# EMP
# A SLEEPING ELECTRONIC DRAGON

## Our growing dependence on solid-state electronics may leave us vulnerable to a potentially devastating type of nuclear fallout

*The first of two parts*

BY JANET RALOFF

A nuclear bomb detonates 250 miles above Omaha, Neb. A type of "fallout" most people have never heard of bathes the entire nation, and within a fraction of a second people coast to coast find themselves without power, without telecommunications, without computers—in a word, vulnerable. The fallout is called EMP, for electromagnetic pulse. Its effects are the opposite of those of the neutron bomb: EMP cripples or kills electronic equipment but leaves humans standing—very much alive and vulnerable.

It has been estimated that roughly one millionth of the total energy of a nuclear explosion is emitted as an EMP. If the pulse from a high-altitude detonation were delivered in the opening salvo of a warring siege, the attacked population might spend precious minutes or hours reeling in chaos. Even if the defending military could respond, the civilian sector — unable to communicate well, if at all—would find recovery of vital services slow. But should the EMP shower down in "peacetime"—also a distinct possibility—a nation might find itself temporarily disabled industrially and seriously crippled economically.

Nuclear-weapons-generated EMP is by no means a new phenomenon, though for years it has had an extremely low profile outside the defense-electronics community. In fact, since the detonation of conventional high explosives sometimes produces an EMP, similar signals were expected to accompany nuclear bursts. But the extent and particularly devastating nature of the nuclear-generated signals did not become obvious until several years after the United States began its program of above-ground nuclear-weapons tests. The signals left their imprint as a series of seemingly unexplainable failures or burnouts in equipment set up to monitor effects of the nuclear tests. Analysis ultimately pointed a finger at EMP as the cause when investigation showed that induced currents and voltages produced the failures.

Around 1960, several more graphic incidents drove home the possible vulnerability of civilian and military electrical and electronics systems. One of the most famous was the simultaneous failure of 30 strings of street lights in Oahu, Hawaii, in 1962. The Hawaiian outages are now attributed to EMP from high-altitude nuclear tests 800 miles away, near Johnston Island in the Pacific. That EMP is also held responsible for having opened power line circuit breakers and for setting off "hundreds" of burglar alarms in Honolulu.

But "EMP was just sort of a sleeping spook out there," says Bill Macklin of IRT Corp. (a firm that specializes in EMP work for the military) until the electronics revolution and related computerization of industrial processes and business functions ushered in a mushrooming escalation in our potential vulnerability to EMP disruption.

The phenomenon wreaks its havoc by inducing current or voltage surges through electrically conducting materials. In some cases the surges merely trip circuit breakers, shutting down a piece of equipment or power line. In other cases, especially where semiconductor materials are involved, individual components or circuits are destroyed.

Vacuum-tube systems tend to be many times more resistant to permanent damage from EMP than are semiconductor systems, and 60-hertz motors are even more resistant than vacuum tubes. "But even motors can be damaged if connected to a very large energy-collecting structure," warns the Defense Nuclear Agency. What's more, every system or electrical complex must be evaluated individually to determine its potential vulnerability to EMP. Laboratory tests, for instance, have shown that the potential vulnerability of similar systems can vary widely depending on the type of components used, the way components are connected to each other and even on the particular manufacturer of seemingly identical parts.

In a crude sense, EMP is similar to radio waves. But it exhibits important differences. EMP waves include a broader range of frequencies and amplitudes than radio transmitters can produce, and electric fields associated with EMP can be millions of times greater than those associated with radio waves. Yet like radio waves, EMP energy is picked up by antennas and conducted to attached — or in some cases, adjacent unattached—equipment.

The actual energy raining down in an EMP pulse is not all that high, which explains why humans are not affected. In fact, EMP is presumed to be no more harmful to humans than is a flash of distant lightning. *Effects of Nuclear Weapons*, a book published jointly by the Departments of Defense and Energy, adds that dogs and monkeys showed no adverse health effects after being exposed to single EMP's or pulses administered repeatedly over a period of months. Contact with an effective EMP collector, though, such as a long wire, pipe, fence, conduit, railroad track or other large metal object, could impart a hefty shock. That's because, as a general rule, the amount of EMP that any antenna collects is proportional to its overall dimensions. And virtually every electrical conductor will serve as an EMP antenna unless it is adequately shielded.

All nuclear explosions generate an EMP, although the intensity, duration and area over which the pulse is effective varies with the altitude of the burst. Even the mechanism by which EMP is generated may differ with the altitude at which a bomb is detonated.

