FEMA 128/June 1987
(Supersedes CPG 2-1A4 dated May 1982, which may not be used.)

ATTACK ENVIRONMENT MANUAL

Chapter 4

What the planner needs to know about Electromagnetic Pulse

FEDERAL EMERGENCY
MANAGEMENT AGENCY

LIST OF CHAPTER TITLES

*Chapter 3 will be published at a later date.

PREFACE TO CHAPTER 4

The discussion of EMP is aimed at the emergency planner and operator rather than the engineer or communications specialist. It is assumed that the reader is familiar with the material in the three preceding chapters. Since equipment damage from the electromagnetic pulse (EMP) is most significant for a detonation outside the earth's atmosphere, other effects of high-altitude bursts (radio blackout and thermal radiation) have been included. Chapter 4 is the only chapter in this manual that discusses these high-altitude attack effects.

One special point should be made about EMP effects. Exposure to the EMP fields is harmless to most people, the possible expectations being those dependent on electrical life support systems such as pacemakers. The energy collected on large metallic objects or long wires might conceivably be great enough to cause burns or electrocution if a person is touching the conductor or is close enough to become part of an arc path.

Equipment effects, in contrast, can be severe. Commercial power is likely to be lost. Protected backup power sources and communication facilities are essential for any system which must operate immediately after attack. Unhardened electrical and electronic components may be damaged. This means that the emergency planner must identify capabilities needed to perform the mission after an EMP event and initiate actions to protect essential equipment.

Information is presented in the form of "panels," each consisting of a page of text and an associated sketch, photograph, chart or other visual image. Each panel covers a topic. This preface is like a panel, with the list of topics in chapter 4 shown opposite. If the graphic portion is converted into slides or vugraphs, the chapter or any part can be used in an illustrated lecture or briefing, if so desired.

After introductory material on EMP, the chapter addresses the general nature of the electromagnetic pulse. There follow panels summarizing the likely effects on various communications and power systems and ways to minimize EMP damage to these systems. Finally, two panels discuss the accompanying high-altitude effects of radio blackout and thermal ignitions. A list of suggested additional reading or references is included.

FOREWORD

WHAT THE EMERGENCY PLANNER NEEDS TO KNOW ABOUT THE NATURE OF NUCLEAR WAR

No one has gone through a nuclear war. This means there isn't any practical experience upon which to build. However, emergency management officials are responsible for preparing for the possibility of nuclear war. Intelligent preparations should be based on a good understanding of what operating conditions may be like in a war that has never occurred. If the planner lacks such understanding, the emergency operations plans produced probably won't make sense if they ever have to be used.

The Attack Environment Manual has been prepared to help the emergency planner understand what such a war could be like. It contains information gathered from over four decades of study of the effects of nuclear weapons and the feasibility of nuclear defense actions, numerous operational studies and exercises, nuclear test experience, and limited experience in wartime and peacetime disasters that approximate some of the operating situations that may be experienced in a nuclear attack. In short, it summarizes what is known about the nuclear attack environment as it could affect operational readiness at the local level.

The data on the effects of nuclear weapons used in this manual have been taken from the 1977 edition of "The Effects of Nuclear Weapons" (ENW), compiled and edited by S. Glasstone and P. J. Dolan and prepared and published by the United States Department of Defense and the United States Department of Energy. Copies are available for purchase from the U.S. Government Printing Office. The ENW is the most widely available authoritative source of weapon effects and is in many public libraries across the country. For these reasons it was chosen as the source data in this manual.

The Attack Environment Manual supersedes CPG 2-1A1 through 2-1A9.

CONTENTS OF CHAPTER 4

WHAT THE PLANNER NEEDS TO KNOW ABOUT ELECTROMAGNETIC PULSE

WHAT IS "EMP"?

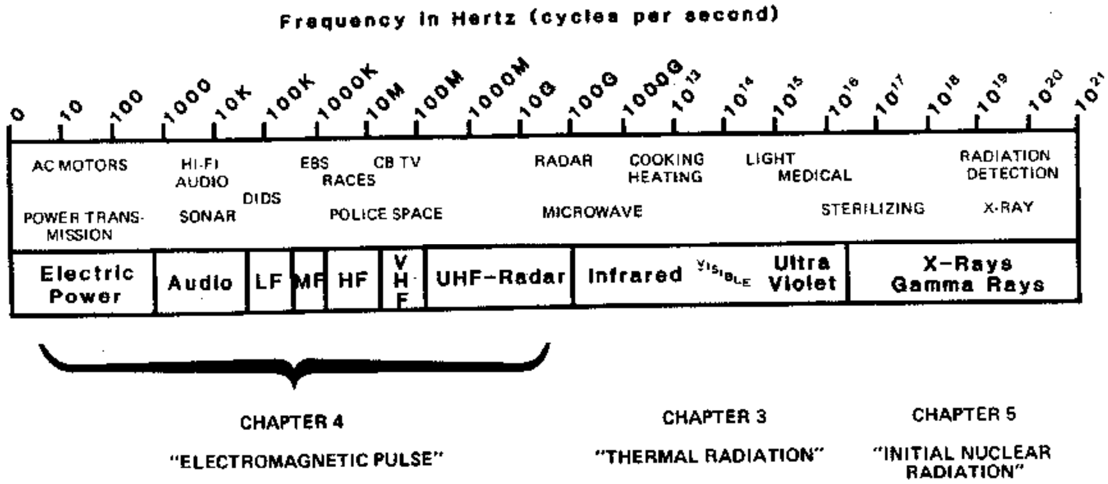
In chapter 3 we discussed the capability of the thermal radiation pulse to burn the skin of exposed people and to ignite flammable materials within the area damaged by the blast wave. We loosely called this radiation energy "heat radiation" to appeal to the human senses. The radiation itself, of course, is merely a form of electromagnetic radiation, such as is sunlight, which manifests itself by a rise in temperature as it is absorbed in or near the surface of objects it strikes.

A nuclear detonation also emits electromagnetic radiation of longer wavelengths (lower frequency) than the infrared and visible light of the thermal pulse. Most of this energy is radiated in the frequency bands commonly used for radio and TV communications. For this reason, it sometimes is called "radio flash."

The effects of electric and magnetic radiation in the electric power and radio frequencies have received a great deal of attention, but the complexities of the phenomena are of concern only to specialized electronic engineers and communications experts. Suffice it to say here that the electromagnetic pulse (EMP) from nuclear detonations is an indirect result of the gamma ray and X-ray output. These radiations interact with the earth's atmosphere, producing electrons which subsequently generate electromagnetic waves.

EMP is generated by a nuclear burst at any altitude. The presentation, however, will emphasize the high-altitude case. A surface or near surface detonation generates an intense but largely localized EMP near ground zero. In regions where surface burst EMP field strengths exceed the high-altitude threat, other weapons effects (such as blast, shock, nuclear and thermal radiations) are usually the dominant destructive mechanisms.

THE ELECTROMAGNETIC RADIATION SPECTRUM



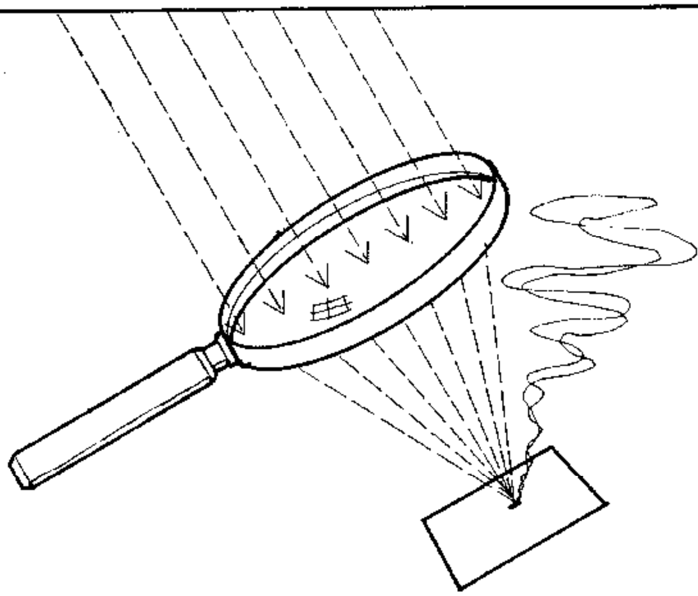
WHY WORRY ABOUT EMP?

Generation of EMP by a nuclear detonation was expected from the earliest days of nuclear testing, but the magnitude and potentially serious nature of the threat were not recognized for several years. Malfunctions of instrumentation and other electronic equipment were observed, however, during atmospheric tests in the early 1950's and attention began to focus on EMP. It was first mentioned in a chapter on radio and radar effects in the 1962 version of the "Effects of Nuclear Weapons" but the description was brief and no hint was given as to its damaging effects.

