Nuclear Pulse (I): Awakening to the Chaos Factor

A single nuclear blast high above the United States could shut down the power grid and knock out communications from coast to coast

A new era in the evolution of the U.S. nuclear arsenal opened on a snowy April morning in 1975, at the very northern edge of North Dakota. The final adjustments had just been made in the $5.7-billion Safeguard ballistic defense system, 100 nuclear-tipped missiles poised to fight off a Soviet attack. Had the radars of Safeguard picked up an approaching warhead, a Spartan missile would have flashed out of its snow-covered silo and shot into space. Upon nearing the Soviet warhead, at a height of perhaps 160 miles, the Spartan would have silently turned into a ball of nuclear fire.

Unfortunately, the fireball would have also bathed the United States with a high voltage wave known as electromagnetic pulse (EMP), which in turn would have knocked out unprotected communications equipment from coast to coast and shut down the U.S. power grid.

The EMP threat is anything but new. Aspects of it were clear to a small cadre of U.S. physicists in 1963. As the Safeguard episode clearly illustrates, however, the dimensions of the EMP threat have been slow to dawn on many Pentagon planners. EMP from a Spartan missile might have precluded the President's ability to communicate with strategic U.S. nuclear forces. The threat was also slow to dawn on the builders. The Bell System, prime contractor for both Safeguard and the military communications network, had built one system in such a way that it would knock out the other.

Today awareness of EMP is keen. For a mix of political and technical reasons, the silos and buildings at the Safeguard site in North Dakota are abandoned and filling with water. The Pentagon now puts hundreds of millions of dollars into "hardening" electronic instruments against the debilitating effects of EMP. In 1981 the Joint Chiefs of Staff spelled out the EMP threat in their posture statement, a sensitive indicator of military concerns. A new antiballistic missile (ABM) program recently proposed by the Pentagon would still use missiles outside the atmosphere—but ones that do not possess nuclear warheads.

ABM systems are not the only area in which EMP influences the strategic debate. Another critical issue is whether the Soviets may have learned of EMP earlier than the United States and designed their strategic systems accordingly. A detailed recounting of the EMP saga suggests that they may have realized the EMP threat right from the start.

Another issue is the political difficulty of providing complete protection against the EMP effect. It would take billions of dollars to totally harden the U.S. military—an unglamorous task without a constituency in the Pentagon, and therefore easily ignored.

In July 1962 the U.S. military detonated a 1.4-megaton hydrogen bomb 248 miles above Johnson Island in the Pacific, and for some time thereafter physicists puzzled over a resulting series of odd occurrences. Some 800 miles away in Hawaii, street lights had failed, burglar alarms had rung, and circuit breakers had popped open in power lines. Today, the mysterious agent is known as electromagnetic pulse (EMP). Physicists say a single nuclear detonation in near space would cover vast stretches of the earth with an EMP of 50,000 volts per meter.

The first installment of this three-part series describes how EMP was discovered and why its potentially chaos-producing effects were overlooked for more than a decade. The second part will examine the ongoing debate in the Pentagon over how to cope with the EMP threat. The third will discuss questions EMP raises about waging a limited nuclear war.

The most pressing issue is telecommunications. In the past, at the request of the Pentagon, the Bell System quietly tried to harden some of its military and civilian circuits and cables, paying for the work with general revenues. Today, with the emergence of a flock of new competitive telephone companies, that cozy arrangement is threatened.

The final unknown is war. If the Soviets detonated an EMP weapon over Nebraska as a prelude to a massive attack, would the military network still operate? On this issue the Joint Chiefs of Staff are less than optimistic. As their recent posture statement put it, with the typical military reliance on acronym-laden and euphemistic prose: "A C^3 [command, control, and communications] deficiency today is the widespread loss of connectivity which would be caused by a high-altitude nuclear explosion and its resulting electromagnetic pulse. . . . Some C^3 hardware has been EMP-hardened; however, full systems analysis and fixes are required."

The slowness of the awakening to the EMP threat is the result of two factors. The first is the circuitous way in which it was discovered. The second is the fact that most of the electronic equipment accidentally exposed in the 1960's during U.S. nuclear tests in space was built with vacuum tubes and thus was too old and rugged to have been damaged by a split-second pulse of tens of thousands of volts. The semiconductor revolution has changed all that.

