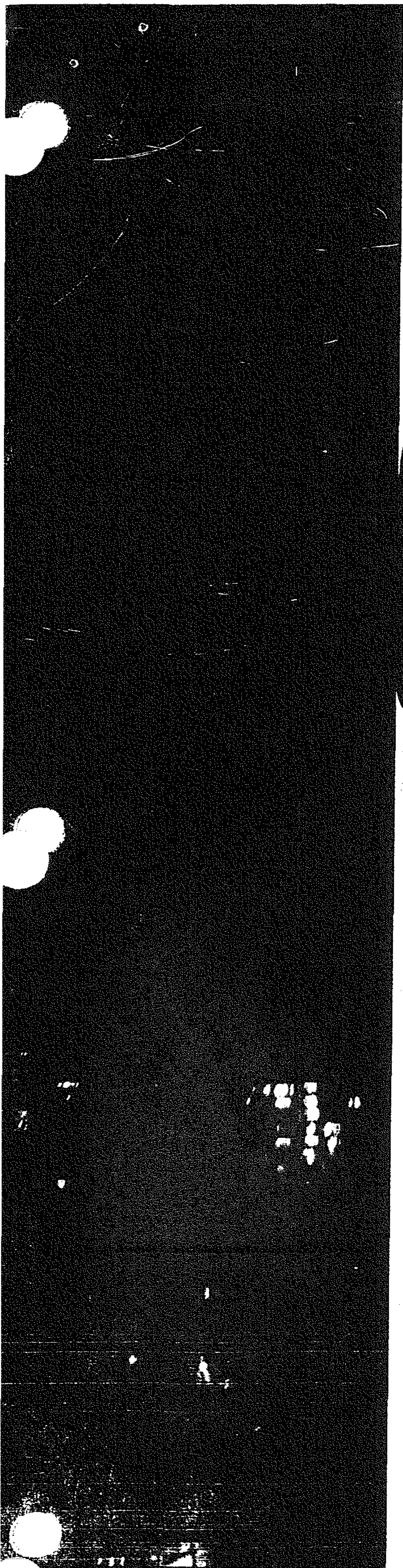
One nuclear blast over Nebraska would bathe the country in an intense electromagnetic pulse likely to cut off power and communications, paralyzing the White House and Pentagon.

THE CHAOS FACTOR



by William J. Broad

"All of a sudden a greenish-white flash lit up all of Hawaii," recalled an eyewitness. "The sky started turning pink, then orange, then red. The heavens were filled with a ghastly light."

It happened one July evening during an atomic test in 1962. A rocket lifted off from Johnston Atoll, a speck in the Pacific 800 miles southwest of Hawaii. At a point in space 248 miles above the Earth, the rocket turned into a ball of nuclear fire.

Not just the heavens inspired awe that evening. Something so unexpected happened that today, two decades later, military planners still ponder its dark implications for the fighting of nuclear war.

A second or so after the flash, the Hawaiian Islands were plagued by problems with things electrical. In widely separated parts of Oahu, 300 streetlights winked out, their fuses blown. Burglar alarms started ringing, and power lines went dead. Honolulu headlines the next day attributed the breakdowns to a nuclear "shock wave." It was not so easily explained.

A 1962 nuclear test 248 miles above a tiny Pacific atoll created this fireball and light show over Honolulu, 800 miles away. Electrical failures following the burst were later linked to a pulse called EMP.

The mysterious agent was EMP, an electromagnetic pulse given life by nuclear blasts. EMP is an intense burst of electromagnetic energy that can travel halfway across a continent at the speed of light and still pack enough punch to burn out electrical systems.