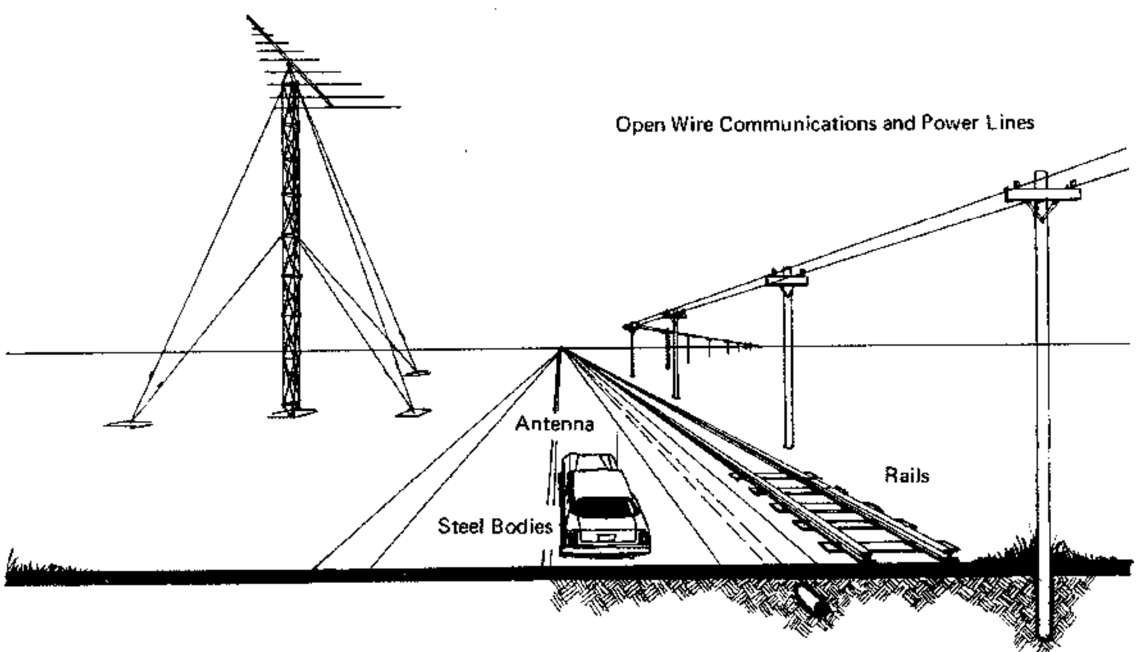
One reason for this lack of attention has been that the energy contained in the EMP pulse is much smaller than that in the thermal pulse. We saw in chapter 3 that, where the blast overpressure is 5 psi, the thermal energy is about 100 calories per square centimeter. At the same distance from a surface burst, the EMP energy is equivalent to much less than one calorie per square centimeter.

We know that sunlight can be focused by a magnifying glass so as to ignite paper. If magnifying glasses or their equivalent were common in target areas, we would need to be concerned about very low levels of thermal radiation in nuclear attack. Fortunately, this is not the case. But natural energy collectors for radio frequencies are widespread. They magnify the weak EMP somewhat as a magnifying glass does sunlight.

Anyone who has improvised a radio antenna, perhaps with a coat hanger, knows that almost any metallic object can collect energy from radio waves. Any long wire can pick up the energy in the electromagnetic field and then deliver it in the form of current and voltage pulses to the attached equipment. The larger or longer the conductor, the greater the amount of energy collected. For example, the sort antenna of an automobile radio will collect less energy than a large broadcast station transmitting antenna. Typical collectors (antennas, whether or not so intended) of EMP energy include long exposed cable runs, piping or conduit, large antennas, metallic guy wires, power and telephone lines, pipes and cables if buried only a few feet below the surface, long runs of electrical wiring in buildings, and the like. Sufficient energy can be collected by these metal objects to cause damage to attached electrical and electronic equipment.



A THERMAL ENERGY COLLECTOR



EMP ENERGY COLLECTORS

PANEL 2

SURFACE BURST EMP

There are two burst conditions of major concern with respect to EMP: (1) the surface or near-surface burst, and (2) the high-altitude detonation above the earth's atmosphere. Detonations at altitudes between these two conditions produce much lower intensities of EMP. The high-altitude burst is covered in later panels.

For a tiny fraction of a second before the fireball is formed, the X-rays from the weapon exploded at the surface create an oscillation of electrical charges in the air molecules surrounding the explosion. This region, somewhat smaller than the subsequent fireball, is called the "source region." A brief pulse of electromagnetic energy is radiated outward as shown in the upper illustration.

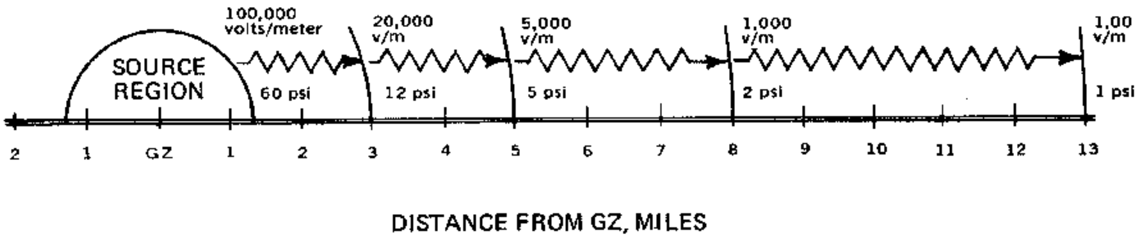
The strength of a radio wave is measured in terms of the voltage stress produced in space by the electric field of the wave, usually expressed in micro-volts (millionths of a volt) per meter. This measure is also the voltage that the magnetic field of the wave induces in a conductor 1 meter long when sweeping across this conductor with the speed of light. (A meter is a little over 39 inches or about 10 percent longer than a yard.)

But the field strength in the EMP pulse is not measured in microvolts. Rather thousands of volts or "kilovolts" per meter is a more appropriate measure. The table shows a comparison of the maximum EMP field strength with more common sources, in every case close to the "source region," whether it be detonation, transmitter, or power line.

Ordinary radio receivers are designed to sense very low levels of electromagnetic energy. Under some circumstances, signal strengths as low as 0.1 microvolt per meter are usable. Occasionally, signal strengths exceeding 1,000 microvolts (1 millivolt) per meter are required to assure satisfactory radio reception. In most cases, the weakest useful signal strength lies between these extremes.

The thousands of volts per meter in the EMP pulse is in a different ballpark compared to signal strengths used in communications. While the EMP problem in a surface burst is largely found closer in, where other effects are much more destructive, in high-altitude bursts the problem is much more extensive.