The discovery of EMP was delayed because other nuclear effects seemed more threatening in 1958, during the first U.S. high-altitude tests of nuclear weapons over Johnson Island in the Pacific. One burst occurred at 27 miles, the other at 48 miles. These detonations greatly upset the ionosphere, and thus disturbed radio communications and radar, and the military was anxious to push the tests higher and see if the blackout got worse. In late 1958, however, the United States and the Soviet Union agreed to a moratorium on all nuclear weapons testing while negotiations continued on a test ban treaty. In 1961, the Soviets broke the moratorium, and the United States soon followed suit. By 1962, the U.S. military was again ready to carry out high-altitude tests, only this time higher up and with weapons of greater yield. On 8 July 1962, a Thor rocket carried a 1.4-megaton hydrogen bomb 248 miles above

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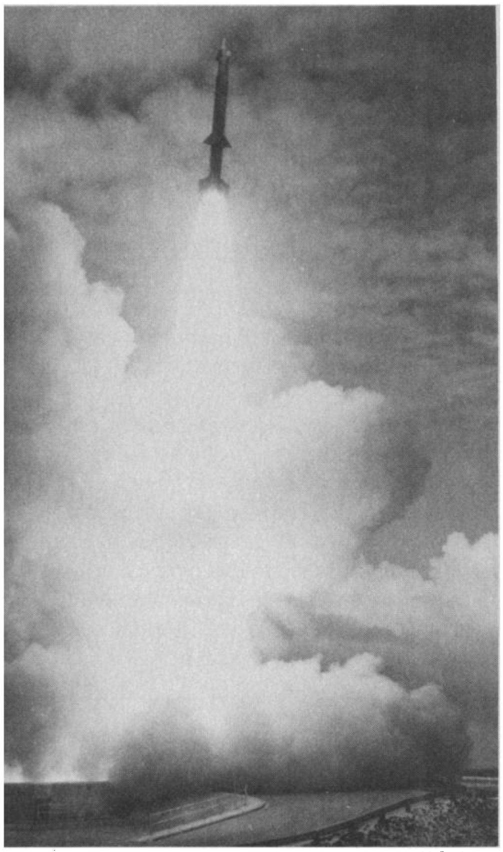


U.S. Army

Countdown to chaos?

Test firing of a Spartan missile in 1969 from the Kwajalein missile range.

Johnson Island, but, to the surprise of the military, the nuclear burst produced only limited effects on radio and radar. Though the next test had been set for a height of 500 miles, the military lowered its sights and detonated the next four shots in the 25- to 50-mile range, so as to better investigate the radio and radar blackout.

While these nuclear fireworks went off over the Pacific, several U.S. physicists were busy trying to explain the unexpected effects on Hawaii from the 248-mile-high burst. Street lights and power lines had broken down and burglar alarms had started ringing. A Honolulu newspaper reported that the problems were due to a nuclear "shock wave." By late 1963, however, physicists from the Rand Corporation in California had arrived at a much more esoteric explanation (*1*). In outline, it goes like this. Earth-bound gamma rays from a nuclear explosion in space eventually hit air in the upper atmosphere and knock out Compton electrons, which are deflected by the earth's magnetic field and forced to undergo a turning motion about the field lines. By a complex mechanism, these electrons emit EMP, which at ground level can radiate over thousands of miles with a peak strength of 50,000 volts per meter. Any metal object picks up the pulse. If the object, such as an antenna or a cable, leads to sensitive electronic components, the pulse can cause extensive damage.

Armed with a theory, military physicists could now explore the experimental subtleties of EMP. Two problems stood in their way, however: the partial test ban treaty of 1963, which stopped atmospheric testing, and the difficulty of retrospective analysis (most of the areas exposed to the high-altitude burst had been stretches of the blue Pacific—not the best natural laboratory for studying the effect of EMP on delicate electronics). Hawaii had experienced some odd occurrences, and searches of other islands during the mid-1960's revealed that some electrical systems there had experienced similar effects. In general, however, the unsophisticated state of most of the exposed technology delayed any deep comprehension by the U.S. military of the EMP threat. Most telephone systems on the islands, after all, had not shut down, since their circuits did not then employ semiconductor devices such as transistors: all switching centers were electromechanical. Most important, the U.S. military itself had not experienced problems, since most of the field equipment and ships exposed to EMP dated from the 1940's and 1950's, their electronic systems relying on vacuum tubes. In the 1970's, it was discovered that vacuum tubes have about 10 million times more hardness against EMP than integrated solid-state circuitry (*2*).