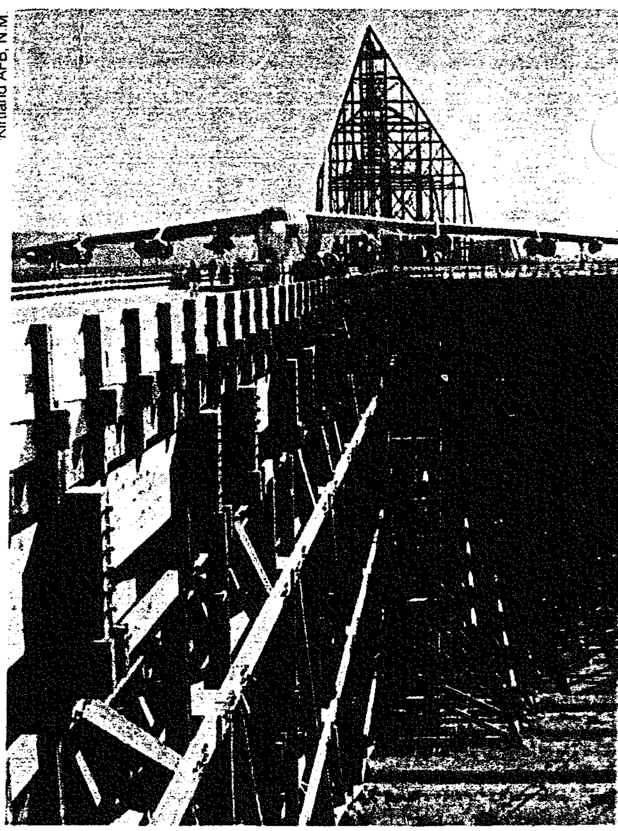
Its disruptive power is frightening. An EMP attack would be the ideal first step in a massive atomic assault against the United States. A single Soviet warhead detonated 250 miles or so above Nebraska would blanket the nation with EMP having peak fields on the order of 50,000 volts per meter—almost certainly strong enough to shut down all power and communications. Though the pulse would do no direct harm to humans, it would throw the United States and its armed forces into confusion.

Recent changes in U.S. defense policy have made this vision all the more menacing. Today the Pentagon foresees the possibility of a prolonged or "limited" nuclear war. This takes for granted exceedingly good communications throughout the military, especially between the president and his troops. But EMP renders this assumption mere wishful thinking and turns the notion of limited nuclear war into fantasy.

Understandably, wrestling with the EMP threat is a top U.S. priority. In unveiling a $180 billion program for rebuilding the U.S. strategic war machine, President Reagan in October 1981 said the number one job was not to deploy the MX missile or build the B-1 bomber but "to strengthen and rebuild our communications and control system—a much neglected factor in our strategic deterrent." Reagan has earmarked $20 billion to this end—much of it for grappling with EMP.

But with hard data about EMP still sparse, a deluge of dollars may not end the questions. So, like a physician treating a disease of mysterious origin, the Pentagon is trying to erect more than one line of defense. Besides protecting communications links around the world, the Pentagon has assigned a top secret mission to a special team in the vaguely named Joint Program Office: to create an altogether new communications system that will work reliably amid the chaos of nuclear war.

Considering that the events on Hawaii took place two decades ago, why has it taken so long to awaken to the threat? What do the Soviets know of EMP? Can the United States defeat the electromagnetic



Kirtland AFB, N.M.

