EMP

Nuclear Weapons Effects on Communications Systems

If the unthinkable should happen, how would Amateur Radio communication be affected? A great deal, says the author.

By Robert Hendrickson,* AG3U

The Amateur Radio Service is well known for providing emergency communications resources in times of need. Radio amateurs have responded well to the local and national disasters of the past. Of all these incidents none can rival the potential destruction released by an atomic weapon. Fortunately the United States has never had to recover from such a disaster. However, we must not allow our good fortune to dissuade us from preparing for yet another challenge. As a public service, Amateur Radio incurs the responsibility to ready itself to provide vital communications functions during all emergencies, including operation during or after a nuclear explosion. The purpose of this article is to acquaint the reader with the major damaging or disrupting effects that nuclear weapons inflict on communications systems.

Many of the "side effects" of nuclear explosions were detected during developmental testing of weapons used against Japan in World War II. Since that time, atmospheric and underground tests performed by the United States and other countries have permitted the study of many direct and indirect nuclear impacts on man, his environment and equipment. One of the major, long-reaching effects on electronic systems was evidenced during atmospheric tests in the Pacific, when it was discovered that high-altitude explosions thousands of miles away were responsible for the popping of local circuit breakers and other system malfunctions, with no other discernible effects. Scientists named this phenomenon *Electromagnetic Pulse (EMP)*, an intense, short-duration burst of electromagnetic energy, capable of traveling thousands of miles and damaging or disrupting sensitive electronic systems.

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NWE Can Be Pervasive

EMP is only one of a number of *Nuclear Weapons Effects (NWE)* that owners or operators of vital communications systems are concerned with. NWE are capable of disrupting message paths (both wire and radiated), introducing errors in data streams, kicking off circuit breakers, burning out vulnerable components or otherwise preventing electronic systems from performing their intended purposes. Some NWE are effective thousands of miles away from an explosion and can render systems useless while their operators remain physically unaffected. Thus, vital electronic systems can be attacked (intentionally or unintentionally) without incurring a single human casualty!

Unfortunately, there are a number of possible events that could result in the generation of NWE. Most governments are extremely concerned with the possibility of nuclear weapons use as an act of terrorism. Additionally, it is believed that NWE might be used to advantage by an aggressive country without resorting to a full-scale nuclear attack. An example might be the use of one or two weapons to produce EMP for the purpose of disabling communications defenses while simultaneously launching a conventional (non-nuclear) force. A third possibility is that a nuclear-tipped antimissile, deployed in defense against a conventional weapon, would produce NWE capable of disrupting most offensive and defensive systems in the vicinity of the explosion. Thus, the chance that a nuclear explosion might take place, with or without full-scale nuclear war, is more than a remote possibility.

Fig. 1 shows some of the primary products of a nuclear weapon detonation. The visible light, audible noise and associated mushroom cloud are familiar to many. Invisible emanations (such as heat, neutrons, and so on) are deadly to both

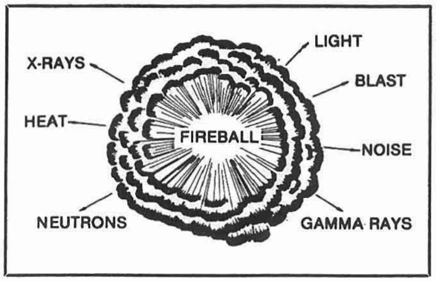

Fig. 1 — The invisible products of a nuclear detonation can be deadly — to both living things and electronics systems such as Amateur Radio equipment.

