The Electromagnetic Pulse (EMP)

This is an essay I wrote about EMP. The sources may not be cited as well as they should, but some documentation was lost when converting to html. If you want a better citation, please ask.

Introduction

Nuclear weapons can have devastating effects. Usually, one thinks only of the blast, thermal, and radiation effects as they relate to the human body. However, considering only these factors ignores some of the other devastating effects. One such effect is that of the nuclear electromagnetic pulse (EMP). The effects of the nuclear electromagnetic pulse must be considered and calculated when preparing for a nuclear war.

This essay will try to describe what the electromagnetic pulse is. It will then explore the types of bursts that produce different pulses, and the possible effects of the pulses will be examined. Next, the ways to guard against EMP will be examined. Finally, the policy issues concerning the vulnerability of the United States will be explored. To achieve these goals, three basic sources will be used to describe the technical aspects of the pulse. Once this has been completed, several journal and magazine sources will be used to consider the vulnerability and policy issues. This format will create a technically based essay. From this science base, several observations of vulnerability will be made to evaluate the United States' policy and strategy.

EMP Physics

Early on in the development of nuclear weapons, the presence of the electromagnetic pulse was known. Before the July 16, 1945 Trinity test, Enrico Fermi had tried to calculate the possible electromagnetic fields that would be produced. Unfortunately, the actual effects of the EMP were still not truly known. It wasn't until the mid-1960s that the true nature of the EMP was better understood. However, even then, many of the possible effects, like other nuclear weapon effects, were not well-known due to the lack of data.1 The basic theory of EMP is now well understood.

In a nuclear detonation, gamma rays are produced. These gamma rays interact with the surrounding air molecules by the Compton effect to produce electrons. In this effect,

"...the gamma ray (primary) photon collides with an electron and some of the energy of the photon is transferred to the electron. Another (secondary) photon, with less energy, then moves off in a new direction at an angle to the direction of motion of the primary photon. Consequently, Compton interaction results in a change of direction (or scattering) of the gamma-ray photon and degradation in its energy. The electron which, after colliding with the primary photon, recoils in such a manner as to conserve energy and momentum is called a Compton (recoil) electron"(2)

These Compton-recoil electrons travel outward at a faster rate than the remaining heavier, positively charged ions. This separation of charges produces a strong electric field. The lower-energy electrons produced by collisions with the Compton electrons are attracted to the positive ions. These ions produce a conduction current. This current is directly related to the strength of the Compton effect. Also, this conduction current flows in a direction opposite to the electrical field produced by the Compton effect. Because of this, the conduction current limits the electrical field and stops it from increasing.(3-5)

Varieties of EMP Explosions

There are three main types of explosions to consider when examining the effects of the electromagnetic pulse. These are near-surface busts, medium-altitude bursts, and high-altitude bursts. Near-surface bursts are those at altitudes up to 1.2 miles, medium-altitude bursts range from 1.2 miles to 19 miles, and high-altitude bursts are those above 19 miles. These altitudes are only rough guidelines, but a better understanding of where each occurs will be gained after examining each type of burst briefly.(6)

The greatest effect on surface bursts is caused by the ground. Unlike in the air, the gamma rays cannot escape the blast in all directions. For this reason, near-surface bursts are also in this category. Although they may not be on the ground, they have similar effects. The ground absorbs many of the gamma rays. This produces an asymmetric field. The resulting field is very similar to that of a hemisphere that is radiating upward. The electrons also are able to return to the burst point through the ground. This makes the area near the center of the burst contain a high concentration of highly ionized particles. This net movement of electrons creates current loops that generate a magnetic field running around the burst point. This is the basic model of a near-surface burst.(7)

When the nuclear explosion occurs in the medium-altitude range, the effects of the ground are much. A medium-altitude range would be away from the ground but below the upper atmosphere. As the height of the burst increases, the asymmetry of the field produced decreases. However, the asymmetry increases, after a point, with altitude due to changes in the atmospheric density. This asymmetry can be seen in Figure One.