EMP FROM A MEGATON RANGE SURFACE BURST



COMPARISON OF ELECTROMAGNETIC FIELDS

SOURCE	INTENSITY (volts per meter)
EMP	UP TO 100,000
RADAR	200
RADIO COMMUNICATION	10
METROPOLITAN "NOISE"	0.1

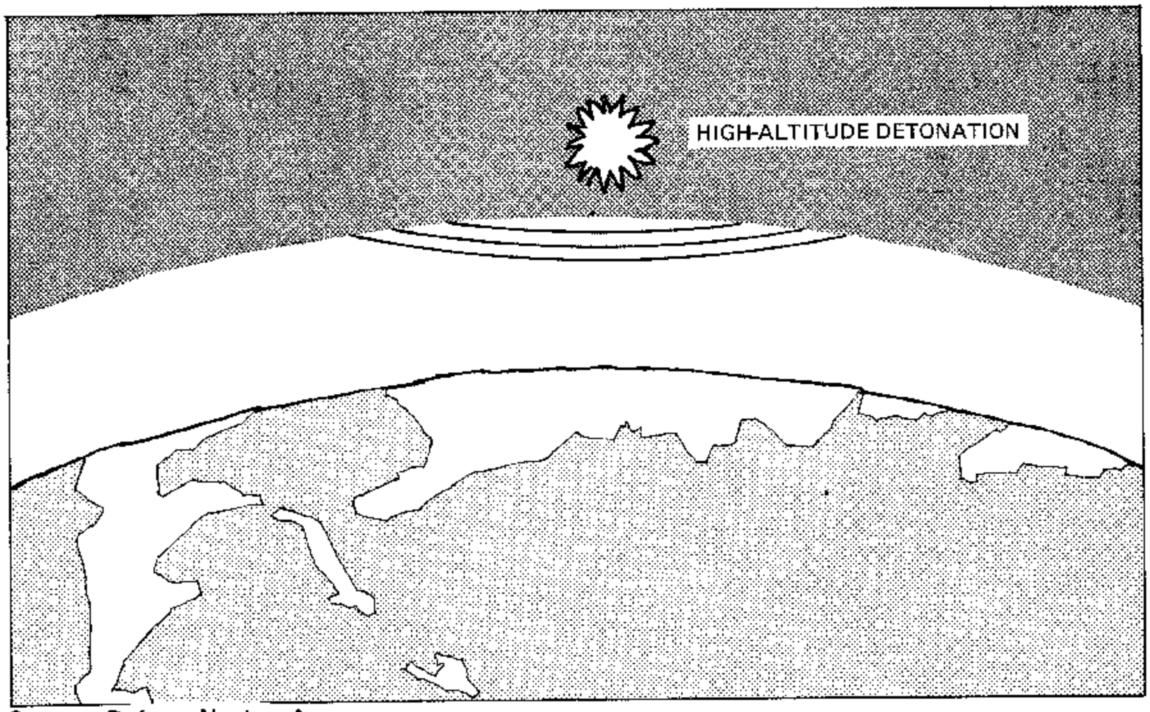
Source: Defense Nuclear Agency

HIGH-ALTITUDE BURST EMP

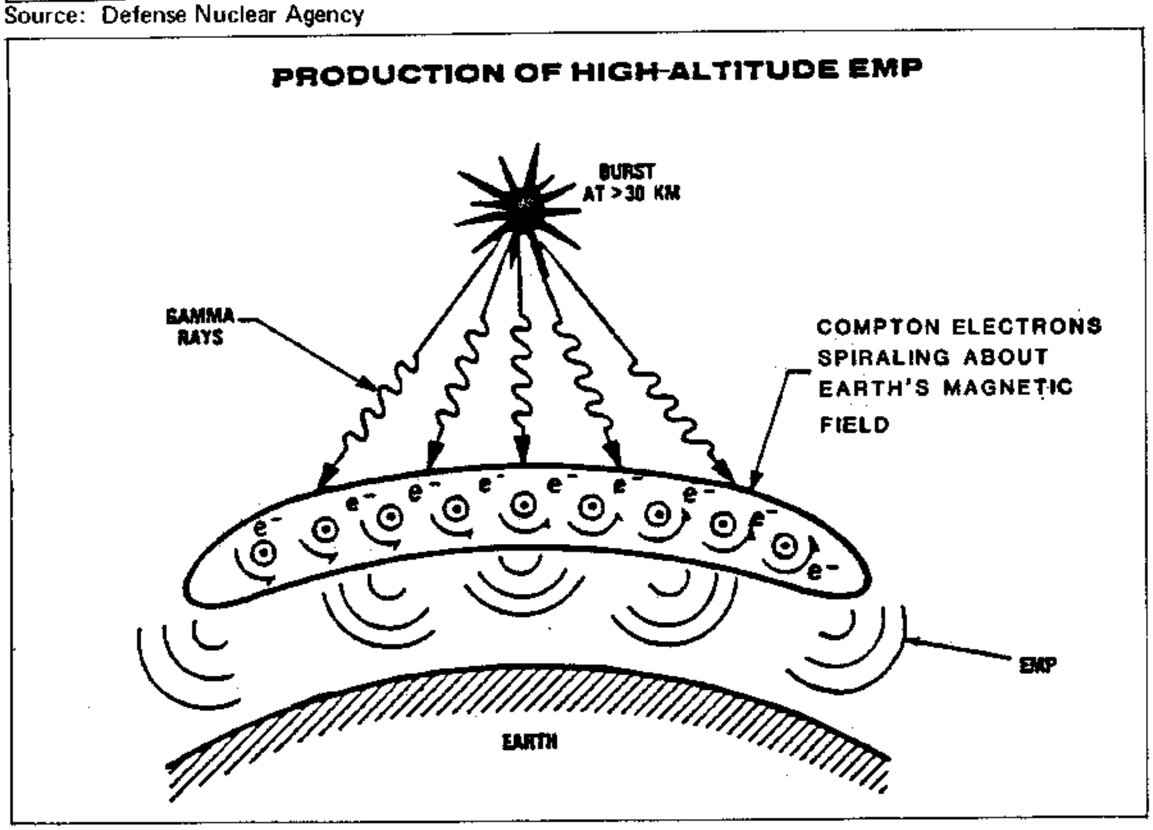
If a nuclear weapon is detonated high above the earth's atmosphere (an exoatmospheric burst), the X-rays and gamma rays emitted downward from the explosion will be absorbed in a big "pancake" layer of the atmosphere between 12 1/2 and 25 miles above the earth's surface, as shown in the upper view.

The gamma energy is converted into lower-frequency electromagnetic energy in this interaction region and propagated downward to the earth's surface as a very brief but powerful electromagnetic pulse. The strength of this pulse on the ground is in the order of tens of thousands of volts per meter, much the same as the field strength in the moderate damage area of a surface burst. However, very large areas, otherwise undamaged, can be affected by the high-altitude detonation, as the lateral extent of the "interaction region" is generally limited only by the curvature of the earth.

The shape and strength of the pulse emitted and of the transient produced by it on a conductor vary with size, shape, conduction properties, location, and soil types. Peak values can be expected to reach thousands of amperes, hundreds of joules, and hundreds of kilovolts. These are less than some lightning peaks, but the EMP induces much energy at frequencies not found in lightning. Thus, lightning protection, especially where long wires are involved, does not necessarily protect against EMP.



Source: Defense Nuclear Agency



Source: Defense Nuclear Agency

HIGH-ALTITUDE EMP COVERAGE

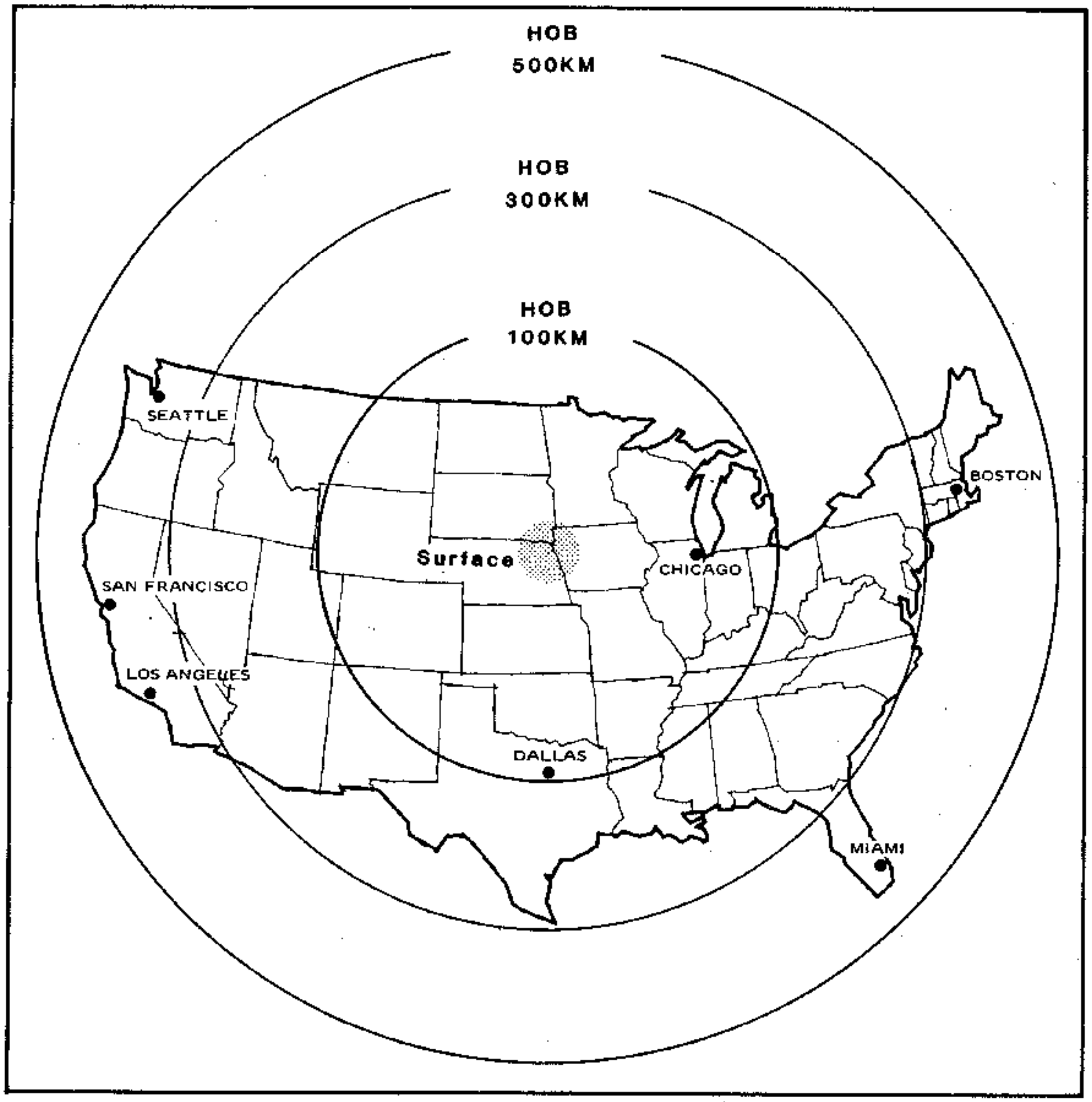
In the case of an exoatmospheric burst, blast damage does not occur at ground level and other effects require no protection, except for the EMP. The source region at 12 1/2 miles above the earth's surface can be quite large, perhaps a thousand miles in diameter. As a consequence, the radiated fields from this source region can cover a substantial fraction of the earth's surface.

This panel shows the ground coverage of the EMP from bursts at three altitudes (100 km, 300 km, and 500 km) centered over Omaha, Nebraska. Within the inner circle (height of burst 100 km) ground level electric fields of a few tens of thousands of volts per meter would be created. The outer circle shows the coverage of a few volts per meter resulting from a similar burst at 500 km altitude. This circle covers the 48 contiguous states. (Actual fields are not really circular, but it is convenient to show them in simple form.)

That these pulses can cause damage to electrical and electronic equipment is not simply a matter of scientific theory. The failure of approximately 30 strings of street lights on Oahu at the time of the Starfish detonation about 750 miles away over Johnson Island was the most publicized effect during the weapons test series Operation FISHBOWL in 1962.

High-altitude bursts are no longer unlikely. The deployment of those ballistic missile defenses permitted by treaty with the Soviet Union could include the use of megaton-yield warheads to intercept incoming weapons outside the atmosphere. Even if this were not in prospect, the effectiveness of EMP in interrupting communications would make it quite possible that some of the thousands of warheads discussed in chapter 1 would be used for this purpose.

An implication for operational planning is that a potential EMP threat must be anticipated in every locality during the first minutes and perhaps hours after a nuclear attack is initiated.



EMP GROUND COVERAGE FOR HIGH-ALTITUDE BURSTS AT 100, 300, AND 500 KM

Source: Defense Nuclear Agency

DAMAGE FROM EMP

Electrical and electronic systems may be disrupted by EMP in two distinct ways:

(1) Functional damage. This requires replacement of a component or parts of a unit, perhaps a circuit board or a fuse.

(2) Operational upset. This is a temporary interruption or impairment of electrical equipment such as opening of circuit breakers or erasure of a portion of the memory of a computer.