A case study in how the EMP threat dawned on Pentagon planners is the saga of the $5.7-billion Safeguard ABM system. By the time the program was proposed, in 1969, discrete systems such as missiles had been hardened for a few years. These were often tested for EMP hardness at the underground nuclear test site in Nevada, where explosions put out a mild form of EMP. With the sheer size of the Safeguard project, which initially involved 12 sites around the country, a new industry was needed for hardening and testing, EMP stimulators were built, and testing at first focused on individual components such as transistors and then on whole guidance systems for the missiles. At the phase I Safeguard sites under construction in Montana and North Dakota, continuous steel shields were wrapped around critical equipment, including radars, emplaced interceptors, and computers. Huge simulators then checked for hardness. By 1971 the U.S. military was sinking more than $250 million a year into EMP testing.

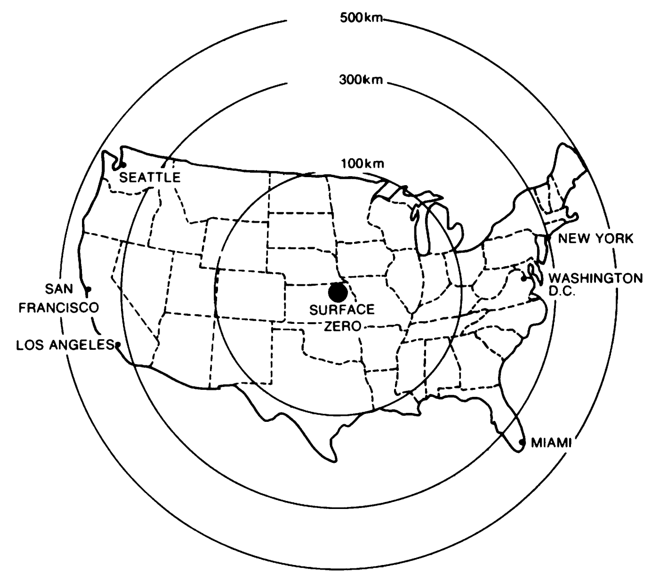
But the military's growing awareness of EMP seemed always to lag a constant distance behind another trend: the increasing vulnerability of electronics as the semiconductor revolution spun off fragile replacements for vacuum tubes. Ever more delicate components such as integrated circuits were put into Safeguard equipment and subsequently tested for EMP hardness. In 1972 Secretary of Defense Melvin Laird told Congress: "These tests [of small components] are now far along enough to cause grave concern about the effects on all our electronic systems, unless special protective measures are taken." More and better shielding was often all that was needed.

Hardening discrete systems was relatively easy, but a more difficult problem emerged during this period: communication links. Safeguard's missiles were nuclear-tipped, and their launch therefore had to be approved by the President. The needed communication links were vast, stretching from the ABM fields in Montana and North Dakota to the underground headquarters of the North American Defense Command (NORAD) in Colorado, and from there to Washington. Commercial telephone lines were leased from the Bell System. The size of the communications network made EMP testing of the whole system impossible, and the few tests that were carried out were not encouraging. Testifying on Capitol Hill in 1972, John A. Northrup, deputy director of the Defense Nuclear Agency, put it this way: "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." One such realization (*2*) was that lightning protectors and conventional antisurge devices, often considered EMP safety valves, did not work because of the extremely rapid rise time (10–20 nanoseconds) of the pulse.

Bell System engineers since the 1960's had designed equipment with EMP in mind, selectively hardening parts of the system. Safeguard, however, showed that additional hardening would be needed for critical circuits leased to the government. Even after additional hardening, complete protection was not ensured. "There is no such thing as proving statistically that a communications system has a particularly low probability of damage from EMP," says Claud L.