Figure One--Approximate variation of an asymmetry factor relative to a surface burst as a function of altitude8

Since the ground is absent, the magnetic field produced in near-surface bursts will be absent. The electric fields will be similar to those of near-surface bursts.(9)

High-altitude electromagnetic pulses (HEMP) produced by high-altitude bursts occur in an area of the atmosphere where the density of the air is low. Because of this, the gamma rays can travel very far before they are absorbed. These rays travel downward into the increasingly dense atmosphere. Here, they interact with the air to form ions as previously described. This region, called the deposition or source region, is roughly circular. It is thick in the middle and thinner toward the edges. It extends horizontally very far creating source regions that are over 1000 miles in diameter.(10) The size of it depends on the height of the burst and the yield of the weapon. The EMP in this source region gets deflected downward towards the earth due to the earth’s magnetic field. Although the fields produced from a high-altitude burst are not as great as those for a near-surface burst, they affect a much larger area.(11) Because of this huge potential, high-altitude bursts could be the most dangerous type of EMP.

EMP Effects

The electrical field produced by the EMP only lasts a very short time before it quickly tails off. The electric field has a rise time of about 1 nanosecond.(12) Even with such a short pulse, the effects can be tremendous. For a high altitude burst, the effects can also be far reaching. By many calculations, one properly placed nuclear bomb detonated above the center of the United States could produce huge electrical fields on the surface of the earth. "The EMP from a single hydrogen bomb exploded 300 kilometers over the heart of the United States could set up electrical field 50 kV/m strong over nearly all of North America"(13). Since EMP is electromagnetic radiation traveling at the speed of light, all of the area could possibly be effected almost simultaneously.

With such a possible threat, it is important to consider what may be affected. "Because of the intense electromagnetic fields (about 10 kV/m) and wide area of coverage, the HEMP can induce large voltages and currents in power lines, communication cables, radio towers, and other long conductors serving a facility"(14). Some other notable collectors of EMP include railroad tracks, large antennas, pipes, cables, wires in buildings, and metal fencing. Although materials underground are partially shielded by the ground, they are still collectors, and these collectors deliver the EMP energy to some larger facility. This produces surges that can destroy the connected device, such as, power generators or long distance telephone systems. An EMP could destroy many services needed to survive a war.

"Society has entered the information age and is more dependent on electronic systems that work with components that are very susceptible to excessive electric currents and voltages."(15) Many systems needed are controlled by a semiconductor in some way. Failure of semi-conductive chips could destroy industrial processes, railway networks, power and phone systems, and access to water supplies. Semiconductor devices fail when they encounter an EMP because of the local heating that occurs. When a semi-conductive device absorbs the EMP energy, it displaces the resulting heat that is produced relatively slowly when compared to the time scale of the EMP. Because the heat is not dissipated quickly, the semiconductor can quickly heat up to temperatures near the melting point of the material. Soon the device will short and fail. This type of failure is call thermal second-breakdown failure.(16)

It is also important to realize how vulnerable the military is to EMP. "Military systems often use the most sophisticated and therefore most vulnerable, electronics available, and many of the systems that must operate during a nuclear war cannot tolerate the temporary disturbances that EMP may induce."(17) Furthermore, many military duties require information to be communicated over long distances. This type of communication requires external antennas, which are extremely susceptible to EMP. Also, some military duties require information-gathering techniques. Many of these techniques use electronic devices connected directly to antennas or radar. Although the devices may be inside shielded buildings, the antennas bring the EMP inside to the electronics. Therefore, the effectiveness of shielding must be examined.

EMP Hardening

There are two things to consider when considering hardening targets against EMP. The first question to answer is whether the hardened system will become useless if shielded. The second question to be answered is whether the target is economically worthwhile to harden. The answers to these two questions are used to determine what devices should be shielded

To explain the first consideration, Makoff and Tsipis give the following simple example. If there was a communication plane with many antennas used to collect and transfer data, it would not be useful if its antennas were removed. However, to harden the plane, the antennas would need to be removed because they provide a direct path to the interior of the plane.(18) It is important to understand how the hardening will affect the performance of the hardened item.