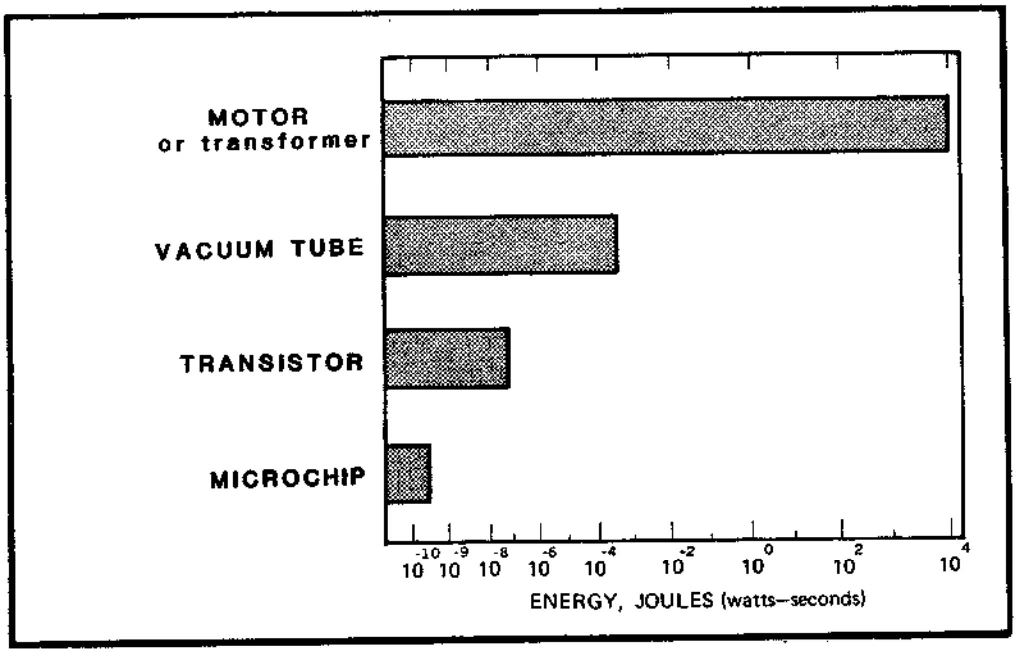
Either of these events will prevent continued operation of the equipment until it can be repaired or replaced.

Relative sensitivity of selected devices is indicated in the accompanying bar graph. Motors, generators, transformers, and other 60 Hz equipment are less susceptible, while control systems and computers are highly susceptible to damage or upset. Values shown in the panel are not truly specific but are given for comparison only, for seemingly similar components may have damage or upset thresholds which differ widely.

Experiments have shown that civil defense radiation detection equipment is not susceptible to direct damage, nor are hand-held Citizens Band walkie-talkies or FM radio receivers.

It has been found that communications equipment employing bipolar transistors with self-contained batteries and loop antennas are not susceptible to direct EMP damage. Equipment with stick antennas up to 40 inches long usually can be operated safely. Equipment using field-effect transistors is sometimes more sensitive.

To put all this in perspective, we must emphasize that while many types of electrical/electronic equipment could be affected or even knocked out by the EMP from high-altitude bursts, a rather small percentage overall is likely to be damaged. There are so many scientific uncertainties that remain in this area of technology that no one can state with any degree of certainty just how much damage could be expected. Certainly, some automobile ignition systems could fail, as could some portions of telephone and radio communications and airline communications, navigational aids, and electrical/electronic equipment. However, the concept of total oblivion for all electronic equipment and data stored on magnetic media (disc or tape) in all North America is a fantasy without scientific validity.



SENSITIVITY OF VARIOUS COMPONENTS

NOTE: 300 feet of wire can absorb about 1/10 to 40 joules of energy depending on orientation and proximity to other conductors.

Source: Defense Nuclear Agency

EMP PROTECTION (HARDENING)

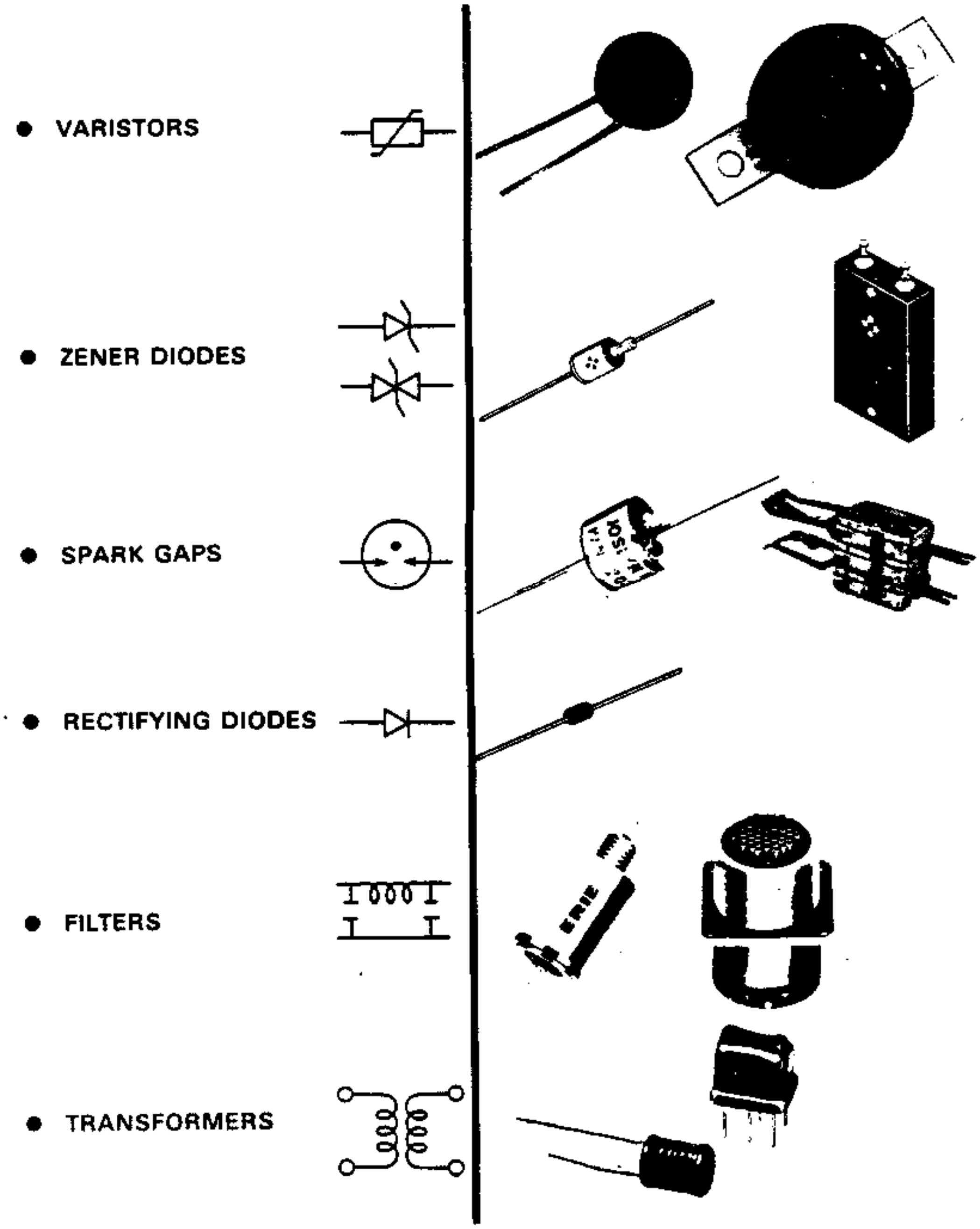
The original designs for all new facilities that must communicate with others during or after a nuclear event should include EMP protection. Simple EMP protective measures include low cost features such as those shown in the opposite panel:

- Use of "voltage clipping" devices to protect sensitive transistors.
- Selection of noise-immune cable and grounding systems, using balanced twisted-pair cables in shielded conduit.
- Careful layout of conductor systems to avoid large loops.

In most EMP shielding situations, the design and construction costs for mechanical fabrication, corrosion protection, and penetrations treatment far exceed the cost of the shielding material. The shielding material, therefore, can be over-designed without significant increase in cost. It is easy to include EMP protection in both the budget and construction of the new EOC's, but it is both tedious and expensive to retrofit existing installations. Older EOC's can suffer from the sometimes invisible effects of deterioration of welds and other connections as well as undocumented modifications and uncontrolled construction practices. Consultation with FEMA regional offices is useful whenever such retrofit is being considered.

For the private individual or business, as well as for smaller EOC's, it is worthwhile to consider intuitively effective ideas. For example, a sensitive unit is much less vulnerable if the "power plug is pulled" and left a foot or so from the power source. Plans for putting much smaller sensitive gear into metal containers--even foil wrapping or garbage cans--are not improper, but their value cannot be stated in quantitative terms.

TYPES OF SUPPRESSORS



PANEL 7

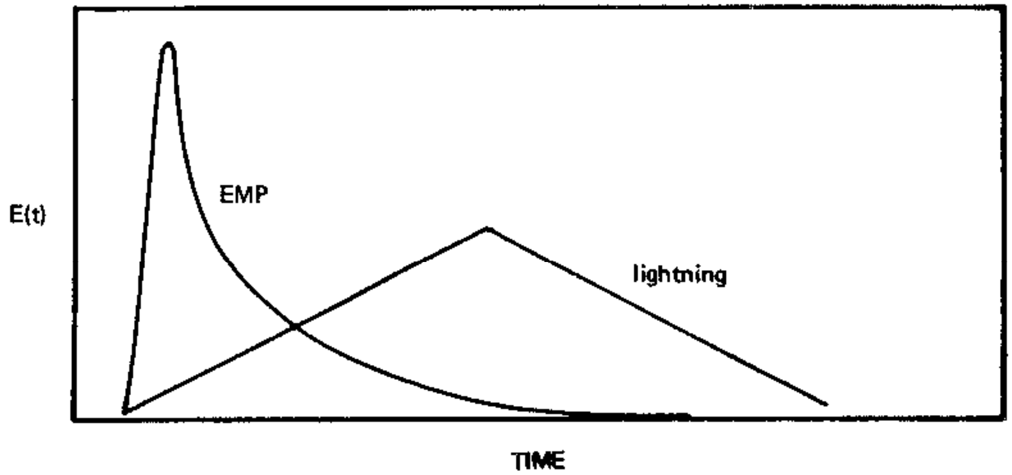
EMP AND LIGHTNING

Engineers and scientists have discussed the protection of radio and electrical equipment from EMP effects by comparing this problem with that of protection against lightning. Lightning is the only naturally occurring phenomenon that has electrical currents, voltages, and fields associated with it that are in any way comparable to the electromagnetic effect of a nuclear explosion. Everyone has heard the electromagnetic static produced in radio reception by distant lightning strokes. Most people are aware that large antennas and other tall structures are protected by "lightning arrestors" to prevent damage to sensitive equipment.