Beckham, a former Bell System official who in the 1960's and early 1970's was AT&T communications liaison to the Pentagon. "The simulations are just that, simulations. The other problem is doing enough experiments so that your results are statistically significant. . . . We wondered with Safeguard whether we were going to knock out our own weapons system." Beckham stresses that his views do not necessarily represent those of the Bell System.

In 1972, the Defense Department put out a thick manual on how to harden emergency operating centers in the civil defense network (*3*). "High altitude bursts are no longer unlikely," it warned. "The deployment of our Safeguard ABM system will include Spartan megaton-range warheads to be used at altitudes greater than one hundred kilometers."



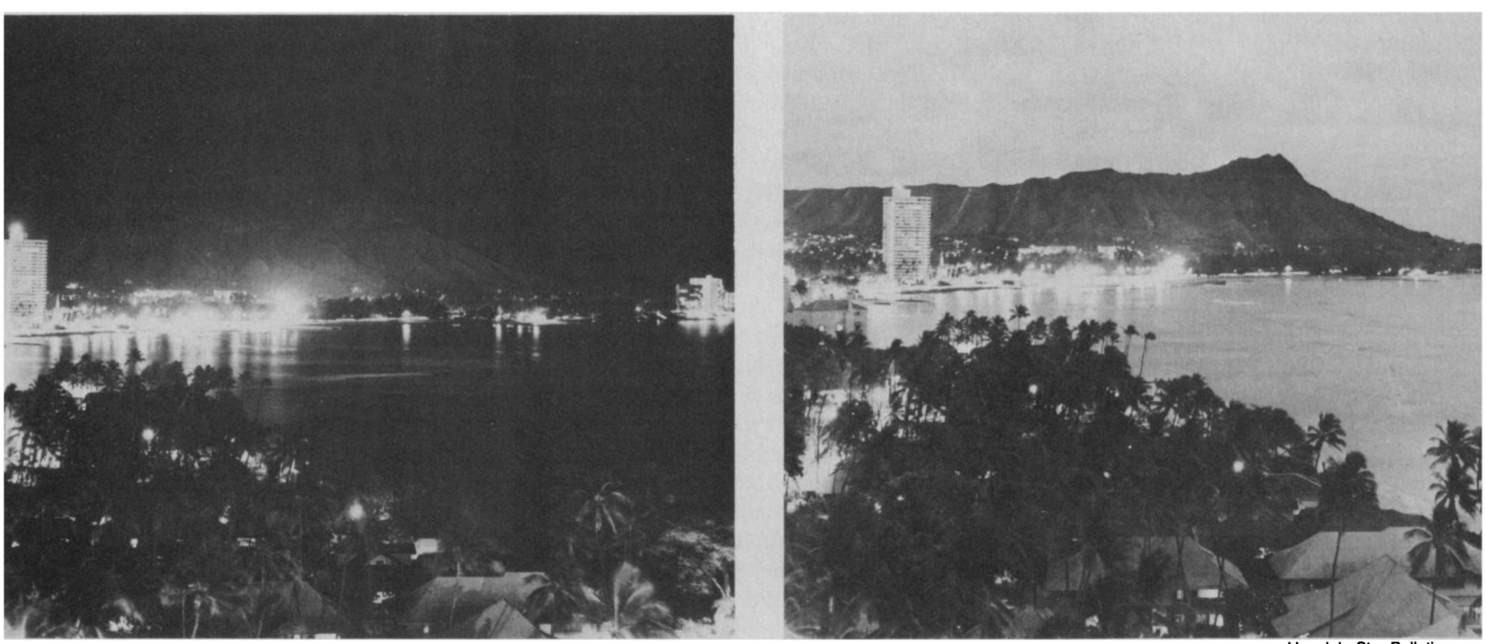
Circles show EMP ground coverage for a nuclear burst at 100, 300, and 500 kilometers above the United States. Within these circles, strength of the pulse would be at least 25,000 volts per meter, with peak fields of 50,000 volts.

It also became clear during this period that the incorporation of semiconductors into the control mechanisms of the U.S. electrical power system would leave it increasingly vulnerable (*Science*, 13 February 1981, p. 683).

