Nuclear Weapon EMP Effects

A high-altitude nuclear detonation produces an immediate flux of gamma rays from the nuclear reactions within the device. These photons in turn produce high energy free electrons by Compton scattering at altitudes between (roughly) 20 and 40 km. These electrons are then trapped in the Earth’s magnetic field, giving rise to an oscillating electric current. This current is asymmetric in general and gives rise to a rapidly rising radiated electromagnetic field called an electromagnetic pulse (EMP). Because the electrons are trapped essentially simultaneously, a very large electromagnetic source radiates coherently.

The pulse can easily span continent-sized areas, and this radiation can affect systems on land, sea, and air. The first recorded EMP incident accompanied a high-altitude nuclear test over the South Pacific and resulted in power system failures as far away as Hawaii. A large device detonated at 400–500 km over Kansas would affect all of CONUS. The signal from such an event extends to the visual horizon as seen from the burst point.

The EMP produced by the Compton electrons typically lasts for about 1 microsecond, and this signal is called HEMP. In addition to the prompt EMP, scattered gammas and inelastic gammas produced by weapon neutrons produce an “intermediate time” signal from about 1 microsecond to 1 second. The energetic debris entering the ionosphere produces ionization and heating of the E-region. In turn, this causes the geomagnetic field to “heave,” producing a “late-time” magnetohydrodynamic (MHD) EMP generally called a heave signal.

Initially, the plasma from the weapon is slightly conducting; the geomagnetic field cannot penetrate this volume and is displaced as a result. This impulsive distortion of the geomagnetic field was observed worldwide in the case of the STARFISH test. To be sure, the size of the signal from this process is not large, but systems connected to long lines (e.g., power lines, telephone wires, and tracking wire antennas) are at risk because of the large size of the induced current. The additive effects of the MHD-EMP can cause damage to unprotected civilian and military systems that depend on or use long-line cables. Small, isolated, systems tend to be unaffected.
Military systems must survive all aspects of the EMP, from the rapid spike of the early time events to the longer duration heave signal. One of the principal problems in assuring such survival is the lack of test data from actual high-altitude nuclear explosions. Only a few such experiments were carried out before the LTBT took effect, and at that time the theoretical understanding of the phenomenon of HEMP was relatively poor. No high-altitude tests have been conducted by the United States since 1963. In addition to the more familiar high-yield tests mentioned above, three small devices were exploded in the Van Allen belts as part of Project Argus. That experiment was intended to explore the methods by which electrons were trapped and traveled along magnetic field lines.

The “acid test” of the response of modern military systems to EMP is their performance in simulators, particularly where a large number of components are involved. So many cables, pins, connectors, and devices are to be found in real hardware that computation of the progress of the EMP signal cannot be predicted, even conceptually, after the field enters a real system. System failures or upsets will depend upon the most intricate details of current paths and interior electrical connections, and one cannot analyze these beforehand. Threat-level field illumination from simulators combined with pulsed-current injection are used to evaluate the survivability of a real system against an HEMP threat.

The technology to build simulators with risetimes on the order of 10 ns is well known. This risetime is, however, longer than that of a real HEMP signal. Since 1986 the United States has used a new EMP standard which requires waveforms at threat levels having risetimes under a few nanoseconds. Threat-level simulators provide the best technique for establishing the hardness of systems against early-time HEMP. They are, however, limited to finite volumes (aircraft, tanks, communications nodes) and cannot encompass an extended system. For these systems current injection must be used.

HEMP can pose a serious threat to military systems when even a single high-altitude nuclear explosion occurs. In principle, even a new nuclear proliferator could execute such a strike. In practice, however, it seems unlikely that such a state would use one of its scarce warheads to inflict damage which must be considered secondary to the primary effects of blast, shock, and thermal pulse. Furthermore, a HEMP attack must use a relatively large warhead to be effective (perhaps on the order of one mega-ton), and new proliferators are unlikely to be able to construct such a device, much less make it small enough to be lofted to high altitude by a ballistic missile or space launcher. Finally, in a tactical situation such as was encountered in the Gulf War, an attack by Iraq against Coalition forces would have also been an attack by Iraq against its own communications, radar, missile, and power systems. EMP cannot be confined to only one “side” of the burst.

Source Region Electro-magnetic Pulse [SREMP] is produced by low-altitude nuclear bursts. An effective net vertical electron current is formed by the asymmetric deposition of electrons in the atmosphere and the ground, and the formation and decay of this current emits a pulse of electromagnetic radiation in directions perpendicular to the current. The asymmetry from a low-altitude explosion occurs because some electrons emitted downward are trapped in the upper millimeter of the Earth’s surface while others, moving upward and outward, can travel long distances in the atmosphere, producing ionization and charge separation. A weaker asymmetry can exist for higher altitude explosions due to the density gradient of the atmosphere.
Within the source region, peak electric fields greater than $10^5 \text{ V/m}$ and peak magnetic fields greater than 4,000 A/m can exist. These are much larger than those from HEMP and pose a considerable threat to military or civilian systems in the affected region. The ground is also a conductor of electricity and provides a return path for electrons at the outer part of the deposition region toward the burst point. Positive ions, which travel shorter distances than electrons and at lower velocities, remain behind and recombine with the electrons returning through the ground. Thus, strong magnetic fields are produced in the region of ground zero. When the nuclear detonation occurs near to the ground, the SREMP target may not be located in the electromagnetic far field but may instead lie within the electro-magnetic induction region. In this regime the electric and magnetic fields of the radiation are no longer perpendicular to one another, and many of the analytic tools with which we understand EM coupling in the simple plane-wave case no longer apply. The radiated EM field falls off rapidly with increasing distance from the deposition region (near to the currents the EMP does not appear to come from a point source).

As a result, the region where the greatest damage can be produced is from about 3 to 8 km from ground zero. In this same region structures housing electrical equipment are also likely to be severely damaged by blast and shock. According to the third edition of The Effects of Nuclear Weapons, by S. Glasstone and P. Dolan, “the threat to electrical and electronic systems from a surface-burst EMP may extend as far as the distance at which the peak overpressure from a 1-megaton burst is 2 pounds per square inch.”

One of the unique features of SREMP is the high late-time voltage which can be produced on long lines in the first 0.1 second. This stress can produce large late-time currents on the exterior shields of systems, and shielding against the stress is very difficult. Components sensitive to magnetic fields may have to be specially hardened. SREMP effects are uniquely nuclear weapons effects.

During the Cold War, SREMP was conceived primarily as a threat to the electronic and electrical systems within hardened targets such as missile launch facilities. Clearly, SREMP effects are only important if the targeted systems are expected to survive the primary damage-causing mechanisms of blast, shock, and thermal pulse. Because SREMP is uniquely associated with nuclear strikes, technology associated with SREMP generation has no commercial applications. However, technologies associated with SREMP measurement and mitigation are commercially interesting for lightning protection and electromagnetic compatibility applications. Basic physics models of SREMP generation and coupling to generic systems, as well as numerical calculation, use unclassified and generic weapon and target parameters. However, codes and coupling models which reveal the response and vulnerability of current or future military systems are militarily critical.

**Sources and Methods**

- [Engineering and Design - Electromagnetic Pulse (EMP) and Tempest Protection for Facilities](http://www.fas.org/nuke/intro/nuke/emp.htm)
- [NATO HANDBOOK ON THE MEDICAL ASPECTS OF NBC DEFENSIVE OPERATIONS PART I - NUCLEAR](http://www.fas.org/nuke/intro/nuke/emp.htm)
http://www.fas.org/nuke/intro/nuke/emp.htm

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