his point of view prevailed. The NATO committee concluded that the danger of sickness and disease from contamination “are no worse than the other hazards which would have to be faced by the survivors of a nuclear war.” As for the long-term genetic effects upon future generations, the committee toed the pro-testing line that the ultimate effects on future generations could not be predicted with certainty.

Nevertheless, some on the committee were convinced that humans were capable of making large alterations to the environment. Throughout the Von Kármán reports were repeated references to unpredictable consequences of human action on the atmosphere. Increasing or decreasing the ozone concentration in the atmosphere was certainly possible, altering the amount of ultraviolet light reaching the earth. Deliberate creation of an ozone hole might confuse surveillance systems; deteriorate aircraft materials such as rubber, plastic, glass; and harm humans and crops. Less purposeful might be the introduction of chemicals from rocket fuel or other sources, resulting in “large inadvertent changes” in atmospheric properties.³⁹

NATO concluded its assessment of environmental warfare with a warning that major changes might already be under way. "Much of the military planning of today assumes that the earth's atmosphere will remain substantially as it is," it wrote. Elaborate detection and surveillance systems were based on that very notion. But more and more booster rockets would traverse the upper atmosphere, depositing exhaust materials. "They may, within the near future, be sufficient in quantities to have a large effect," the committee concluded. The composition and temperature of the atmosphere, and along with them weather and climate, likely would change due to atmospheric pollution.⁴⁰ This warning undoubtedly sprang from Jerome Pressman's work on the effects of rocket trails, done for the Geophysics Corporation of America and funded by ARPA.⁴¹ His work, some of it unclassified, would lead *New Scientist* writer Peter Stubbs to suggest in 1963 that there was "ample evidence that the amounts and types of contaminants that are likely to be ejected by the large rockets envisaged for future space programmes may radically change the environment of the layers surrounding the Earth. The modifications may extend to being world wide and of long duration and would clearly be substantial over large areas."⁴²

Despite their belief that geophysical forces could be harnessed with nuclear explosions, several of these NATO scientists refused to entertain the notion that these environmental changes were anything but ephemeral. They would be wartime actions, justifiable in a total war against the Soviet Union, with only short-term consequences for man and the climate of the earth. Teller routinely emphasized the huge power differential between the forces of nature and the forces of man. Like the professional meteorologists, he had stiffened his resolve on this issue and was deeply skeptical—even dismissive—of ideas to the contrary. Yes, it would be possible to use nuclear weapons to make local changes to the earth's crust. Indeed, Teller encouraged creative uses such as constructing harbors. It might even be possible to use nuclear weapons to create ocean upwelling. But it was inconceivable to him that even a nuclear war could have a substantial and permanent effect on weather and climate. The intense fires would be brutal in the short term, but the energies were equivalent to what the sun delivered in the course of a day. Giant firestorms would devastate selected areas, but these were no different in scale from the large hurricanes that occurred as natural phenomena. These changes could ultimately be justified by the supreme need to stop the Soviet Union. In the final analysis, Teller and others insisted, even the most devastating change would not be permanent.

Teller and his like-minded colleagues built upon this notion and denied that even gradual changes to the composition of the atmosphere could be significant. This was a position that he had hardened over the years as he defended atmospheric nuclear testing. Addressing the NATO group, he said that even worldwide fallout would have negligible effects, because of the earth's ability to rejuvenate itself. The radioactive carbon-14 in the air technically should last thousands of years. However, Teller believed that within a decade all of it would exchange with the carbon dioxide in the oceans. He said that the radioactivity "will be precipitated by the calcium carbonate to the bottom of the ocean where it is outside the range of any living organism."⁴³