Gamma rays emitted by nuclear reactions and gamma rays produced by neutron interactions with bomb residues and other materials are largely responsible for the processes that create EMP. As the gamma rays interact with materials, they produce an ionized region about the detonation point. "The negatively charged electrons move outward faster than the much heavier, positively charged ions," say Samuel Glasstone and Philip Dolan in their book, *The Effects of Nuclear Weapons*. This initially sets up a separation of charges, with regions nearer the blast point bearing a net positive charge while those farther away build a net negative charge. Charge separation creates an electric field that can attain its maximum value in about one hundred millionth of a second.

If the explosion occurred in an environment of perfectly homogeneous density, the electric field would be radial, symmetric and of equal strength in all directions, Glasstone and Dolan say. It would also fail to radiate electromagnetic energy—such as EMP—from the ionized deposition region. But for a variety of reasons (which can range from the detonation's proximity to the earth, to the configuration of the weapon or the vapor content of the air) truly homogeneous environments never exist. The result of nonhomogeneity is EMP.

In surface or near-surface blasts, the region of peak EMP hazard is restricted to a range of only about two to five miles from ground zero. For higher blasts — those occurring at altitudes up to 19 miles—the EMP-hazard range will increase to a nine-mile ground radius.

True high-altitude blasts are another matter. Unlike the relatively localized EMP effects experienced with surface bursts, high-altitude detonations — those occurring 19 miles up or higher — blanket a line-of-sight penumbra on earth. For a blast 50 miles up, the affected ground radius on earth would be roughly 600 miles; at 100 miles up, the ground radius would be 900 miles. And for an explosion centered over the country at an altitude of 200 miles, the entire continental United States (including parts of Canada and Mexico) would be drenched in a bath of EMP.

In these high-altitude bursts, gamma rays traveling upward enter an atmosphere of such low air density that they must go long distances before getting absorbed. Meanwhile, earthbound gamma rays encounter an atmosphere of increas-

## COMPONENTS SUSCEPTIBLE TO EMP EFFECTS

**Components Highly Susceptible to Damage**

microwave semi-conductor diodes
field effect transistors
audio transistors
silicon or selenium rectifiers
power rectifier semi-conductor diodes
vacuum tubes

**Components Highly Susceptible to Operational Malfunction**

computers
computer power supplies
transistorized power supplies
semiconductor devices terminating in long cable runs
alarm systems
intercom systems
transistorized receivers and transmitters
transistorized converters
transistorized control systems
power systems control

**Components Moderately Susceptible to Operational Malfunction**

Vacuum tube equipment such as:
- transmitters
- receivers
- alarm systems
- intercoms
- teletype-telephone
- power supplies

Equipment with low current switches, relays, meters, such as:
- alarms
- power system control panels
- panel indicators
- status boards
- process controls

Other equipment:
- long power cables
- high energy storage capacitors or inductors

**Components Least Susceptible to Operational Malfunction**

High voltage 60 hertz equipment:
- transformers
- motors
- heaters
- rotary converters
- filament lamps
- heavy duty relays
- circuit breakers
- air insulated cables

## HOW LIKELY IS A RAIN OF EMP?

Only a few years ago, nuclear war was depicted as the end of civilization: After the radioactive clouds settled, life as we know it was supposed to grind to a halt. No more. Today, military strategists speak in terms of surviving a nuclear volley, and civil-defense planners are concentrating on postwar recovery schemes to restore vital services and government once the nuclear exchanges cease. So long as strategists think the nation can survive a nuclear volley — perhaps even win one — the concept of nuclear warfare remains plausible. It becomes a real option, ghastly as that option may be.

Hence, a growing civilian interest in EMP. While the radioactive contamination and explosive effects of nuclear warfare could prove massive, there has conventionally been reason to believe some hinterlands would escape relatively unharmed. But "EMP removes the possibility of an unscathed 'hinterland,' and thereby potentially adds an entirely new dimension of damage," explains a 1972 study by Oak Ridge National Laboratory.

It's this aspect that makes high-altitude detonations so awesome. While the searing heat, radiation and explosion will probably obscure any EMP effects in most ground blasts, it will be the other way around with high-altitude explosions; EMP effects will dominate.

And, "In a nuclear attack, a series of high-altitude bursts is likely," notes a July 1973 report prepared by the former Defense Civil Preparedness Agency. "The source of these bursts may range from an attacker's offensive missiles detonated explicitly to produce EMP effects, to our own defensive missiles deployed to intercept offensive missiles. It seems reasonable, then, to expect dozens or perhaps hundreds of high-altitude defensive and offensive bursts spread out over a period of a few minutes or an hour."