The upper sketch shows that EMP occurs much more rapidly than does a lightning stroke. Thus, devices, such as spark gaps, that are suitable for lightning protection may permit large EMP-induced overvoltages to pass before they operate.

The lower sketch shows that EMP is a broadband pulse with frequencies ranging from almost zero to more than 100 megahertz. It therefore spans all of the communications frequencies. The electromagnetic waves associated with lightning are confined to the lower frequencies. Thus, filtering out the EMP frequencies is more difficult that is the case with lightning.

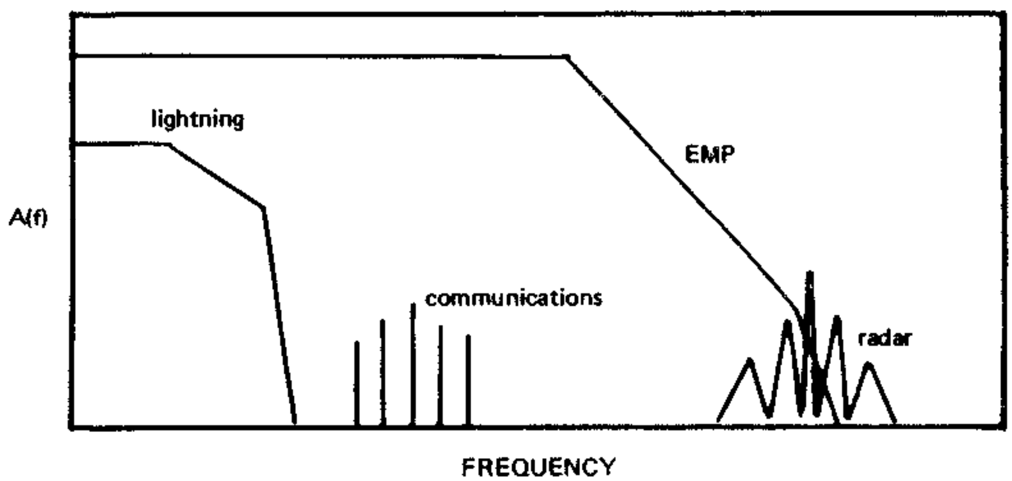
TIME HISTORY
COMPARISON WITH LIGHTNING



NOTE: Rapid rise of EMP pulse

Source: Defense Nuclear Agency

SPECTRUM COMPARISON



NOTE: Broad frequency range of EMP

Source: Defense Nuclear Agency

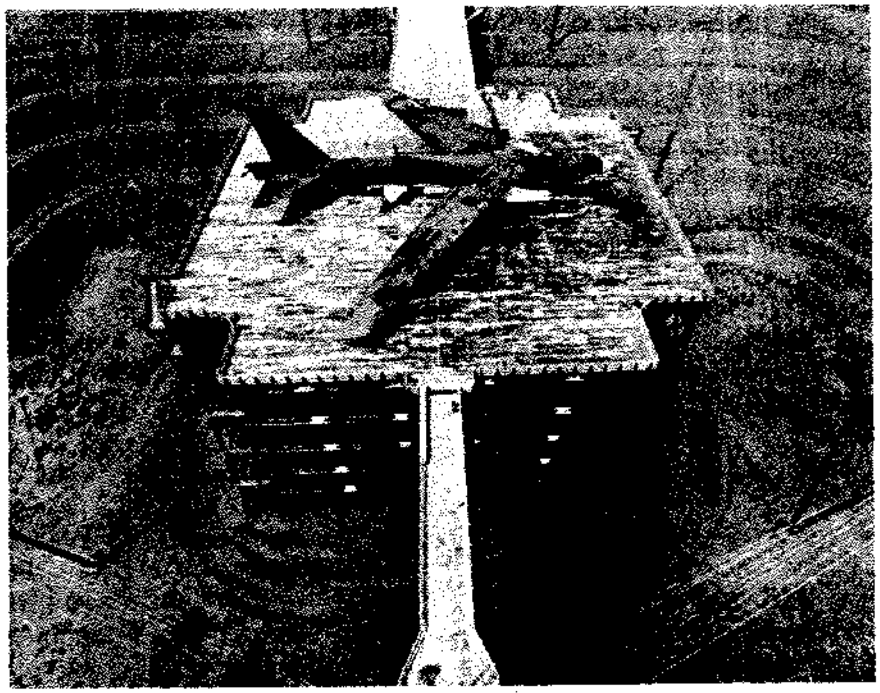
EMP TESTING

Many obscure details determine the actual vulnerability of a given system. This requires testing, and experimental facilities have been developed for evaluating system survivability.

Survivability of an electrical or electronic system in an EMP environment is often highly dependent upon relatively minor details of its design and installation. For example, control systems with identical functions may be implemented using heavy duty relays and vacuum tubes, transistorized circuits, or highly sensitive microcircuit technology. The quality of EMP suppression and grounding may reduce the induced signal at the component level by several orders of magnitude.

Simulators are usually unable to reproduce the pulse from a wartime burst in full detail, but testing agencies can compensate for this by wiring directly into sensitive components. Some test units of this type are available for field evaluations.

One fixed simulator is shown in the accompanying illustration. The environment generated by this facility approximates the pulsed electric and magnetic fields of the typical EMP threat waveform shown earlier. A complete system can be placed in the test volume and illuminated with near threat fields in its operating configuration.



Source: Defense Nuclear Agency

VULNERABILITY OF BROADCAST RADIO

EMP poses a potential threat to AM, FM, and TV broadcast transmitters. There are three areas of concern regarding EMP damage to radio station operation: (1) pulse energies collected by large broadcast antennas; (2) conducted pulses from power lines and other long external conductors; and (3) directly induced transient currents in low voltage circuits.

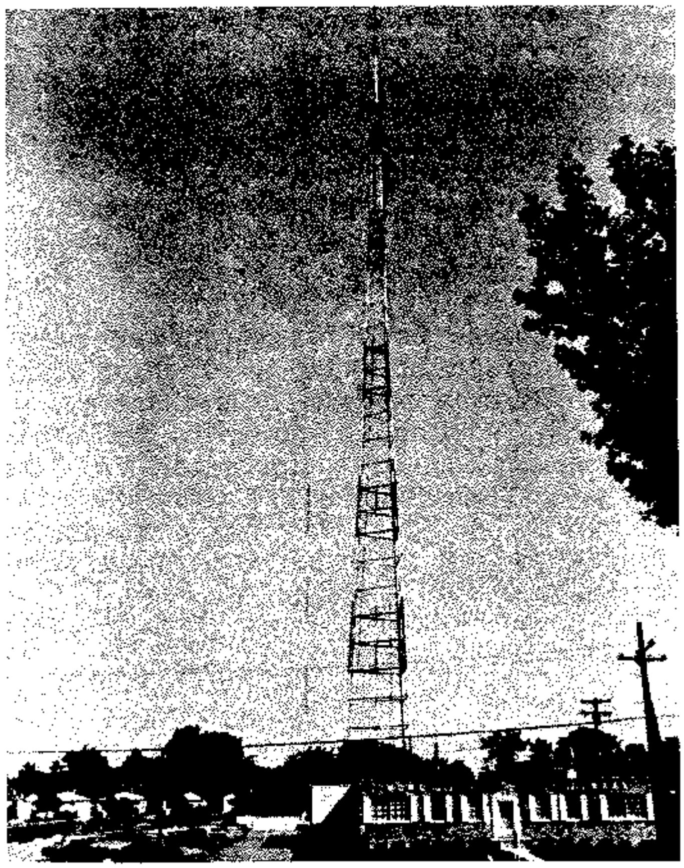
Although the energy collected by large antennas may be less than that from an average direct lightning stroke, the limited protective capability of the usual spark gap against the higher frequency components of EMP may place a strain exceeding that of lightning on transmitter, antenna insulators, transmission lines, and matching network components. Since we know that lightning frequently damages high-voltage capacitors, it may be concluded that EMP would cause capacitor damage and perhaps also problems with other components.

Damage from pulses arriving on commercial power connections is also possible since about one-quarter of the voltage collected by the power lines will pass the nearby distribution transformers. Such problems could be more serious than those from antenna coupling because they could be harder to diagnose and rectify. A standby electric generator would solve this problem, providing the station can be disconnected from commercial power before the first detonation. Because this must be done manually, station personnel should make provisions to react promptly to attack warning.

Broadcast station wiring and circuits can act like loop and wire antennas, collecting radiated energy. Transistors are especially susceptible to low-level energy pulses induced in connected circuits. Vacuum-tube transmitters are much less vulnerable.

There are many known ways to protect broadcast stations from possible EMP damage. Technical training is required to understand these protective measures. The planner should assure that local broadcast station operators have access to the EMP protection publications. Those stations in the Broadcast Station Protection Program (BSPP) have access to the EMP Protection Program through their FEMA Regions. EMP protection also protects against lightning and surges of power on commercial lines.

Hand-held, battery-powered receivers, with either internal loopstick antennas or their usual short pullout antennas, are seldom affected by EMP. They thus could receive information broadcast by EMP protected radio stations. These receivers, however, should be kept away from any electronic lines, pipes, or conductors that might carry the high voltage, high current EMP that could in turn affect the receiver.