In light of the Argus experiment, the fallout controversy, and the ill-fated Alaskan adventure, many others in government held less certain views. President John Kennedy stated openly his belief that American scientific experiments could have global consequences. He also was diplomatically astute enough to recognize that the rest of the world did not see the earth as America's scientific playground. In April 1963, the president secretly directed his cabinet to ensure that any future experiments with potentially large-scale impacts should be reviewed first at the highest level.⁴⁴ At an event commemorating the 100th anniversary of the country's most esteemed scientific body, the National Academy of Sciences, he also conveyed a warning about America's responsibility to control the effects of scientific study: "For, as science investigates the natural environment, it also modifies it—and that modification may have incalculable consequences, for evil as well as for good. . . . [S]cience today has the power for the first time in history to undertake experiments with premeditation which can irreversibly alter our biological and physical environment on a global scale." Kennedy chided the scientists, saying that every time they came up with a major invention, politicians had to invent new institutions to cope with them. That usually meant new international bodies. The ocean, the atmosphere, and outer space, he said, "belong not to one nation or to one ideology but to all mankind."⁴⁵

The president was warning about the catastrophic consequences of human action—specifically, American scientists in concert with the military. His words suggested that America's military experiments had arrogantly tinkered with the global environment. But Kennedy was not just reacting to American (and Soviet) large-scale experiments. His words also reflected other stern warnings from his presidential science advisors and from others outside government that American practices were inadvertently

altering or poisoning the environment. He urged scientists to continue their global vision but to train their eyes on the world's diminishing resources and to consider the earth's vulnerability. Land, water, forests, wildlife—all these needed protection, and measures to stop contamination of water and air were sorely needed. "The earth can be an abundant mother," Kennedy said, "if we learn to use her with skill and wisdom—to tend her wounds, replenish her vitality and utilize her potentialities." He called to mind the prophecy of doom issued a century and a half earlier by Thomas Malthus, who said that men's numbers would push past the limits of subsistence, condemning them to famine, poverty, and misery.⁴⁶ Such prophecies, renewed by the rhetoric of Cold War conflict and the expectation of global war, soon were rampant in discussions of the environment.

44. Kennett Love, "London Soaks up Weather Debate," *New York Times* (September 14, 1958), 26.
45. "Weather Quirks Puzzle Experts," *New York Times* (August 10, 1958), 96.
46. W. H. Parker, "Storms across the World," *The Times* (September 9, 1958), 9.
47. Gordon Manley, letter to the editor, *The Times* (September 12, 1958), 11.
48. Peter Ball, letter to the editor, *The Times* (September 12, 1958), 11.
49. Adrian C. Boulton, letter to the editor, *The Times* (September 17, 1958), 11.
50. "It's Icy in West, Midwest, and East," *New York Times* (January 19, 1963), 14.
51. "Arctic Weather Grips Northern Hemisphere," *The Times* (January 25, 1963), 9;
"Continent Still in Grip of Cold Weather," *The Times* (January 28, 1963), 7.
52. "800 Die in Europe as Cold Persists," *New York Times* (January 3, 1963), 1.
53. "A Winter for the Records," *New York Times* (February 1, 1963), 8.
54. "A Winter for the Records," *New York Times* (February 1, 1963), 8.
55. "Belt of Radiation from Atom Test Above Estimates," *New York Times* (September 2, 1962), 1.

CHAPTER 6

1. H. Wexler, "Modifying Weather on a Large Scale," *Science* 128:3331 (1958), 1059-63.
2. John W. Finney, "U.S. is Urged to Seek Methods to Control the World's Weather," *New York Times* (January 1, 1958), 1.
3. George H. T. Kimble, "Storm Clouds over Weather Control," *New York Times* (February 9, 1958), SM15.
4. E. V. Truefitt to George Deacon, February 6, 1958, GERD D5/1 Secret and Confidential files, 1950-58, George Edward Raven Deacon Papers, UK National Oceanographic Library.
5. Zuoyue Wang, *In Sputnik's Shadow* (New Brunswick: Rutgers University Press, 2008).
6. Ann Finkbeiner, *The Jaxons: The Secret History of Science's Postwar Elite* (New York: Viking, 2006).
7. This study was conducted under the National Academy of Sciences at the request of the Air Research and Development Command of the US Air Force. See NAS-ARDC Committee on Weapons, "Long Range Scientific and Technical Trends of Interest to the United States Air Force," 1958, NARA RG 359, Subject Files, 1957-1962, Box 17, Folder "NAS ARDC Study Group."
8. NAS-ARDC Committee on Weapons, "Long Range Scientific and Technical Trends of Interest to the United States Air Force," 1958.
9. NAS-ARDC Committee on Weapons, "Long Range Scientific and Technical Trends of Interest to the United States Air Force," 1958.
10. NAS-ARDC Committee on Life Sciences, "Long Range Scientific and Technical Trends of Interest to the United States Air Force," 1958, NARA RG 359, Subject Files, 1957-1962, Box 17, Folder "NAS ARDC Study Group."