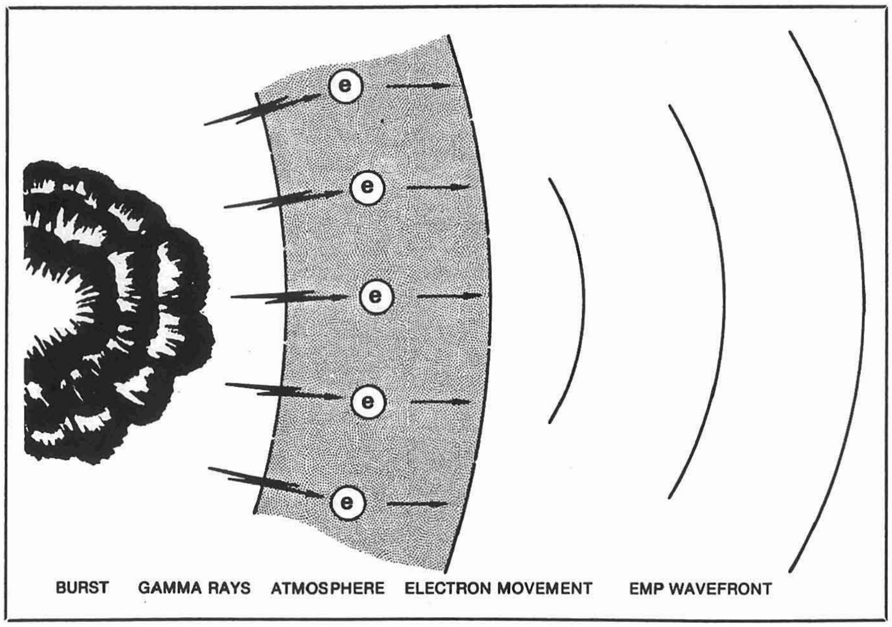

Fig. 2 — An electromagnetic pulse occurs when fast-moving free electrons created by the blast form an intense electromagnetic wave.

man and electronics systems. Secondary effects (that is, effects not produced directly by the weapon), such as EMP and disruptions of the ionosphere, are capable of rendering selected electronic systems useless while having no biological effects on man.

Nuclear explosions are responsible for increasing or decreasing the levels of ionization in the atmosphere, not only locally but at large distances away. Communications systems that rely on the "normal" characteristics of the ionized atmosphere may find that the intended propagation path is disrupted for a period of time varying from seconds to hours. Such disruptions might include an increase in noise level, raised or lowered reflection-producing ionospheric levels, signal absorption or blackout. The area affected may be local to the explosion or may cover very wide areas.

An Electromagnetic Pulse is generated when gamma rays resulting from the thermonuclear reaction produce free electrons (called Compton electrons) in the atmosphere surrounding the explosion. See Fig. 2. The outward movement of these fast-moving electrons, influenced by the earth's magnetic field, creates an intense electromagnetic wave whose spectral content extends from a few hertz to several hundred megahertz. A high-altitude detonation of moderate strength (yield) is capable of producing field amplitudes of up to 50,000 volts per meter at ground levels, over a diameter of thousands of miles, as illustrated in Fig. 3. This field couples into all metallic structures (pipes, wires, rain gutters and especially antennas) and may burn out sensitive front-end electronic components or at least cause internal disruptions to normal operation.

Nuclear weapons are known to produce energetic, liberated neutrons (subatomic particles) as a result of the thermonuclear reaction of the weapon. These uncharged subatomic particles travel at high speeds and may physically damage everything they meet. Solid-state electronics devices are particularly susceptible to neutron damage. So is the operator.

Gamma rays (an electromagnetic emanation) are produced directly by the weapon. Both prompt and delayed gamma rays are produced by the initial explosion and the debris, respectively, of the weapon. Gamma rays penetrate materials deeply and cause transients to be generated across semiconductor p-n junctions. The end result is the production of interference or false signals. Damage from burnout by intense transients is also possible.

Neutron and prompt gamma radiation induced responses are also called *Transient Radiation Effects on Electronics (TREE).* It is possible for TREE phenomena to permanently damage or disrupt electronic systems while the operator survives. TREE impacts are especially important to managers of repeaters or other unmanned communications systems. Other weapon products such as heat, blast and shock wave are not treated here, as they do not have such a long-reaching impact as those effects discussed.