Chu... ...ear/West Light

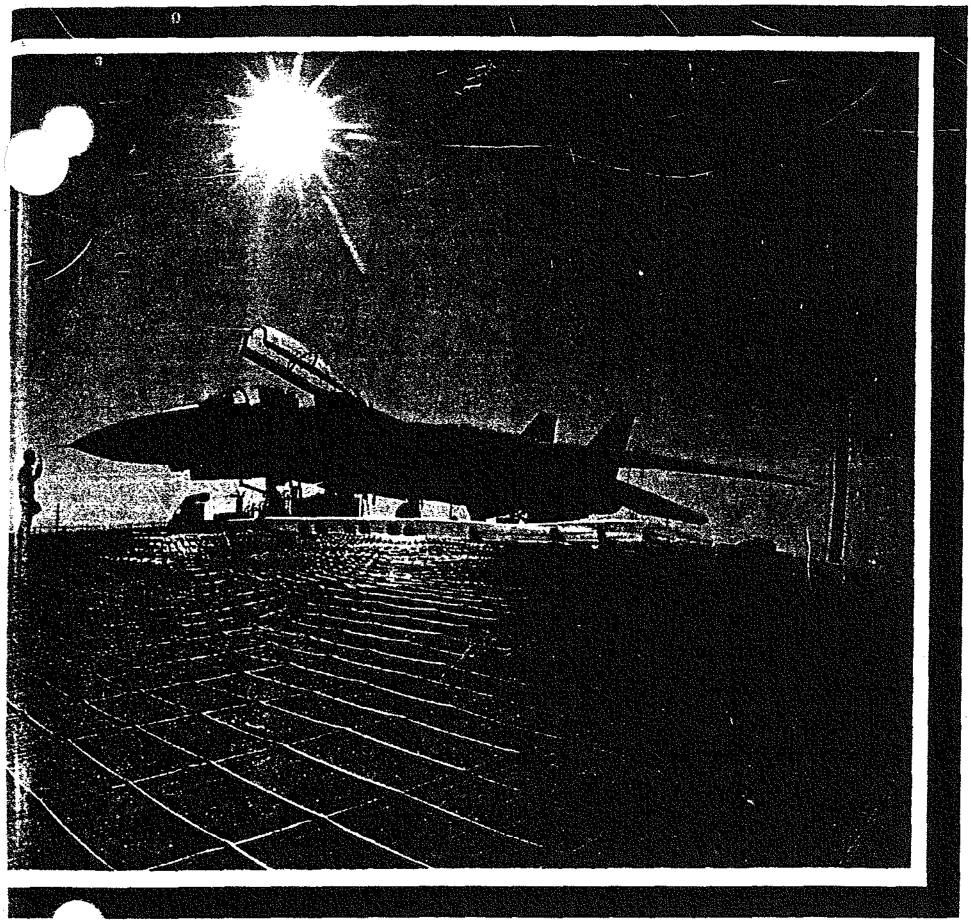
At right, a B-52 bomber squats atop Trestle, an all-wood structure at Kirtland Air Force Base in New Mexico built to test aircraft for EMP "hardness." Far right, an F-14 Tomcat fighter is tested for EMP by the Air Force's horizontally polarized dipole simulator.

crippler? The answers are buried deep in the history of the nuclear arms race.

The 1962 test, a 1.4-megaton blast known as Starfish Prime, was one of the last held aboveground. A few months later President John F. Kennedy and Soviet Premier Nikita Khrushchev agreed to ban nuclear tests from the atmosphere and space, ending the possibility of observing EMP in peacetime. Unfortunately, the U.S. military misread the hints already at hand. Military scientists knew there had been a strong electrical pulse on the Hawaiian Islands. But they felt reassured by the fact that power failures had been scattered, not total, and that most telephone systems had gone right on working.

By late 1963, military physicists had come up with an explanation for the pulse. On Earth the atmosphere quickly absorbs the gamma radiation and X rays unleashed by a nuclear blast. In the airlessness of space, however, this high-energy radiation travels unimpeded over vast distances at the speed of light. A blast 50 to 500 miles above the Earth sends radiation into the upper atmosphere, knocking my[illegible] electrons out of air molecules. [illegible] electrons twirl around and down the lines of force of the Earth's magnetic field. The spinning electrons act like a radio transmitter beaming out a powerful pulse spanning the frequencies from zero to about 100 megahertz—a range that takes in everything from power-line frequencies to most AM and FM radio and many television channels. The higher the blast, the greater the area on Earth covered by the EMP broadcast.

Anyone who has used a bedspring or window screen as a radio antenna knows that almost any metallic object can collect electromagnetic energy. In the same way, EMP can be picked up by airplane hulls, radio antennas, telephone lines, car bodies—anything metal. The longer or wider the collector, the more energy is induced. A wire the length of a football field would catch enough EMP energy to power a 100-watt bulb for an instant in 1,500 homes. A transcontinental power line would pick



.nough EMP to cause blinding arcs between transmission cables.