But Bill Macklin of IRT Corp. points out that there are other possible scenarios. For instance, a small terrorist group could seek ostensibly peaceful retribution against economic threats and political aggression by unexpectedly detonating one or a series of nuclear devices in the upper atmosphere of their enemy's territory. It needn't kill anyone, but it could certainly take an enormous economic toll.

Paul Fleming of the Defense Nuclear Agency tends to discount such hypothetical scenarios, asking, "Is that a creditable terrorist action?" He suggests that it's a costly and difficult gambit with no clear payoff and adds that it may also require more technological sophistication than most poor terrorists can muster.

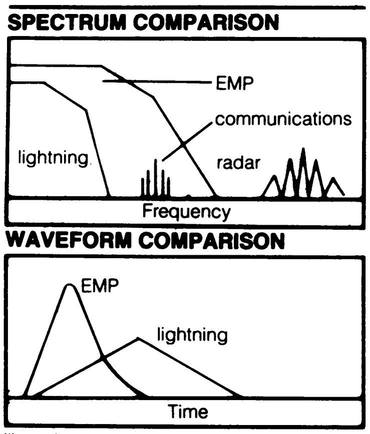
What worries people like Macklin, however, is the existence of firms that might sell a launch capability to anyone with money. The West German firm Otrag (Orbital Transport und Raketen Aktiengesselschaft AG), for instance, is preparing to offer just such a service and has focused its marketing on the Third World. Last month Otrag announced a fourth test of its low-cost single-stage launch vehicle from a site in Libya. A two-stage vehicle is expected to be test launched later this year, and by 1985 the company expects to be able to launch craft into orbit.

According to the March 23 AVIATION WEEK AND SPACE TECHNOLOGY, Otrag's president, Frank Wukasch, "confirmed that the test firings in Libya have led to recent charges from the government of Morocco that the revolutionary regime of Libya's Col. Muammar Qadhafi was using Otrag to acquire a capability to develop medium-range missiles." While Wukasch dismissed this assertion, NASA's Lynn Hanold told SCIENCE NEWS, "It is a fact that this company has basically said they'll launch any customer who would pay them. And there are people who are concerned they would then be open to launch something military because they're not interested in approving or passing judgment on what the payload is but just providing a launch service."

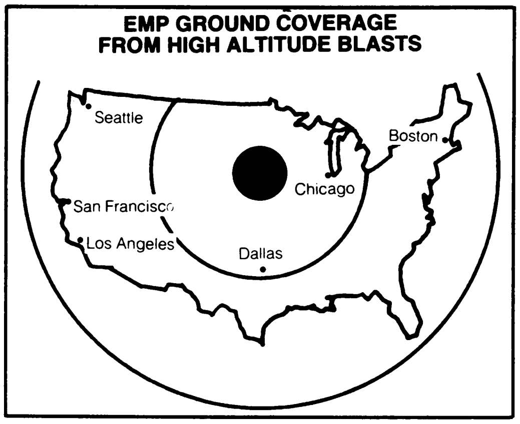
Otrag and Av. Week and Space Tech.

*Otrag launch vehicle lifts off from Seba Oasis in Libya's Sahara Desert during test. Otrag hopes to have vehicles able to put satellites in orbit by 1982.*

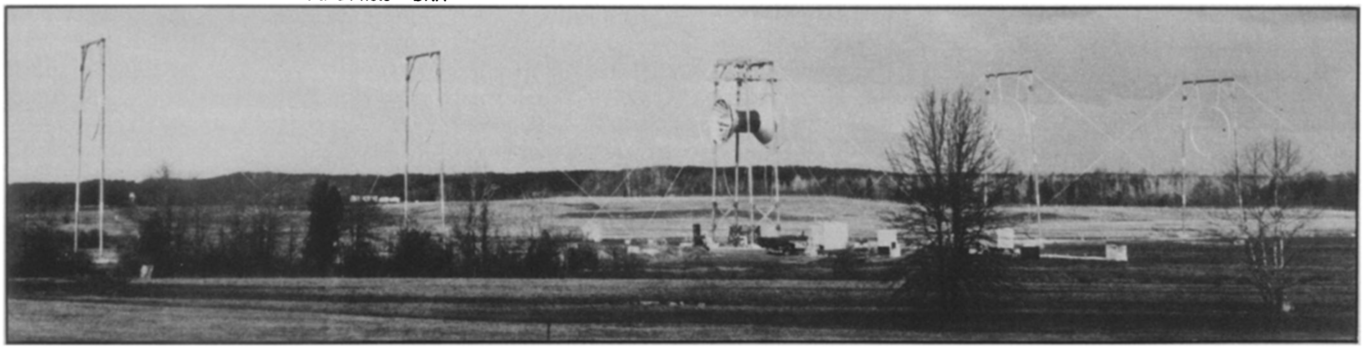
*Unlike lightning, EMP delivers its energy across a broad spectrum of frequencies, including those used for broadcast communications (top). And though EMP imparts less energy than does lightning, it delivers its energy 100 times faster, usually faster than lightning arrestors can handle.*