End Result: Trouble

The end result of this collection of effects is trouble for communications systems and their operators. Many miles away from a detonation operators may find their radio links unusable owing to blackout, abnormal reflections or absorption of signals in the atmosphere, phase distortion or increased noise. They may discover that EMP has burned out sensitive microprocessor-controlled equipment or field-effect transistor front ends of receivers. If they are close enough to the explosion, they may discover that temporary or permanent electronics damage

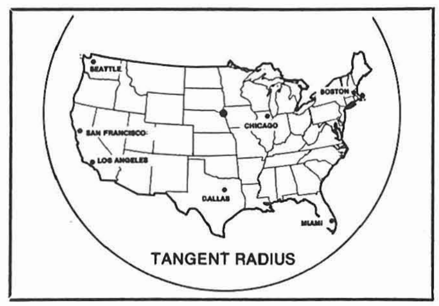

Fig. 3 — A high-altitude nuclear blast centered on the continental U.S. would create field amplitudes that could couple into antennas and damage sensitive communications equipment.

prevents them from using solid-state equipment. Data stored in semiconductor memories may be altered or lost. Given the variety of possible problems, two or more of these effects may combine to produce a synergistic result, a product of simultaneous influences of more than one effect. The following paragraphs describe why these problems may occur.

In all radio-frequency communication systems, the atmosphere either helps or hinders in some way. The ionosphere aids hf communications by refracting (or "reflecting") signals from the ground, permitting propagation over long distances by multiple hops. At the same time, the atmosphere (particularly the lower or D layer of the ionosphere) also hinders communications by absorbing signals and by propagating undesired noise such as that from lightning. Nuclear explosions in the atmosphere generally

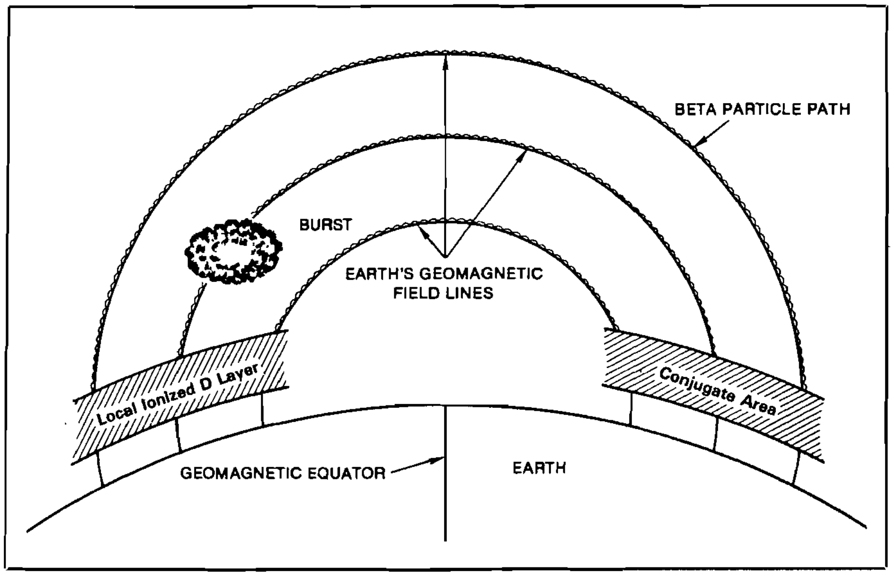

Fig. 4 — Local and remote ionization caused by an air burst is influenced by the earth's magnetic field. Propagation in the affected area may change suddenly — or make radio communication impossible.

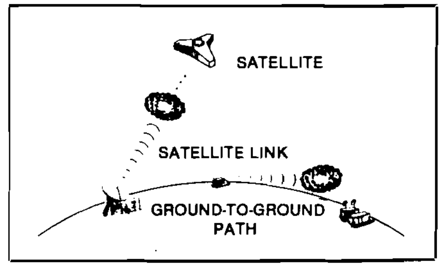

Fig. 5 — Although less susceptible to ionospheric disruptions, vhf, uhf and satellite communication may also be affected by a nuclear explosion.

produce free electrons and increase the level of ionization in the atmosphere. This results in either degradation or enhancement of the normal reactions of the atmosphere to radio signals.