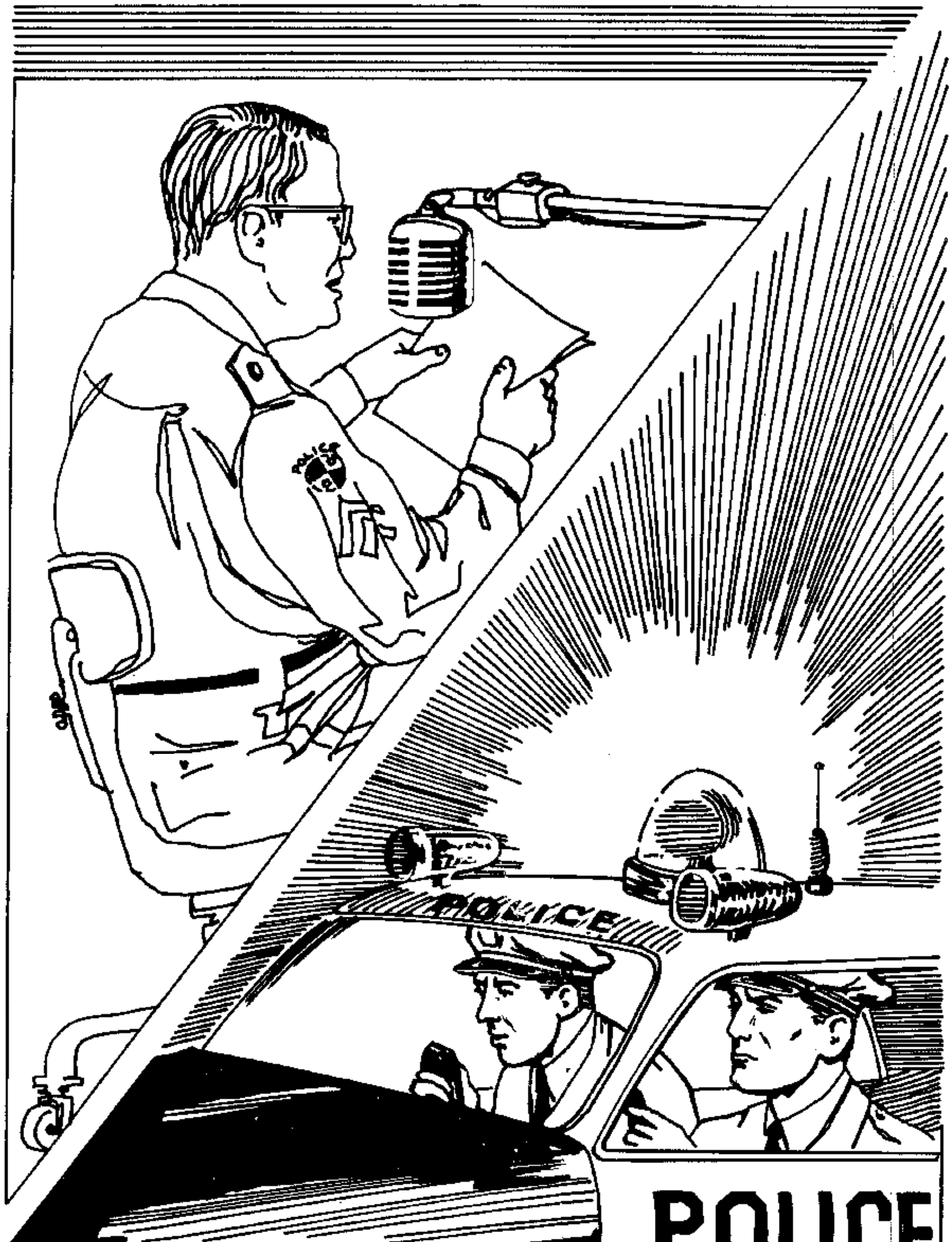


Photograph courtesy of Carl T. Jones Associates, Springfield, Virginia.

VULNERABILITY OF PUBLIC SAFETY RADIO

Police, fire, public works, and other local government radio nets typically perform a crucial role in disaster operations. To these systems can be added emergency amateur radio organizations, such as RACES (Radio Amateur Civil Emergency Service). The base stations (and relay stations) in these networks have the same general vulnerability to EMP as do commercial broadcast stations. Even at high frequencies where antennas are short, long cables are often used to connect the antenna to the transmitter. Furthermore, many base stations cannot operate in the absence of commercial power. Unless these facilities are equipped with standby electric power and EMP protective devices, they are likely to go off the air in a nuclear emergency.

Mobile units in these systems have battery powered supplies and relatively short antennas. They are most likely to remain operable, particularly older models, most of which have vacuum tube circuits. But even those should be considered for EMP testing, along with the more obvious solid state systems. Many mobile systems have functioned after being within 30 meters of a lightning strike. These models are most likely to survive EMP. The implication for emergency planners is that arrangements to permit mobile-to-mobile communications will be important as an alternative in the event of loss of a base station.



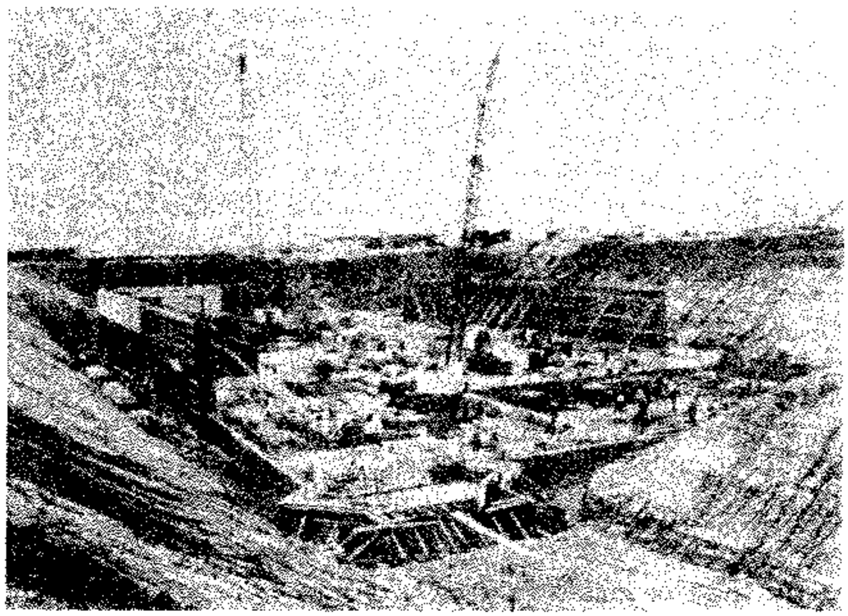
PANEL 11

VULNERABILITY OF TELEPHONE SYSTEMS

Telephones are another important communication resource for emergency operations. In addition to the public telephone system, telephone lines are often used in public safety radio nets to connect dispatchers to transmitters and to interconnect transmitters. The American telephone companies have taken strong measures to protect transcontinental and other critical land lines against nuclear attack, including EMP effects. The vulnerability of local telephone exchanges is less well defined but certain characteristics are favorable. Local exchanges do not depend on commercial power. Increasingly, lines are being placed belowground rather than on poles. Nonetheless, some components of conventional telephone plants are very sensitive to the effects of EMP. Even the rugged and conservative design and construction used in telephone systems are not sufficient to give high confidence that telephone service will operate reliably immediately after exposure.

Despite these problems, the use of the local telephone system should hold a key place in local emergency planning. Local radio nets are used mainly to communicate with mobile units in the field. During the major part of the nuclear attack period, these units should be parked as discussed in chapter 2 with personnel taking refuge in the best available shelter. Moreover, the telephone system is the one system that cannot be disconnected in the way a radio transmitter can. Therefore, it would be prudent to plan for maximum use of telephone service between temporarily immobilized field units and dispatchers so long as service continues, reserving the radio service until the main threat of EMP damage is past.

While it is not realistic to place total reliance on telephone lines for emergency use, maximum utilization of any surviving capability should be planned. Radio should be reserved for communications that have no viable alternative routing.



PROTECTED FACILITY FOR AT&T LONG LINES
DEPARTMENT UNDER CONSTRUCTION

Bell Laboratory Record, January 1969.

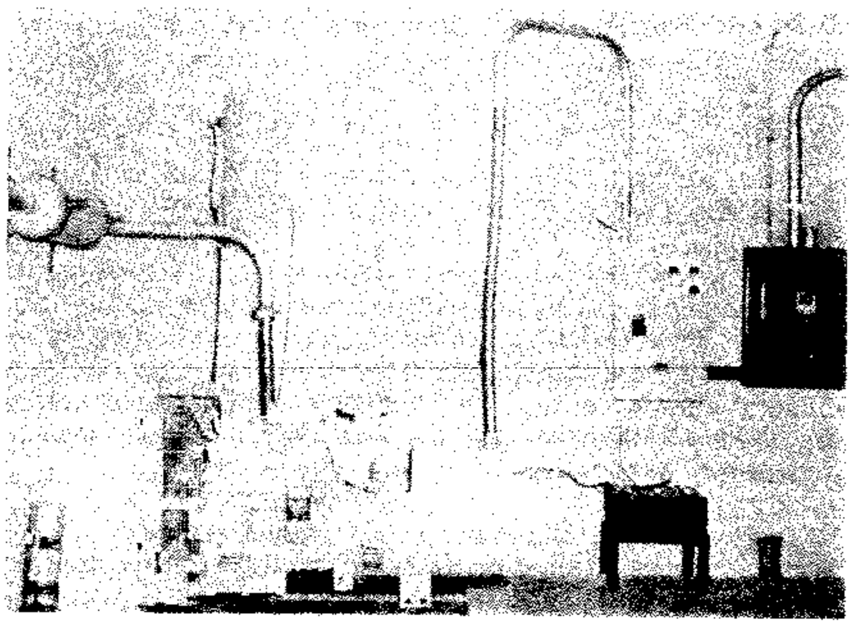
VULNERABILITY OF ELECTRIC POWER

Power lines exposed to EMP will have induced in them currents and associated voltage surges in much the same way that antennas collect radio signals. For power systems, this means that a high-altitude detonation will induce surges on all the myriad of power conductors, control and communication cables, interconnecting wires, and other conductors virtually simultaneously throughout the entire system. Probably the largest surges will occur on overhead power lines because they are located well above the ground and are essentially unshielded. Moreover, overhead "ground wires" that are used to shunt lightning strokes have little effect on the magnitude of EMP-induced surges. Surge voltages on overhead power lines may be sufficiently large to cause arcing in substations and at branches or changes in direction along the lines. Insulators can be damaged and circuit breakers locked out. System controls are increasingly solid state, and their malfunction could also lead to disabling of some generating units.