The physicists who looked at EMP in 1963 were not particularly concerned, for they could not foresee the host of vulnerable devices waiting to be spun off by the semiconductor revolution. Vacuum tubes, still in widespread use in 1963, have thick metal parts, separated by a near vacuum, that can handle a high-voltage surge and operate as if nothing had happened. Solid-state devices, on the other hand, are built up of successive layers of silicon thinner than a human hair. Something akin to panic came in the 1970s, when military engineers discovered that solid-state integrated circuits are a billion times likelier to be destroyed by EMP than vacuum tubes.

Physicists at the dawn of the EMP era also had faith that the pulse could be tamed, especially by shielding. Key systems would be covered with a thin sheet of metal it would siphon off the high-voltage surge. A primitive version of such a shield is described in *Nuclear War Survival Skills*, a handbook published only four years ago by the Oak Ridge National Laboratory: "Having a radio to receive emergency broadcasts would be a great advantage. . . . A radio may be shielded against EMP by placing it inside a metal cake box or metal storage can, or by completely surrounding it with aluminum foil."

A cake tin indeed might work for a radio, and finding out is not difficult. Small systems can be "hardened" and then tested by blasting them with simulated EMP. But there is no way to test the reliability of a coast-to-coast communications link short of detonating a warhead high above the atmosphere.

The implications of the shielding problem dawned on the military during the construction of the $5.7 billion Safeguard antiballistic missile (ABM) system. Safeguard's nuclear interceptors were to confront Soviet warheads high above the atmosphere, sending EMP surges across most of North America. The military initially considered EMP a bothersome side effect. But after trying vainly to build an invulnerable transcontinental phone line between Safeguard and the president, military planners began to see EMP as potentially fatal.

The Safeguard project was started in 1969, a time when attempts to harden small systems such as strategic U.S. missiles against EMP had begun. Safeguard's massive size, however, required a higher level of effort. Shields of steel were wrapped around entire buildings holding radars, missiles, and the computers used to guide them. Huge EMP simulators then checked for hardness. But the wires, pipes, and other metal objects that penetrated the shielding made complete protection extremely difficult. The slightest gap in a shield would allow EMP energy to pour in. By 1971 the U.S. military was sinking more than $250 million a year into EMP hardening and testing.

Compounding the problem, lightning protectors and antisurge devices, meant to back up the shielding by discharging the EMP energy across a gap or shunting it to the ground, did not work. The pulse went through a system in 10 to 20 billionths of a second—a hundred times faster than lightning—and did its damage before the devices could trigger.

To those in the know, the situation was ominous. Safeguard's 100 missiles were nuclear-tipped; the president therefore would have to approve their launch. That required telephone lines stretching 2,000 miles from Washington, D.C., to the ABM fields of North Dakota. Special shielded lines were leased from the Bell System. But the vulnerability of Bell's amplifiers and switching centers had skyrocketed with the wide use of solid-state circuitry. The size of the system, moreover, meant huge amounts of EMP would be collected—and complete testing for "hardness" would be impossible.

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Soviet radars, tanks, radios, and planes may be more resistant to EMP than those of the United States.

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Engineers also belatedly recognized the EMP threat to other phone lines, such as those between the president and nuclear troops at B-52 bomber bases.

On a snowy April Fool's Day morning in 1975, technicians made the final adjustments on the missiles. Ten months later, Congress closed Safeguard down. "We wondered with Safeguard whether we were going to knock out our own weapon system," says Claud L. Beckham, a former Bell official who worked on the project. Today ABM designers avoid hypothesizing nuclear intercepts in space at all costs. Instead, they assign blasts to the atmosphere, where EMP effects are intense but extend only a few miles rather than thousands. Defense strategists consider Safeguard a $5.7 billion fiasco.

Are the Soviets so careless? Evidence came to light shortly after Safeguard's demise that the Soviets are preparing for the pulse quite seriously. In 1976 a Soviet pilot defected with his MiG-25 to Japan. CIA director George Bush exulted that it was an "intelligence bonanza." The plane, an interceptor known as a Foxbat, had been clocked at three times the speed of sound and was the Soviet warplane most feared in the West. Air Force Secretary Robert C. Seamans in 1973 called it "probably the best interceptor in production in the world today."