While a debate heated up during the early 1970's over the hardness of communication links, both in Safeguard and the commercial U.S. network, the Safeguard program was dealt a number of political blows. In May 1972 an ABM treaty between the Soviet Union and the United States was signed, and by 1974 each country agreed to limit its AMB defenses to one site. The North Dakota base, with its "statistically unproven" communication links, opened on April Fool's Day in 1975. It was closed some 10 months later.

Today, Safeguard is considered something of a fiasco among those defense planners responsible for EMP protection and testing. Still, they say, Safeguard may have had its political uses. "Planning for the system was frozen in the 1960's," says Gordon Soper, scientific adviser to the deputy director of the Defense Nuclear Agency. "There were only a handful of people in this country who understood high-altitude EMP to the extent that they could impact on policy. Besides, there is a philosophy that says nuclear war is never going to happen. This leads people to say that only Soviet perceptions of U.S. capability are important. ABM is important. EMP hardening on the other hand is not very impressive, and declaring that a vulnerable system is hard is probably as effective as hardening the blasted thing."

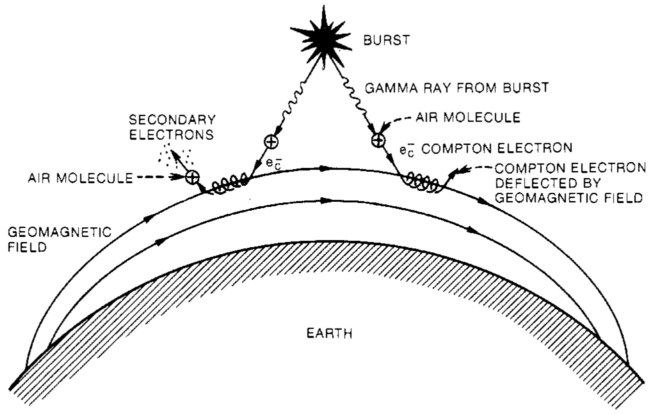
How aware of EMP are the Soviets? The consensus today among defense strategists is that the United States and the Soviets have an EMP parity. The issue is hotly debated, however, some Pentagon officials testifying on Capitol



Honolulu Star-Bulletin

Nighttime nuclear blast over Johnson Island lights up Diamond Head and beaches of Waikiki

Photo on left was taken a few minutes before 11 p.m. on 8 July 1962. Seconds later, the burst high above Johnson Island lit up all of Hawaii. In widely separated areas of Oahu, 300 street lights suddenly went out and circuit breakers in power lines popped open.



All nuclear bursts produce some EMP, but only ones outside the atmosphere produce a microsecond burst, a hundred times more powerful than a lightning bolt, that covers huge tracts of the earth. EMP in these explosions is produced by the turning of Compton electrons about the earth's magnetic field lines.

Hill that the Soviets in the early 1960's structured their high-altitude testing program around an exploration of the EMP threat. Without access to classified material, these claims cannot be substantiated. What is clear, however, is that the Soviet high-altitude tests were conducted over central Asia, which, though sparsely populated, still has more cities and therefore gave them more opportunities to observe the effects of EMP on electronic technology than there were around Johnson Island. Further, Soviet military journals often carry discussions of the use of EMP weapons (*4*). In 1968, *Voyennaya mysl'* (the official military-theoretical organ of the Soviet Ministry of Defense) is quoted as saying: "A considerable threat to the intercontinental ballistic missiles are powerful nuclear explosions set off at great altitudes, because the impulses of electromagnetic energy created by such explosions can put out of commission not only the on-board missile equipment, but also the ground electronic equipment of the launch complexes."

A final indication of what may be Soviet EMP awareness is the case of the Foxbat. The plane, a MiG-25, was flown into Japan in 1976 by a Soviet defector. It was something of a paradox. Until the hands-on inspection, the Foxbat had been considered the world's hottest warplane. In 1973, Robert C. Seamans, Secretary of the Air Force, described it as "probably the best interceptor in the world today." And indeed, when the plane was inspected in Japan the engines were found to be state-of-the-art. Rather than relying on titanium, however, the aircraft's body used steel. The electronics, moreover, were old—vacuum tubes used throughout. But the circuits themselves were far from antiquated. "Of particular interest is the aircraft's high-quality airborne computer," notes the 1981 edition of *Jane's All the World's Aircraft*. No U.S. official with whom this reporter spoke would address the issue of whether the use of vacuum tubes was intentional and indicative of Soviet EMP planning or whether their use was forced because of the slow dissemination of semiconductor technology into the Soviet economy.