A nuclear fireball carries an intense level of ionization that both increases radio-frequency thermal noise in the area and produces an opaque spherical volume that radio signals will not penetrate. A low-altitude burst at night within the D layer of the ionosphere may case absorption or refraction of ground signals by enhancing the level of ionization. A high-altitude burst near the F region of the ionosphere may either increase or decrease the "reflectivity" of the region depending upon yield, time of day, existing conditions, and so on. Users of the hf bands rely on F-layer reflectivity (skip) to work long distances as the signal reflects from the sky to ground with one or more hops. A high-altitude explosion also will generate beta particles, or free electrons, which spiral along the field lines of the earth's magnetic field. This creates an increase in the ionization of the D layer of the ionosphere, not only at the local area but also at the area known as the magnetic conjugate in the opposite hemisphere! The free electrons spiral along the earth's magnetic field lines and cause ionization at the two regions above the earth's surface where the lines touch the surface. See Fig. 4. This results in either an increase in the ability of the layer to absorb signals or an increased ability of the D layer to refract local signals and thus change the direction of propagation. An operator in both the local and the opposite hemisphere from a nuclear conflict may also find a sudden loss in his ability to communicate.

VHF, Satellites May Be Affected

Ionospheric disruptions mostly concern the hf band. Vlf, lf and mf bands are not as susceptible. Vhf and uhf communications links that rely on ground-to-ground line-of-sight links are also generally immune. However, it is possible for vhf-uhf links to be blocked, scattered or attenuated by explosions between the points of transmission and reception. Likewise, a satellite link that must penetrate or pass through a disrupted ionosphere may become impaired. Figs. 5 and 6 illustrate these concepts.

EMP is a nuclear effect that is somewhat similar to lightning, although EMP has a faster risetime and less power. It is a radio-frequency electromagnetic wave and as such has all the characteristics communications systems operators are already familiar with. It is of short duration, and if the equipment is not susceptible to damage or upset, the operator will otherwise not know of its existence. Its high-amplitude field intensity and wide spectral content cause it to couple to wires and other electrical conductors, pass through apertures and cause circuits to ring at their resonant frequencies. When large currents are allowed to couple to sensitive circuits there may be physical damage caused by overheating of low-power devices or arcing between conductors. All high-impedance, low-power, non-radio-frequency-shielded circuits are susceptible. Small calculators and commercial-grade processors with their plastic cases are notoriously affected.

If no damage occurs, the simultaneous coupling of large numbers of transients of high amplitude is likely to cause improper operation of all sensitive electronic systems. Commercial data processing equipment without error-correcting designs are quite susceptible.

Prompt gamma radiation produces a transient signal across p-n junctions in semiconductors. Vacuum tubes are immune from this effect. This transient is similar to semiconductor photoresponse and is thus known as a *photocurrent*. It is evidenced as a leakage current across the junction. In transistors with grounded emitters, it appears across the collector-base junction where it is called a primary photocurrent. It then couples to the base-emitter junction where it may be amplified and is then known as a secondary photocurrent. Primary and secondary photocurrents appear almost simultaneously across many semiconductor junctions in a typical electronics system, causing disruption of normal operation. Additionally, if the transients are of sufficient amplitude, permanent damage may occur. Or, if the power supply must support the amplification of many transients, it may become overloaded and trip circuit breakers. Operational impacts of a collection of simultaneous transients vary according to the function of each electronic system. A wide variety of equipment errors or disruptions is possible. Integrated circuits sometimes behave as discrete circuits as far as transients are concerned. Their construction, however, generally reduces their susceptibility compared to discrete circuits of similar function.

Fast neutrons affect semiconductors by physically altering the molecular structure of the bulk silicon material. The neutrons collide with and dislodge atoms from their normal positions and place them in abnormal spaces, called interstices, within the structure. Intersticial defects cause an increase in the resistivity and a decrease in the minority-carrier lifetime of the material. These changes, in turn, could cause an increase in the saturation voltage of a diode, or in transistors, a loss of gain might be experienced. Loss of gain could cause loss of function or failure in amplifiers, oscillators, regulated power supplies, and so forth. A decrease in gain might also cause integrated circuits to display reduced performance.

Not all components in systems are affected by TREE impacts. Electromechanical parts, transformers, passive components and other non-semiconductor components are practically immune. Also, different types of semiconductors respond with more or less vulnerability. In general, those with small junction sizes and/or higher gain-bandwidth products (F_T) are more immune.