Peals of laughter soon rang throughout liberal circles when it turned out the fearsome Foxbat relied on old-fashioned vacuum tubes. But a few Western defense experts were far from amused. One year after the Foxbat landed, the Pentagon quietly revised *The Effects of Nuclear Weapons*, its EMP bible, to include the warning: "It may be advisable to design equipment with vacuum tubes rather than solid-state components."

Some defense specialists, including George J. Keegan Jr., past chief of Air Force Intelligence, say the Foxbat indicates the backward state of the Soviet economy. But Edward Teller, an architect of the hydrogen bomb and an outspoken Sinophobe, points to the Foxbat as an example of Soviet superiority. "That plane was designed by a person as crazy as a fox," he recently told a group of electrical engineers at the Air Force Weapons Lab in Albuquerque, New Mexico.

Even if antiquated technology has been forced on the Soviets by their economy, the implications are eerie. Their radars, tanks, radios, and planes may be more resistant to EMP than this country's. If so, the Soviets may be ahead because they are behind.

In any event, the Soviets clearly could have developed an early appreciation of EMP. They conducted their atomic tests in space high above central Asia. It is a sparsely populated region, but unlike the watery expanses around Johnson Atoll, it has towns. So the Soviets have had more of a chance to observe how EMP is picked up by intercity power and telephone lines and the way it affects electronic apparatus. Soviet manuals and magazine articles are rife with such references to EMP as this passage: "To achieve surprise in a modern war . . . high-altitude nuclear explosions can be carried out . . . to destroy the system of control and communications and to suppress the antimissile and antiair defense radar system. . . ."

Can the United States protect itself? Vacuum tubes cannot be used in every military device that has to function during a nuclear war. Energy efficient, reliable, compact, and cheap, solid-state devices are irresistible to designers.

One possible way around the conundrum would be to rely on shielding only in small systems that can be fully tested for EMP hardness. So as transcontinental land-based communications lines lost their luster, military planners turned their attention to airplanes. "In the future we expect to fire advanced U.S. missile systems on the basis of a signal sent from an aircraft," Harold Brown, then Secretary of the Air Force and later Secretary of Defense, informed Congress. "This will eliminate any vulnerabilities of launch control centers or control cabling.

But can airplanes be made impregnable? The president and his generals have many airborne command posts from which they might orchestrate a nuclear war. The president has four specially designed Boeing 747s. The Strategic Air Command flies a fleet of two dozen Boeing 707s for the control of Minuteman missile fields alone.

Yet the doomsday fleet might survive an EMP attack. The p[illegible]ful evolution of the presidential planes is a case study. In the early 1970s Boeing took three 747s off the production line and tried to protect and shield individual systems. Bundles of wire cabling and thousands of key electrical systems were wrapped in special metal shielding. Pulse-limiting devices were installed in important circuits. The upshot was depressing. Tests showed that up to 11,500 essential solid-state circuits would fail if the planes were hit by EMP from a nuclear explosion half a continent away. A few years later Boeing, with another 747, tried to make the aircraft's hull one giant shield. The plane was built from scratch so the 2,000 or so openings in the hull could be covered or shielded. Windows, for example, were covered with fine metal mesh. The inside of the plane even had to be isolated electrically from the hull. It worked but cost five times more than a commercial plane—so only one airborne command p

This Soviet poster warns of the dangers of EMP. Some defense specialists believe that the Soviets have been arming themselves against the pulse for some time.

in all the U.S. military is considered reliably "hard."

Other command aircraft are slated for hardening, but whether the resulting aircraft will truly be invulnerable is doubtful because of testing inadequacies. In 1980, for instance, a $58 million EMP simulator at Kirtland Air Force Base in Albuquerque, New Mexico, was placed into use, allowing large planes to be completely tested for the first time.