11. NAS-ARDC Committee on Life Sciences, "Long Range Scientific and Technical Trends of Interest to the United States Air Force," 1958.
12. Michael Gorn, *Harnessing the Genie: Science and Technology Forecasting for the Air Force, 1944–1986* (Washington: Office of Air Force History USA, 1988), 18.
13. Von Kármán's work typically was executed through NATO's Advisory Group for Aeronautical Research and Development (AGARD), though the group did not always limit itself to aeronautics. On aeronautical forecasting, see Gorn, *Harnessing the Genie*.
14. Although more than 200 scientists and military experts participated in the activities and reports under the Von Kármán committee, the original principal members were Von Kármán, G. S. Field (Defence Research Board, Canada), Karl Fischer (Ministry of Defense, Federal Republic of Germany), J. Guerin (Comité d'Action Scientifique de Défense Nationale, France), H. P. Robertson (Department of Defense, USA), Sir Solly Zuckerman (Ministry of Defence, UK), and as an ex-officio member, William A. Nierenberg (NATO Assistant Secretary General for Scientific Affairs). See Von Kármán Committee, "Long-Term Scientific Studies for the North Atlantic Treaty Organization: Final Report," September 1961, VKC-Final Report, NATO Archives, Brussels, Belgium.
15. NATO report VKC-EX1-GPIII on "Geophysics," March 1961, NATO Archives, Brussels, Belgium. P. 16. For a discussion of this military acclimatization, see Matthew Farish, "Creating Cold War Climates: The Laboratories of American Globalism," in J. R. McNeill and Corinna R. Unger, eds., *Environmental Histories of the Cold War* (New York: Cambridge University Press, 2010), 51–83.
16. NATO report VKC-EX1-GPIII on "Geophysics," March 1961, NATO Archives, Brussels, Belgium. P. 9.
17. NATO report VKC-EX1-GPIII on "Geophysics," March 1961, p. 23.
18. Part of this enthusiasm came from postwar confidence in weather prediction due the integration of meteorology with machine-based calculating power. See Kristine C. Harper, *Weather by the Numbers: The Genesis of Modern Meteorology* (Cambridge: MIT Press, 2008).
19. NATO report VKC-EX2-GP3&4 on "Weapons," June 1961, NATO Archives, Brussels, Belgium. P. 106.
20. NATO report VKC-EX1-GPIII on "Geophysics," March 1961, p. 30.
21. NATO report VKC-EX1-GPIII on "Geophysics," March 1961, Addendum i.
22. NATO report VKC-EX2-GP3&4 on "Weapons," June 1961, pp. 95–96.
23. On Plowshare, see Scott L. Kirsch, *Proving Grounds: Project Plowshare and the Unrealized Dream of Nuclear Earthmoving* (New Brunswick: Rutgers University Press, 2005). See also Daniel O'Neill, "Project Chariot: How Alaska Escaped Nuclear Excavation," *Bulletin of the Atomic Scientists* 45:10 (December 1989), 28–37.
24. NATO report VKC-EX2-GP3&4 on "Weapons," June 1961, p. 101.