Hardening

Despite the variety of complex problems the communications operator is faced with, there are a number of useful approaches to prevent or work around difficulties caused by nuclear weapons. Using established guidelines, it is possible to design modern solid-state equipment with reduced susceptibility to nuclear effects. When a piece of equipment is designed to operate within a nuclear environment without degradation it is said to be "hardened." A number of hardening techniques have proven to be effective. As far as impacts on the atmosphere are concerned, there is not much that can be done except to be knowledgeable as to the effects one might experience and to alter operational methods (switch bands, for example) to bypass the impacts of such disturbances.

As discussed previously, altered ionization levels in the atmosphere will impact various bands differently. The probability of successful communications during ionospheric disruptions will be maximized when the operator has a choice of the medium-, high- and very-high-frequency bands and beyond. Terrestrial line-of-sight communications paths will generally be the most reliable. Additionally, being able to change antenna directivity will help. Barring other approaches, the method of waiting for the disturbance(s) to subside may be effective. Ionospheric effects may last from several seconds to several hours.

As far as TREE effects are concerned, it is not practical to consider major alterations internal to amateur station equipment to achieve hardness, or immunity to such influences. Perhaps the simplest approach might be to avoid discarding vacuum tube equipment when its apparent useful life has been reached. Such gear is not nearly as susceptible as solid-state equipment to TREE damage or disruption. An awareness that transient radiation may upset or damage equipment may explain why communications gear refuses to function properly. Some TREE effects are temporary. Under certain conditions the operator would be well advised to apply power and test the equipment after a few seconds have passed to determine if the phenomenon was truly transient or whether it had produced permanent damage.

Equipment can be "hardened" against EMP as well as TREE by protecting sensitive circuits against unusual voltage or current spikes. Again, for commercial equipment without rf-shielded cabinets this may not always be practical. Backup equipment may also be useful in this case, especially if it has been stored on a shelf, disconnected from antennas or power sources. The main threat is that of upset or disruption, which may de-energize equipment if circuit breakers pop. In such cases, normal operation may be restored by resetting the breaker.

Although there is a general awareness of nuclear weapons effects in the communications industry, there seems to be little protection of our valued resources in the event of a nuclear weapon explosion, outside of military circles. Thus, the impacts of such effects will be distributed more or less equally among all communications systems users. The Amateur Radio Service has provided vital communications functions in areas previously thought to be protected from communications disruptions. It is possible that this service might be one of a few that would survive such a powerful influence. The amateur community certainly possesses the flexibility to work around many obstacles through the use of diversified communications media.

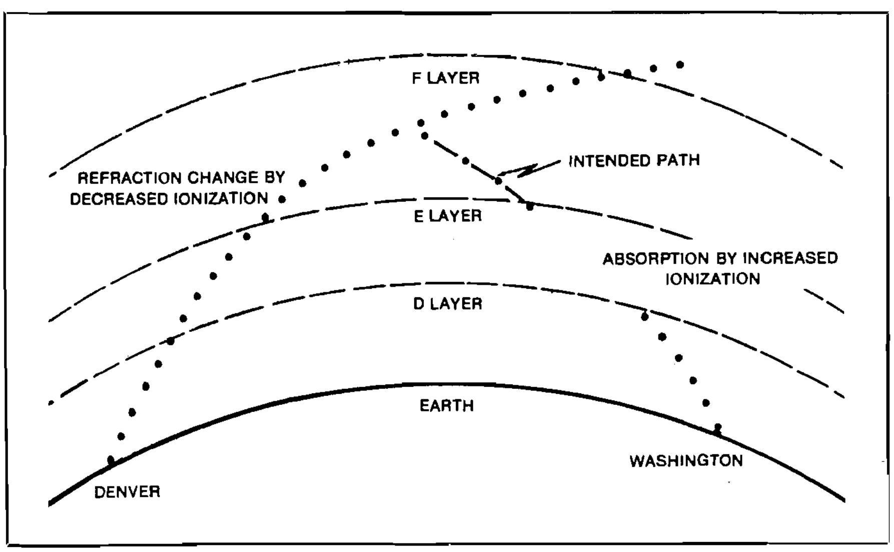

Fig. 6 — Propagation may be affected in various layers of the ionosphere.