Known as Trestle after the railroad structure it resembles, the test platform is made from massive beams of Douglas fir and stands 12 stories high to get a plane off the ground and into simulated flight. Metal would affect the electromagnetic pulse, so Trestle is held together with 250,000 laminated beech bolts the size of broom handles. During a test, two five-million-volt pulsers discharge a surge of electricity into wires surrounding the test stand. For a few billionths of a second the pulsers are putting out 160 billion watts of power—a level which, if sustained, would meet the power needs of more than 160 cities the size of Albuquerque.

Yet that huge jolt cannot mimic a peak EMP surge. The pulse of about 40,000 volts per meter that Trestle lays down at an aircraft's hull is 10,000 shy of the peak accepted by most U.S. scientists. Trestle's creator, Carl Baum of the Air Force Weapons Lab, says damage expected at peak levels can be mathematically extrapolated but with difficulty. Work is now under way to raise Trestle's power.

Even 50,000 volts may be too little. There is a quiet but intense debate over the theoretically maximum power of the pulse. The Pentagon states it is 50,000 volts per meter no matter how big the bomb. (The Soviets once detonated a device more than 4,000 times bigger than the bomb that leveled Hiroshima.) But some French physicists, among others, envision a pulse of about 100,000 volts per meter. If they are correct, the nominal protections the Pentagon has tried to build into communications networks, missiles, radars, and radios would almost certainly be useless.

A way around the difficulty is to make critical communication links transparent to EMP by transmitting messages with pulses of light along hair-thin glass fibers. Unlike wires, fiber optics do not pick up EMP or conduct electricity and thus will not send damaging pulses to fragile solid-state devices. Better yet, a single glass fiber can carry as much information as hundreds or even thousands of copper wires. Glass fiber is also relatively cheap. Understandably, the military uses glass wherever it can. The B-1 and Stealth bombers will use glass fiber to make them less vulnerable to EMP. So, too, the Bell System, whose lines carry military messages, is installing a 496-mile fiber optic line between Washington and Boston—the first of many such conduits around the country.

At first glance a transcontinental web of glass fibers might seem a perfect solution to the EMP dilemma. The facts are less sanguine. Telephone calls on fiber optic lines must repeatedly be turned back into electric signals as they pass through switching centers and amplifiers full of solid-state equipment. And shielding is difficult, since the switches, computers, and amplifiers are powered by the commercial power grid—a perfect conduit for EMP. In fact, the Bell System is not attempting to harden its fiber links to EMP. The cost would be prohibitive.

In the war against EMP, the space front looks particularly grim. Communications satellites carry more than 70 percent of all long-distance military messages. For some time the military thought satellites

Don't touch that dial!

Someone standing in an open field would feel no shock, not even a tingling, during an EMP attack. EMP passes harmlessly through human flesh, glass, wood, and plastic, knocking out machines rather than people.

But someone in contact with or close to a metal object might be shocked or burned. The bigger or longer the object and the better the human connection, the greater the jolt. It would be hazardous to touch a toaster, since it plugs into the national power grid. Or to iron a shirt, adjust a television, wear headphones hooked up to a home stereo, talk on the telephone, ride a train (on miles of metal rail), lean on a chain link fence, or take a bath (unless the pipes were plastic).

The Department of Defense, in an apparent afterthought, tells of the human threat on the very last page of an EMP manual. "The energy collected in a long wire "might cause electrocution or burns," it warns. "Such conditions are not generally expected." Expected or not, a jolt to a tiny fraction of the U.S. population could represent death or injury to hundreds of thousands, even millions, of people. —*W.J.B.*

would be immune to all but a nearby nuclear blast. But in the early 1970s, physicists found that radiation from a nuclear blast in space travels vast distances and knocks electrons out of a satellite's skin and innards, causing an EMP-type surge. The pulse was clearly different from terrestrial EMP but even stronger—about one million volts per meter driven directly into the satellite's electronic heart.

The oversight had dark implications. For more than a decade, starting in the early 1960s, the Air Force kept a secret arsenal in the Pacific, armed with missiles tipped with nuclear warheads. The arsenal's sole mission was to destroy enemy satellites. But the system also would have knocked out dozens of U.S. satellites used for early warning, reconnaissance, and communication. In short, the secret arsenal might have blundered into altering the outcome of a nuclear war. The system was scrapped in 1975 when Pentagon managers were finally convinced the EMP threat was real.