Illustrations and Photo—DNA




*High-altitude detonations blanket wide penumbral regions on earth with EMP. Peak electromagnetic fields reach 50,000 volts per meter. Inner circle shows ground showered by EMP from blast centered above dark spot at altitude of 62 miles; outer circle shows coverage for blast 330 miles up.*



*Portable EMP simulators, like this one in Maryland, are used to test the vulnerability of components and systems in war environments.*

ing density. Their inevitable interaction with air molecules sets up an EMP source region. Roughly circular, this source region may climb 50 miles in its center. Horizontally it blossoms too; how far depends on the bomb's kiloton yield and altitude at detonation.

In this EMP-generating source region, gamma rays emitted by the blast collide with air molecules, creating what are known as Compton electrons. (In 1922 Arthur Holly Compton discovered that photons such as gamma rays are able to knock electrons from orbits about the atoms to which they had been bound. The process is roughly analogous to a flying billiard ball colliding with another at rest. The recoil electron, like the initially stationary billiard ball, is generally propelled forward.) The earth's magnetic field deflects the Compton electrons, forcing them to spiral about the magnetic-field lines. "This motion causes the electrons to be subjected to a radial acceleration, which results, by a complex mechanism, in the generation of an EMP that moves down toward the earth," Glasstone and Dolan say.

The pulse crescendos to a peak, then decreases. In fact, it's the nature of this time-varying radiation to peak rapidly, then decay somewhat more slowly. Amplitude, or strength, varies widely over its broad frequency domain, which extends from about zero to 150 megahertz (million cycles per second) with 99.9 percent of the energy below 100 MHz. The rise and fall of the signal occurs more rapidly than in an equivalent-size surface burst; therefore, more of the electromagnetic energy pulsed by the high-altitude explosion falls into a higher frequency range. And for high-altitude bursts with yields of a few hundred kilotons or more, electric-field strength will vary by no more than a factor of two over most of the area showered by EMP. Maximum EMP fallout can reach 50 kilovolts per meter.

Comparing EMP with lightning illuminates some of the problems that come in designing systems to withstand a large EMP. For instance, the induction field created in association with a 100 kV/m lightning stroke is on the order of one kV/m electric field, with a high amplitude rise time peaking in one to five microseconds. In contrast, for a large, high-altitude nuclear burst, the fields radiated onto the earth's surface peak in 10 nanoseconds —roughly 100 times faster than lightning.

This fast rise time represents a double-edged sword. First, it means the spectral energy will be distributed much more broadly throughout the electromagnetic band — including the lower microwave range. Second, the rise time is so rapid that an EMP can zip through a system — destroying sensitive electronics along the way — before lightning arrestors or other defensive power-shunting switches can respond to the surge.

"In other words, EMP is sufficiently different from any other electromagnetic environment usually encountered that protection practices and components for non-EMP environments—radio-frequency interference, lightning, radar, etc. — are not directly applicable to EMP problems," explains the Defense Nuclear Agency's EMP Awareness Course Notes.

For systems whose continuous operation is deemed critical, such as military surveillance, communication and attack units, EMP protection — known in the jargon as "hardening" — becomes essential. And not surprisingly, the military has attacked the problem of hardening more aggressively than has any other industry. Just last month, at a conference in the State Department, Lt. Gen. Paul Gorman, policy and planning director for the Joint Chiefs of Staff, announced that "hardening our [communications, command, control and intelligence systems] against electromagnetic pulse ... will be one of the major strategic undertakings of the 1980s."

The public communications and power industries have been far less ambitious, however, for a number of reasons, including the cost necessary to retrofit EMP hardening to their vast networks.

But the single most vulnerable segment of society—the electronics industry—has to date largely been overlooked in terms of assessing the degree to which its products are increasing the nation's vulnerability to EMP. However, IRT Corp. has begun a rough survey of the computer's role in society with an eye toward generalizing just that. And based on preliminary data, Macklin says, "We're awed by it." From automation of food processing to the computer control of fuel and power supplies, there could be a major civil defense threat brewing, he suggests. "And I think it's an issue that [the Federal Emergency Management Agency] should be interested in," he says. To underscore that point, he will see that FEMA gets one of the first drafts of the IRT study. □

*Next week: EMP hardening strategies.*