25. NATO report VKC-EX2-GP3&4 on "Weapons," June 1961, p. 102.
26. The entire report, including the transcript of an address by Edward Teller to the participants, is NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, NATO Archives, Brussels, Belgium.
27. "Wave Out of Chile," *New York Times* (May 29, 1960), E2.
28. William L. Laurence, "Tsunamis' Power," *New York Times* (May 29, 1960), E8.
29. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, NATO Archives, Brussels, Belgium. P. 9
30. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, p. 15.
31. An example of Pressman's work is J. Pressman, F. F. Marmo, and L. M. Aschenbrand, "Artificial Electron Clouds—VI: Low Altitude Study, Release of Cesium at 69, 82, and 91 km," *Planetary and Space Sciences* 2:4 (1960), 228–37.
32. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, p. 28.
33. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, pp. 59, 60.
34. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, p. 9.
35. Lynn Eden, *Whole World on Fire: Organizations, Knowledge, and Nuclear Weapons Devastation* (Ithaca: Cornell University Press, 2004).
36. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, p. 54.
37. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, p. 5.
38. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, p. 6.
39. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, pp. 19–24.
40. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, p. 25.
41. See J. Pressman and R. Casey, "A Heuristic Examination of the Kinematics of Simplified Rocket Trails," ARPA Order No. 258–61, Air Force Cambridge Research Laboratories, Bedford, Massachusetts, February 1962. This and other studies available at <http://handle.dtic.mil/100.2/AD274153> Accessed December 16, 2010.
42. Peter Stubbs, "May Rockets Disturb the Weather?" *New Scientist* 350 (August 1, 1963), 230–33. Quote on p. 233.
43. NATO Report VKC-Ex3-PH1/GP2 on "Environmental Warfare," November 1962, p. 57.
44. Ronald E. Doel and Kristine C. Harper, "Prometheus Unleashed: Science as a Diplomatic Weapon in the Lyndon B. Johnson Administration," *Osiris* 21 (2006), 66–85, quote on p. 70.

45. "Text of Kennedy's Address to Academy of Sciences," *New York Times* (October 23, 1963), 24.
46. "Text of Kennedy's Address to Academy of Sciences," *New York Times* (October 23, 1963), 24.

CHAPTER 7

1. Zuoyue Wang, *In Sputnik's Shadow* (New Brunswick: Rutgers University Press, 2008), 174–75.
2. Herman Kahn, *On Thermonuclear War* (Princeton: Princeton University Press, 1960), 21.
3. Jerome Spingarn, "Picking Up the Pieces," *New York Times* (January 1, 1961), BR3.
4. Paul Deats Jr., review of Herman Kahn, *On Thermonuclear War*, *Journal of Bible and Religion* 30 (1962), 170–71. Donald N. Michael, review of Herman Kahn, *On Thermonuclear War*, *Science* 133:3453 (March 3, 1961), 635. Christopher Lasch, review of Herman Kahn, *On Thermonuclear War*, *The Massachusetts Review* 2 (1961), 574–80.
5. Peter Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21 (1994), 228–66.
6. Sharon Ghamari-Tabrizi, "Simulating the Unthinkable: Gaming Future War in the 1950s and 1960s," *Social Studies of Science* 30 (2000), 163–223.
7. NAS-ARDC Committee on Life Sciences, "Long Range Scientific and Technical Trends of Interest to the United States Air Force," 1958, NARA RG 359, Subject Files, 1957–1962, Box 17, Folder "NAS ARDC Study Group."
8. NAS-ARDC Committee on Life Sciences, "Long Range Scientific and Technical Trends of Interest to the United States Air Force," 1958.
9. Robert K. Plumb, "Science Group Maps Drive to Advise on Public Issues," *New York Times* (July 8, 1960), 1.
10. "Science Integrity Said to Be in Peril," *New York Times* (December 31, 1964), 21.
11. Michael Egan, *Barry Commoner and the Science of Survival: The Remaking of American Environmentalism* (Cambridge, MA: MIT Press, 2007), 47.
12. Nigel Calder, ed., *Unless Peace Comes: A Scientific Forecast of New Weapons* (New York: Viking, 1968), 14, 20.
13. Calder, *Unless Peace Comes*, quotes on p. 142 and p. 164.
14. Calder, *Unless Peace Comes*, 183.
15. Calder, *Unless Peace Comes*, 202.
16. James Rodger Fleming, *Historical Perspective on Climate Change* (New York: Oxford University Press, 1998).
17. Calder, *Unless Peace Comes*, 191.
18. Lewis Mumford, "History: Neglected Clue to Technology Change," *Technology and Culture* 2:3 (1961), 230–36. Quote on p. 234. Such ideas are more fully developed in Lewis Mumford, "Authoritarian and Democratic Technics," *Technology and Culture* 5:1 (1964), 1–8.