As part of President Reagan's program, the Air Force is currently trying to harden some satellites. Shielding does not work well; much of the radiation that causes EMP in space passes right through a thin metal covering. So engineers are designing special circuits, filtering antenna inputs, and fabricating cables from aluminum and other metals with low atomic weights, since they release electrons less readily than copper. Such limited protections will work only if the satellite is far from a nuclear blast—just how far, the Pentagon will not say. A relatively small explosion of two megatons just outside the upper atmosphere at an altitude of 50 to 75 miles would damage an unprotected satellite in geosynchronous orbit 22,300 miles above the Earth. And the kill range can easily be extended by increasing the size of the bomb. As Wallace D. Henderson, a nuclear engineer and the Pentagon's former director of surveillance and warnings systems, recently put it: "What if the Soviets will not play our way and increase the yield of their nuclear space mine by a factor of 100?"

In an attempt to cope with the satellite threat, the Air Force is now building launchers that would quickly send new satellites aloft to replace any that are knocked out.

At worst, EMP adds up to a potential nuclear nightmare. The United States is frequently crisscrossed by picture-taking Cosmos satellites at a height of some 150 miles. Just one of them, carrying a few pounds of plutonium instead of a camera, could knock out key U.S. military satellites and, as radiation from the blast slammed into the Earth's upper atmosphere at the speed of light, touch off coast-to-coast pandemonium.

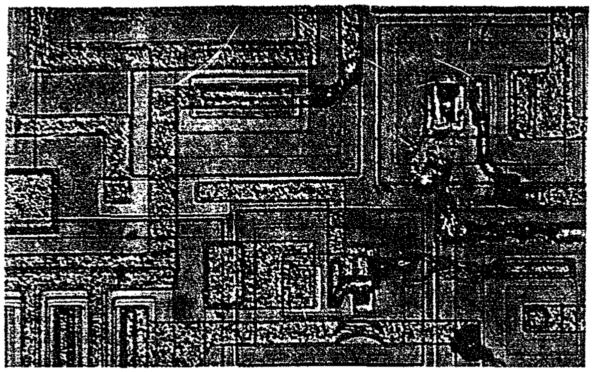
In a worst-case scenario, the powerful surge of EMP would trip circuit breakers throughout the power grid, silence telephone lines, lobotomize computer memories, and throw the armed forces into disarray. Civilian and military planes alike, their solid-state controls and radios knocked out, would attempt, perhaps successfully, to make emergency landings. Most of the military would be out of electricity and thus out of action. Backup power would kick on deep within Cheyenne Mountain in the Colorado Rockies, the nerve center of the North American Aerospace Defense Command. Yet here too chaos would rule. The super-secret satellites that warn exactly where to expect a rain of Soviet warheads would have been knocked out, and the defense command's other eyes, the U.S. early-warning radars, would have been blinded, as predicted in the Soviet manual. Worse, communications with the outside world would be cut off, leaving the nerve center unable to flex its military muscle. Retaliation would be difficult at best. On strategic bomber bases, B-52 flight crews might run for their trucks to find they would not start, their electronic ignition systems dead.

The president might get to his hardened airborne command post to learn, too late, that the prediction of a 100,000-volt peak, double the expected destruc[illegible] power, was correct. Even if his plane got off the ground, its radio range would be sharply reduced; the satellites used to relay its messages would be out of action.

Some defense strategists are more optimistic. Perhaps the president could get enough of a signal through the atomic static to launch wave after wave of U.S. nuclear warheads in massive retaliation. It is just such uncertainty that keeps the Soviets from mustering an EMP attack, according to such defense strategists as Gerald P. Dinneen, the top communications specialist in the Pentagon during the Carter administration.