System "instability" is a probable result of these outages. Since the major blackout of the Northeastern part of the U.S. in 1965, most people are aware of the catastrophic and widespread effects of system instability. The cumulative weight of EMP effects thus makes likely widespread power failure on a national scale at the very beginning of a nuclear attack.

Recall that in chapter 2, panel 28, we described the effects of blast damage on the electric power system. Blast damage would be extensive above 5 psi. In the moderate damage region, early restoration of power seemed likely and, beyond the reach of 2 psi, the distribution system would be essentially intact. Even here, however, the availability of electric power would depend on the amount of EMP damage and measures taken to repair the damage that occurred.

The implication for emergency planning is that no reliance should be placed on the presumed availability of electric power during and immediately following a nuclear attack. Restoration of service may require hours or days, so provision for protected standby power is a must for facilities that must function soon after attack.



TYPICAL VIEW OF A STANDBY EMERGENCY GENERATING PLANT FOR AN EOC OR EBS STATION

VULNERABILITY OF EMERGENCY OPERATING CENTERS

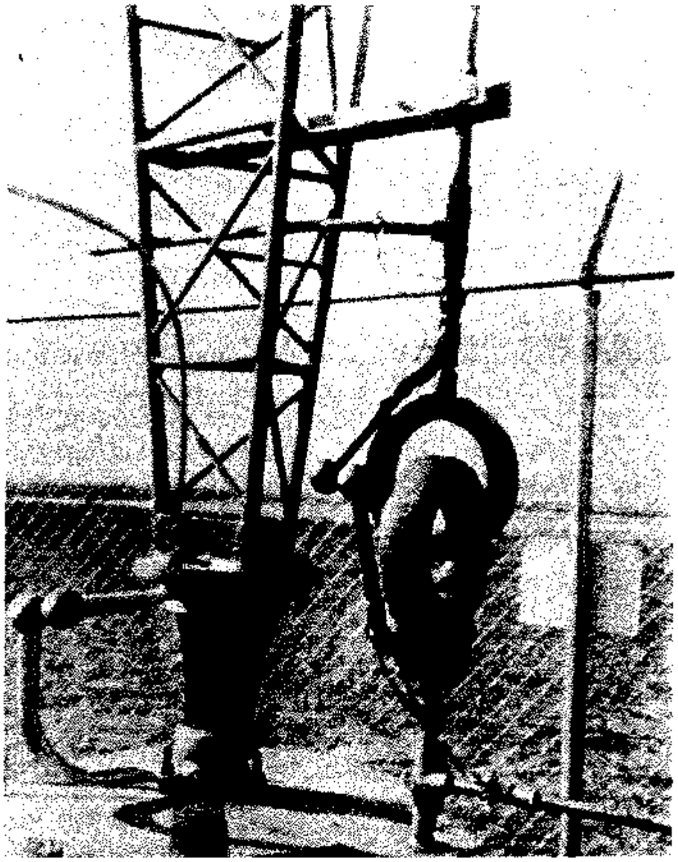
The local EOC represents a key nerve center for emergency operations. As such, it must be in a position to communicate with others during and after a nuclear attack. Since EMP from high-altitude detonations can cripple communications anywhere in the country, every locality must concern itself with protection of its EOC against EMP effects.

An obvious first step is to provide standby emergency power and a means for isolating essential units from high level transients occurring on commercial power lines. Operating procedures should provide for switching to emergency power at the maximum readiness condition or at Attack Warning rather than waiting until weapons detonate or power is lost.

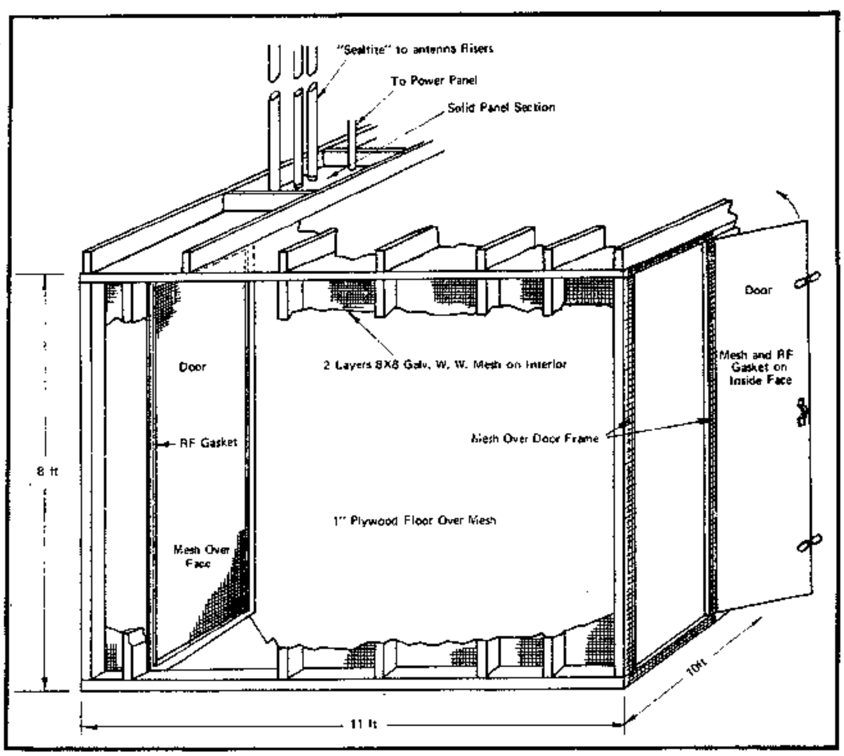
The next step is to protect communications equipment against voltage surges from other incoming lines, such as telephone and antenna lead-in cables. Devices for this purpose, such as gas-gap shunting devices that react very rapidly, are now available commercially at low cost. At slightly higher costs, filters can be added to transient suppressors and will significantly increase the level of protection. The upper view shows a full-scale protection system for a broadcast antenna.

Finally, the communications equipment itself should be placed in a shielded enclosure. A solid metal lining for the communications room is best, but galvanized steel-wire mesh enclosure, properly grounded provides a degree of protection. One such full room size enclosure that can be locally constructed is shown in the lower view.

At much lower cost, EOC communications equipment can be isolated in "boxes" much less than room size, or in shielded equipment racks protected against EMP surges. The power lines, emergency power equipment, antenna systems, and incoming telephone lines can be protected by means similar to the systems used for protecting radio stations. The technical expertise and assistance in planning this protection is available through the FEMA regional offices.



Photograph courtesy of
Carl T. Jones Associates,
Springfield, Virginia



SHIELDED BOX

PANEL 14

OPERATIONAL EMP DEFENSES

Whether or not physical EMP hardening has been accomplished in local EOC and communications facilities, there are a number of low-cost operational actions that should be incorporated into emergency operating plans to deal with the possibility of EMP damage. These actions can help minimize the possibility of catastrophic communications failure. Some of the actions shown here can be undertaken readily; others may require some modifications in equipment before they can be incorporated into plans.

Maintain an extra supply of spare parts and standby components so that any EMP damage can be rectified as quickly as possible. Elements most likely to be affected are identified in FEMA publications or can be identified by assistance from the Region. If vulnerable elements are located in unprotected or unmanned areas, repair actions should be planned as essential emergency actions.

The need for specific plans to shift to emergency power as early as possible and desirability of relying on telephone reporting during the early shelter phase have been mentioned before.

If telephone service fails or if there is no alternative to continued use of certain radio nets, the use of existing facilities in a coordinated way should be investigated and planned for. There are a variety of ways in which coordinated communications can be achieved. If the community or area has set aside a common emergency frequency, as many base stations as possible should be equipped to transmit on this frequency in addition to normal frequencies. Then, plan to use only one base station at a time for essential communications to all services. Essential field units can be equipped to monitor and/or transmit on several nets, such as police, fire, and public works. Again, only one base station would be used at a time during the threat period. Those not required should be disconnected from antennas, powerlines, and other long conductors to avoid EMP damage.

Also, plan to back up the normal transmitter capability by mobile-to-mobile communications. For systems that use one frequency for transmitting from base stations and another for mobile response, this backup capability would require mobile communications vans or the equipping of a limited number of mobile units to transmit on both frequencies. Such backup arrangements have been found useful in hurricanes, tornadoes, and other natural disasters.

Finally, emergency operations plans should be designed so that they are not completely dependent on communications with the EOC or normal dispatching procedures.

OPERATIONAL ANTI-EMP ACTIONS

1. Maintain a supply of spare parts.

2. Shift to emergency power at the earliest possible time.

3. Rely on telephone contact during the threat period as long as it remains operational.

4. If radio communication is essential during the threat period, use only one system at a time. Disconnect all other systems from antennas, cables, and power (do not use low-voltage switches but pull the plug).

5. Disconnect radio base stations when not in use from antennas and power lines.

6. Plan for mobile-to-mobile backup communications.

7. Design emergency operations plans so that operations will "degrade gracefully" if communications are lost.

RADIO BLACKOUT

Since this chapter is the only one in which we will consider directly the effects of high-altitude nuclear detonations, the planner should be aware of some effects other than EMP that might affect emergency operations. One of these other effects is "radio blackout."