In its most recent edition, however, the Pentagon's bible on EMP description and protection says the following (*5*): "Some of these methods of hardening against the EMP threat are shielding, proper circuit layout, satisfactory grounding, and various protective devices. If these measures do not appear to be adequate, it may be advisable to design equipment with vacuum tubes rather than solid-state components."

Today the pace of EMP testing and protecting in the U.S. military is at an all-time high. Critical aircraft and satellites are routinely checked for EMP hardness. The MX missile system, if built on land, will use EMP-proof fiber optics for its on-site communications. In 1980, the Air Force Weapons Laboratory at Kirtland Air Force Base in New Mexico started using a huge EMP simulator that can hold a B-52 bomber. The all-wood structure is 12 stories high, so that ground effects do not nullify the EMP. Since metal would affect the pulse, it is held together with 250,000 wooden bolts. Called Trestle, the simulator discharges two 5-million-volt pulsers into transmission lines surrounding the aircraft.

Yet with all the protective measures, the EMP problem becomes more, not less urgent, as the electronics revolution spews forth new and more delicate devices to be incorporated into the nation's arsenal. Despite their vulnerability, the devices are irresistible because they deliver gains in signal processing, reductions in weight and volume, and decreases in consumption of power. "Unfortunately," Harry R. Griffith, director of the Defense Nuclear Agency, told Congress in April, "this trend in microminiaturization also has increased component sensitivity to both natural and nuclear radiation."

Why did it take so long for the military to clearly see the threat? The dizzying pace of the semiconductor revolution is certainly a factor, as is the roundabout way in which EMP was discovered. Yet even after the threat was fully manifest, most of the military bureaucracy was interminably slow in doing anything about it. Full EMP testing of aircraft did not start until 1980, long after some observers had pointed out the threat.

Officials and scientists at the Defense Nuclear Agency have tried to call attention to the magnitude of the problem for more than a decade. Theirs is a small voice, however. For every $10 in the defense budget, the research programs of the Defense Nuclear Agency get one penny. Lack of action is perhaps explained by the sheer size of the general bureaucracy at the Pentagon, and by the disconcerting fact that to a nonspecialist the EMP problem is both huge and hard to understand, and would require billions of dollars to fix. A final, unanswerable question concerns cynicism, and whether, as Soper put it, "the philosophy that says nuclear war is never going to happen" has pervaded the military and its contractors to the point that they do not mind building self-defeating systems. It is clear that the problems with Safeguard emerged over a prolonged period. In the end, however, the system was deployed and for 10 months was apparently ready to blast off.

In any event, the EMP problem looms ever larger as the electronics revolution moves forward. Today the most unfortunate beneficiaries of the new technology are the giant, ground-based networks for military communications, which, because of their size, are incapable of exhaustive EMP testing. Questions about the hardness of the Bell System and its special military circuits have not faded away with the demise of the Safeguard ABM system. Today, more than ever before, these networks rely on fragile spinoffs of space age technology.

—WILLIAM J. BROAD

References and Notes

1. The paper did not appear in the open literature until 2 years later. W. J. Karzas *et al.*, "Detection of the electromagnetic radiation from nuclear explosions in space," *Physical Review* **137**, B1369–B1378 (8 March 1965).
2. M. A. King *et al.*, "An overview of the effects of nuclear weapons on communications capabilities," *Signal* (January 1980).
3. *EMP Protection for Emergency Operating Centers* (Defense Civil Preparedness Agency, Washington, D.C., July 1972), p. 8.
4. For translations and discussion, see J. D. Douglass, Jr., *Soviet Strategy for Nuclear War* (Hoover Institution Press, Stanford, Calif., 1979).
5. S. Glasstone, *The Effects of Nuclear Weapons* (Departments of Defense and Energy, Washington, D.C., 1977), p. 526.