The second consideration is very easy to understand. Some systems, although important, may not seem worthwhile enough to harden due to the high costs of shielding. "It may cost from 30% to 50% of the cost of a ground based communication center…just to refit it to withstand EMP," and, "as high as 10% of the cost for each plane."(19)

There are two basic ways to harden items against EMP effects.20 The first method is metallic shielding. The alternative is tailored hardening. Both methods will be briefly described.

Metallic shielding is used to, "Exclude energy propagated through fields in space."(21) Shields are made of a continuous piece of some metal such as steel or copper. A metal enclosure generally does not fully shield the interior because of the small holes that are likely to exist. Therefore, this type of shielding often contains additional elements to create the barrier. Commonly, only a fraction of a millimeter (22) of a metal is needed to supply adequate protection. This shield must completely surround the item to be shielded. A tight box must be formed to create the shield. The cost of such shielding (in1986 dollars) is $1000 per square meter for a welded-steel shield after installation.(23)

The alternative method, tailored hardening, is a more cost-effective way of hardening. In this method, only the most vulnerable elements and circuits are redesigned to be more rugged. The more rugged elements will be able to withstand much higher currents. However, a committee of the National Academy of Sciences is skeptical of this method due to unpredictable failures in testing.(24) Also, the use of this method is not recommended by the National Research Council. They doubted whether the approximations made to evaluate susceptibilities of the components were accurate. They did concede that tailored hardening may be useful to make existing systems less vulnerable.(25)

United States Policy

There are four issues to examine in the United States policy toward EMP. The effects of EMP must be considered when the United States decides when to launch its missiles to avoid possible EMP damage, how effective their nuclear warheads will be, where to use extra EMP hardening techniques after considering costs, and if development of an EMP device is in its best interest. These issues are very crucial to maintaining the United States deterrence against attack.

The first issue arises from the possible effects of the EMP. When deciding whether to launch missiles in a nuclear war, the United States must be aware of the EMP. A high-altitude burst or local-surface burst used on the

United States could negate many of the United States advantages. Although many crucial systems are hardened, "Predicting the effects of EMP on givens systems…are riddled with uncertainty."(26) The first nuclear burst used on the United States might disable some or many key systems. The United States is using simulators to better estimate EMP effects, but even with good EMP hardening technology, many systems, particularly the older ones, may not get hardened. This is because, "The high cost of EMP hardening implies that only the most important systems will be made to withstand the pulse."(27) If some of these less important systems include some missile systems or other offensive systems, it may be worthwhile to use them before they are potentially destroyed.

Once the missiles have been launched, they may still be vulnerable to EMP effects. "Intercontinental missiles and their fire control centers depend heavily on sensitive electronic systems for guidance, radar, and communications as well as to control the functioning of their nuclear warheads."(28) The vulnerability of radar and communication has already been discussed, and because of this, the vulnerability of intercontinental missiles can be seen. Also, EMP from neighboring "friendly" warheads may destroy the warhead, as well. So, once the missile is fired, it is by no means safe from EMP.

Cost also has to be considered. With EMP hardening so expensive, the United States must decide what are reasonable losses due to EMP. These considerations have to include not just military losses. Many of the new military systems are having hardening technology built into them, but much of the civilian world is left unguarded. The single hydrogen bomb alluded to earlier could cause an EMP that would destroy, "In an instant tens of billions of dollars worth of communications equipment and other electronics. Almost all electric power will be knocked out."(29) With the United States' electronic and social base of today, this would be catastrophic. This amount of losses would probably be unacceptable. However, the United States must decide if it is worthwhile to shield all of its vulnerable systems. This scope of hardening would be incredibly expensive. However, after the war, society would need these systems to rebuild itself. With such a potential for destruction, it does not seem wise for the United States to continue development of EMP weapons.

Right now, "The electromagnetic pulse generator is emerging as one of the strongest contenders...to find effective weapons to defeat an enemy without causing loss of life."(30) The motive may be right, but the idea may be bad. It is nice to be searching for a weapon that reduces casualties, but such a weapon could be very destructive if used against the United States. Although the weapon is designed to be used by the United States, the possibility of it being used against the United States may not be as unlikely as it seems. With the extensive technology base of the United States, it seems extremely vulnerable to such a weapon.