Radio blackout occurs when the debris and radiations from a nuclear weapon cause major alterations in the electrical properties of the high atmosphere upon which some radio communications depend. This region, called the "ionosphere," extends from about 40 to 300 miles above the earth's surface. High-altitude detonations produce a large amount of electrical "fog" in the ionosphere; surface and near-surface bursts in the megaton yield range can also have some effect.

As shown here, long-distance communications in the high-frequency (HF) band can be interrupted for several hours since they depend on the bending of radio waves back toward the earth for distant communication. Short-range communications within a city or county are unlikely to be affected by radio blackout. The current trend toward use of very-high-frequency (VHF) and ultra-high-frequency (UHF) bands for public safety and amateur broadcasts decreases the likelihood of blackout of these communications.

The "20-meter" and "40-meter" bands are still popular for long-distance amateur communications, however. Since radio blackout can be confused with EMP damage to equipment, the planner should take account of its existence. Radio blackout will not cause damage to equipment, but will merely interfere temporarily with receipt of radio transmissions. This is unlikely to be of serious consequence to emergency operations.

SUSCEPTIBILITY TO RADIO BLACKOUT

Radio Band	Frequency	Transmission	Effects
LF	30-300 kHz	Groundwave	Some attenuation due to ionospheric depression
MF	300 kHz - 3 MHz (AM radio)	Groundwave	No significant effects
		Skywave	Long duration loss of communications
HF	3 - 30 MHz	Skywave	May be severely degraded for many hours. Selective, but unpredictable, frequencies may continue to be useful.
VHF	30 - 300 MHz	Line of Sight (LOS)	No significant effects
		Satellite Link	Signal absorption for periods of hours
UHF	300 MHz - 3 GHz	LOS	No significant effects
		Satellite Link	Absorption for periods of minutes
SHF	3 GHz - 30 GHz (Microwave)	LOS	No significant effects
		Satellite Link	Signal scintillation for periods of hours. Receivers not designed for high fading rates can be severely affected.

PANEL 16

HIGH-ALTITUDE BURST THERMAL EFFECTS

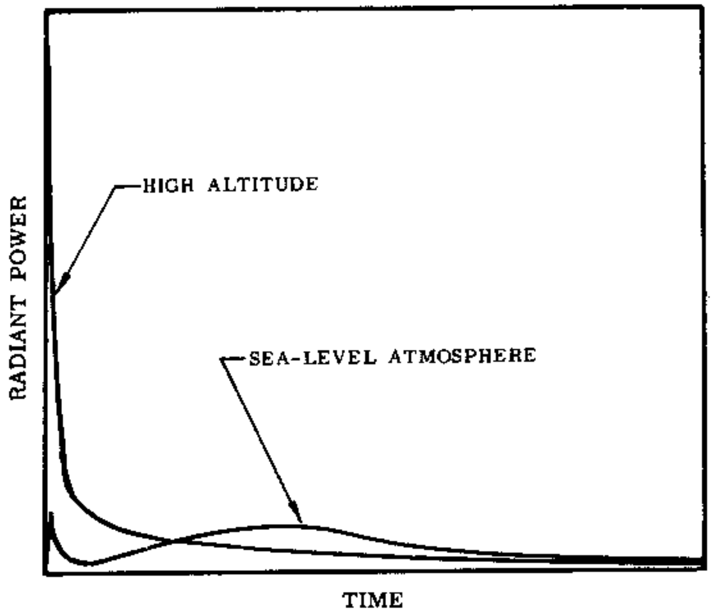
Below a height of about 20 miles above the earth's surface, the thermal radiation pulse accompanying a nuclear detonation has the characteristics described in chapter 3 and corresponding effects. Above 20 miles, however, the rarefied atmosphere in which the burst occurs results in most of the thermal radiation being emitted in a brief pulse of about a second's duration. In other words, the duration of the heat flash from a very large multimegaton detonation at high altitude could be similar to that which occurred from kiloton-yield weapons at Hiroshima and the Nevada Proving Grounds.

The importance of this behavior lies in the fact brought out in chapter 3 that it is not merely the amount but the rate of energy delivery that determines whether ignitions will occur. As a consequence, common kindling fuels could ignite at about half the total energy delivery (in calories per square centimeter) described in chapter 3. Of course, the detonation itself occurs at a great distance from the earth's surface, thereby reducing the energy received at the surface and compensating a great deal for the added susceptibility of kindling fuels.

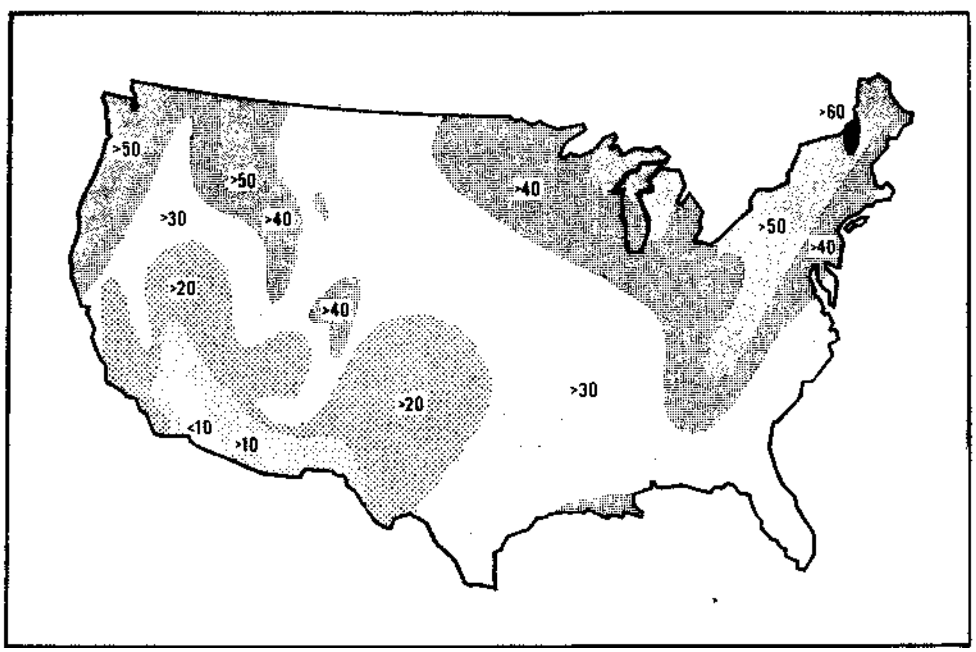
If this multimegaton weapon were detonated at a height of 60 miles, which is an altitude that can be expected to cause EMP damage, the thermal energy reaching the ground on a clear day could be up to 4 calories per square centimeter directly under the explosion. This might be just enough to cause ignition of exposed ignitables of the most sensitive class, but since the high-altitude burst could not "see" into rooms within buildings except at great lateral distance, the thermal energy actually received by the ignitables would be much reduced. If the weapon were detonated at a significantly lower altitude, the EMP effectiveness would be less, the thermal ignition effectiveness greater.

A blast wave that might suppress thermal ignitions would not result from a high-altitude burst but neither would windows and screens be blown out. No debris would block firefighting activities, and both workers and equipment could be fully operational. When the facts are added that clouds prevail over a substantial portion of the country nearly every day and it is cloudy in most localities a substantial part of each year, one concludes that high-altitude detonations would be very unlikely to cause ignitions.

Nonetheless, weapons might be detonated at high altitudes to cause EMP damage or as a result of missile defense measures. The implication for emergency planning is that possible ignitions should be expected, searched out, and suppressed if found, no matter how remote a nuclear detonation appears to be.



COMPARISON OF RATES OF THERMAL ENERGY
RELEASE FOR MEGATON WEAPONS



PERCENTAGE OF ANNUAL "OPAQUE" CLOUDINESS

SUGGESTED ADDITIONAL READING

1. CPG 2-17, Electromagnectic Pulse (EMP) Protection Guidance, Federal Emergency Management Agency, Electromagnetic Pulse Protection Support Manual, January 1986.

2. Manual 9300.1, Electromagnetic Pulse (EMP) Protection Guidance, Federal Emergency Management Agency, September 1985.

3. Manual 9300.2, Retrofit Devices and Materials, Requisition Manual for Electromagnetic Pulse (EMP) Protection Guidance, Federal Emergency Management Agency, Electromagnetic Pulse Protection Support Manual, April 1985.

4. TR-61, EMP Threat and Protective Measures, Federal Emergency Management Agency, April 1980.

5. Babb, David D. and Martinez, Joe P., Electromagnetic Pulse Analysis of Small Power Systems, Albuquerque, New Mexico: Dikewood Industries, Inc., AFWL-TR-75-181, March 1976 (AD-A023 927).

6. Barnes, Paul R., Effects of Nuclear Electromagnetic Pulse (EMP) on State and Local Radio Communications, Oak Ridge National Laboratory, October 1972 (AD 773 423).

7. Clark, D.B., Development of a Low Cost EMP Protection Concept for Emergency Operations Centers, Port Hueneme, CA: Naval Civil Engineering Laboratory, January 1982, TN No. N-1617.

8. Marabel, James H., et at, Effects of Electromagnetic Pulse (EMP on a Power System, Oak Ridge, TN: Oak Ridge National Laboratory, December 1972 (AD 757 718).

9. Nelson, D.B., Effects of Nuclear EMP on AM Radio Broadcast Stations in the Emergency Broadcast System (EBS), Oak Ridge, TN: Oak Ridge National Laboratory, January 1971 (AD 717 319).

10. Uman, M.A., et al, A Comparison of Lightning EMP with the Nuclear EMP in the Frequency Range 10 -10 Hz, IEEE Trans. on EM Compatability, Vol. EMC-24, November 1982, pp. 410-416.

U.S. GOVERNMENT PRINTING OFFICE: 1987 - 720-964 - 1302/60207