"Since there is a great deal of uncertainty about EMP, and most of the information has been derived from simulations, it is unlikely the Soviets would take a chance," says Dinneen. The Soviets also run the risk that launch officers of Minuteman missiles and commanders of nuclear submarines, cut off from superiors by an EMP attack, n[illegible]

U.S. Army/Har... Laboratories



A pulse simulating EMP has destroyed this integrated circuit. Its semiconductor junctions broke down, sending current rushing through to vaporize the metal pathways.

fire missiles on their own accord, unleashing an uncontrolled nuclear spasm.

In light of these apocalyptic visions, critics of the Pentagon say that a limited nuclear war waged over days, weeks, or months, as proposed by defense secretary Caspar W. Weinberger, is simply impossible. Weinberger's aim is to give the United States, should it be attacked, choices other than releasing the entire nuclear arsenal in all-out retaliation or letting the country be destroyed. The knowledge that the United States can exact precisely measured punishment—if the Soviets bomb three large cities, the United States will retaliate in kind—serves to check the possibility of a Soviet preemptive strike. Or so Weinberger and his aides believe.

Yet Jeremy Stone, president of the 5,000-member Federation of American Scientists, says that only the raw threat of convulsive massive retaliation will discourage the Soviet Union from toying with the idea of a first strike. The scientists point to EMP as a technical reality that makes mincemeat of the political myth of carefully controlled retaliation. In an influential article in 1980, Stone raised the specter of EMP and military chaos: "We ought not kid ourselves that we are prepared to fight a protracted nuclear war when no plausible improvement in command, control, and communications is likely to permit it."

Pentagon hardliners claim that eventually the armed forces can be protected against EMP and thus could wage any kind of war. They cite the increased use of fiber optics and President Reagan's $20 billion program with its impending improvements that include altogether new technologies, not just better airborne command posts. The Air Force, for instance, is developing an emergency communications system that uses ground wave signals at low frequencies. The Army, after many failures with shielding, has begun trying to clip EMP pulses with new, fast-acting types of Zener diodes. They are relatively inexpensive and seem to work fairly well in field radios, which have small antennas and pick up little EMP. But the diodes offer no protection against EMP picked up by the national power grid or long communications lines.

Perhaps the most troublesome parts of the EMP story will never be heard by the public. Military officials let the issue out of the bag grudgingly. Top secret speculation, after all, started in the wake of a nuclear test that put out lights and power in Hawaii 20 years ago. Even today the Pentagon still will not declassify an old Air Force movie that describes EMP in outline.

The military initially tried to sweep EMP under the rug, according to William D. Hershberger, professor emeritus of electrical engineering at the University of California at Los Angeles. During the 1960s Hershberger studied the feasibility of nuclear ABM systems at the Pentagon's Institute for Defense Analyses. He was told to ignore EMP. "Concentration on the less difficult part of the problem rather than on the bottleneck was contrary to anything I had ever experienced in industrial or university research," he says.

One reason EMP came into public view was that the military felt obligated to warn Congress, defense contractors, and civil defense authorities of the flaws being uncovered in large communication networks. As Pentagon official John A. Northrup admitted to Congress in 1972: "In our initial studies it was hoped that we could identify that the problem would not be a continuing one. That is, that the problem would go away. I think what has happened here is the recognition that the problem appears to be a potential hazard that must be addressed, and that our initial studies were not successful in making it go away."

What troubles nuclear physicist Theodore B. Taylor are the nuclear effects other than EMP that Pentagon specialists have succeeded in "making go away." Strange and top secret effects that might considerably complicate the fighting of a nuclear war have been brushed aside, he says. Taylor, who directed the Pentagon's first agency to examine the exotic effects of nuclear weapons, and now speaks nationally in favor of a nuclear freeze, says that Pentagon officials have not admitted the threat posed by these nuclear specters. He counts roughly 50 exotic effects from a nuclear blast, including many types of EMP, gamma radiation, X rays, and electron effects from bomb debris. The laws of classification, he says, forbid him from elaborating to the extent he would like.

A point Taylor does feel free to address is the fallibility of human understanding. "One of the most dangerous situations in the world occurs when people think they really understand the effects of nuclear weapons," he says soberly. "I especially worry about the politicians." ▣

William J. Broad is a reporter for Science.