Protecting Your Gear

The first step in solving a problem must be to acquire the knowledge that the problem exists. It is hoped that this introductory article has served that purpose. The hardening of Amateur Radio systems en masse as a result of public education would be as improbable as motivating the public to build private fallout shelters. Yet, there are simple practical approaches to ensure the survivability of either commercial or home-built equipment.

The first is to obtain *flexibility*. Maintain communications capability in more than one band. Participate in local traffic nets, if even only occasionally. Establish line-of-sight communications functions on vhf or ground-wave frequencies.

The second is to acquire *redundancy*. Don't discard old "spare" equipment, especially vacuum-tube equipment. Even backup solid-state gear may be valuable if it remains disconnected while not in use.

The third is to achieve independence, especially from utilities. Capitalize on any battery-powered equipment, or better yet build and maintain your own source of emergency commercial grade power. A word about microprocessors. These powerful communications-aiding devices are sure to be utilized more frequently in the future, but strict dependence on a single processor to control a communications station will probably increase the station's vulnerability.

Finally, awareness is needed to understand what is happening and why. Once the source of difficulty is identified most problems are easier to overcome. More descriptive information may be found in the references. QST

Author Hendrickson is a communications engineer and nuclear survivability specialist employed at the Arlington, Virginia branch of ORI, Inc., a firm that specializes in defense-related research.

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NUCLEAR AFTERMATH

☐ *QST* is an international journal. Presumably the author of "Nuclear Weapons Effects on Communications Systems" (August 1981 *QST*) was addressing the global amateur community. Instead of discussing ways to harden our equipment, shouldn't we be discussing ways to "soften" the weapons before we're left with the appalling task of providing communications for mass burials? — *Michele Bartlett, N1AGD/9, Champaign, Illinois*

☐ In his article on nuclear weapons effects (August 1981 *QST*), AG3U has given us some very important information about the little-known EMP effects on electronic gear that would follow nuclear explosions. I am concerned that we should have a better perspective on what the real impact of nuclear weapons use would be on ham radio.

It's apparently true that a few high-altitude nuclear blasts could wipe out a large fraction of electronics in the U.S. Since the majority of even *military* gear is not EMP hardened, such an attack would gravely compromise our military "Communications, Command and Control" systems.[1] It's hard to see how there could be any response by our government short of the all-out launch of our ICBMs, and that's World War III.

While we should all take prudent technical precautions to be able to communicate in *any* disaster, let's not be overly optimistic about how much help we can give after the big ones drop. Many experts predict that there would be over 100 million Americans dead in the first 30 days after an attack. That's no hurricane or tornado!

If there ever were a problem where prevention was better than cure, nuclear war is it. We can do our part through another side of ham radio. We can, and do, build international goodwill through our DX contacts. Why not depart a little from our usual QSO topics and ask friends in other countries what their feelings are on the nuclear issue?

We as hams, of course, are usually concerned with radio techniques — that's our big common interest. Like most people, we'd rather not think about nuclear wars or how to prevent them. But when you look at the hard technical data on nuclear weapons effects, you have to confront the reality: ***nuclear war means no more Amateur Radio.*** — *Dr. Martin S. Ewing, AA6E, Altadena, California*

☐ Your article in August *QST* by Robert Hendrickson describing the nuclear weapons effects on communication systems is one that should be "must" reading for all amateurs. His recommendations about saving old tube-type equipment is a good one. If only a few amateurs survive a nuclear exchange, I am sure they will be of great value to our nation's defense.

I believe the time is present when we should seriously consider the measures involved in protection from nuclear explosions. I would disagree with Mr. Hendrickson's statement that private fallout shelters would be of value since the protection might be only for the initial blast and not for the fire storms and for the many years of lethal radiation that would remain from a nuclear blast.

We as Amateur Radio operators should prepare, but we should also, as citizens, encourage our leaders to proceed with discussions aimed at eliminating or reducing the possibilities of nuclear war. — *K. W. Covey, M.D., WØZQJ, Moorhead, Minnesota*

[1] *Public Interest Report,* Federation of American Scientists, Vol. 33, No. 8, Oct. 1980.