Conclusions

The threat of EMP effects is real. The first nuclear bomb detonated over the United States could cause widespread destruction. It should be noted that in EMP tests not all electronics and systems at risk were initially destroyed. Some items did not fail in the first test or even the second. However, eventually they all failed. This poses a problem. The actual effects of EMP are not clear. It is clear that the potential for damage is there. Following this conclusion, the need for EMP hardening is clear.

If the United States is still preparing for war, it must shield itself from the effects of EMP. Theoretically, damage due to EMP could be extensive. Much of this damage may be avoidable if the United States takes measures to harden all its communication systems, power systems, and such. Also, the United States must further explore EMP effects to better prepare for them. This includes informing the United States public about the effects of EMP simulators. If current public opinion continues(31) and all the EMP simulators close, further EMP testing cannot be done. The public must understand that the EMP simulators are not harmful, and that the destruction of the American infrastructure would be devastating. This must be avoided at all costs, but without testing, America is vulnerable to this destruction. This is why the United States must be prepared for the effects of the EMP.

Works Cited

1. Makoff, Greg and Kosta Tsipis, "The Nuclear Electromagnetic Pulse," Report #19. Program in Science and Technology for International Security, Cambridge, MA, March 1988, p.3.

2. Glasstone, Samuel and Phillip J. Dolan, The Effects of Nuclear Weapons. Department of the Army, Washington D. C., 1977, pp. 353-54

3. Ibid, pp.514-41.

4. Makoff and Tsipis, "The Nuclear Electromagnetic Pulse," pp. 6-13.

5. Bridges J. E., J. Miletta, and L.W. Ricketts, EMP Radiation and Protective Techniques. John Wiley and Sons, New York, New York, 1976, pp.3-35.

6. Glasstone and Dolan, The Effects of Nuclear Weapons pp. 515-519.

7. Ibid. pp. 515-517.

8. Bridges, Miletta, and Ricketts, EMP Radiation. p. 19.

9. Ibid. p.18.

10. Ibid. p.6.

11. Glasstone and Dolan, The Effects of Nuclear Weapons. pp. 518-519.

12. Bridges, Miletta, and Ricketts, EMP Radiation. p.11.

13. "Mushrooming Vulnerability to EMP," Aerospace America, August, 1984, p.74.

14. High Altitude Electromagnetic Pulse Protection for Ground Based Facilities. Naval Facilities Engineering Command, Alexandria, VA, 1986, p. 12.02-4.

15. International Union of Radio Science, "Nuclear Electromagnetic Pulse and Associated Effects," Telecommunication Journal, Vol 52, p.57.

16. Bridges, Miletta and Ricketts, "EMP Radiation and Protective Techniques," pp. 75-121.

17. Makoff and Tsipis, "The Nuclear Electromagnetic Pulse," pp. 15-17.

18. Ibid, p.18.

19. Ibid, p.19.

20. Klass, Philip J., "Study Raises Doubt on EMP Protection," Aviation Week and Space Technology, September 17, 1984, pp. 76-77.

21. High Altitude Electromagnetic Pulse Protection for Ground Based Facilities. p. 12.02-85.

22. Ibid. p. 12.02-85.

23. Ibid. p. 12.02-217.

24. Norman, Colin, "NAS Study Casts Doubt on Existing EMP Protection," Science. August 24, 1984, pp.816-817.

25. Klass, "Study Raises Doubt," p.77.

26. Makoff and Tsipis, "The Nuclear Electromagnetic Pulse," p.24.

27. Ibid, p.19.

28. Ibid. p.17.

29. "Mushrooming Vulnerability," p.76.

30. Fulghum, David A., "EMP Weapons Lead Race for Non-Lethal Technology," Aviation Week and Space Technology, May 2, 1993, p. 61.

31. Norman, Colin, "Court Order Puts EMP Test Program on Hold," Science. May 27, 1988, pp. 1139-1140.