Chapter 22

SPACE SYSTEMS SURVIVABILITY

"You know, if we really wanted to hurt you, we would set off an atomic weapon at high altitude above your country and produce an EMP that would destroy your entire electrical power grid, computer, and telecommunications infrastructure."

Member of the Russian Duma

Throughout this orientation of satellite operations, you have been exposed to the modern world's dependence on space systems. This dependence varies from simple commercial long distance calls to the implementation of a nation's strategic offensive and defensive forces. Furthermore, the United States Government and military forces require space systems support, such as early warning, navigation, intelligence, and communications, to maintain and formulate policies during and after a nuclear conflict.

The threat to space systems from nuclear weapons and Electro Magnetic Pulse (EMP) weapons exploded at high altitudes is real, yet largely ignored. Concerns about the proliferation of nuclear weapons and the possession of such weapons by rogue nations, make the discussion of problems associated with EMP and the magnitude of those problems a most timely topic.

Fig. 22-1. Nuclear Burst

NUCLEAR THREAT

The environmental effects of a nuclear explosion have been divided into three categories: Electromagnetic Pulse (EMP), transient nuclear radiation and thermal radiation. As for the success of a nuclear strike, it depends on three basic factors: the type of warhead (e.g., thermal nuclear, enhanced radiation and yield); the altitude of the detonation and the distance of the burst from its intended target. The altitude of a nuclear burst (**Fig. 22-1**) will depend on the mission of the weapon system. For example, if the objective is to produce maximum physical damage, a surface burst would be used.

Surface Burst

A surface burst is defined as a burst taking place between the surface and two kilometers (km) in altitude. This burst will produce the largest amount of debris, as the fireball will touch the surface and vaporize rocks, soil and other material. In addition, ground shock waves, over pressure (air blast) and EMP are present.

Low Altitude Burst

A low altitude burst is defined as a burst between two and 30 km in altitude. This burst will produce EMP, air blast and disruption in communications, such as scintillation (the distortion of radio waves) and absorption/ blackout (the denial of any communications within the affected area).

High Altitude Burst

A high altitude burst takes place at altitudes greater than 30 km. The high-altitude burst will produce EMP, scintillation and absorption and direct-radiation exposure to satellite systems. However, one effect that is common with an air and surface burst, the fireball, is not present in a high-altitude detonation. This is due to the lack of oxygen (the atmosphere is less dense at higher altitudes), which is needed to produce the fireball. The generation of EMP effects is present in any nuclear detonation, regardless of the altitude.

Electromagnetic Pulse (EMP)

The EMP threat is unique in two respects. First, its peak field amplitude and rise rate are high. These features of EMP will induce potentially damaging voltages and currents in unprotected electronic circuits and components. Second, the area covered by an EMP signal can be immense. As a consequence, large portions of extended power and communications networks, for example, can be simultaneously put at risk. Such far-reaching effects are peculiar to EMP. Neither natural phenomena nor any other nuclear weapon effects are so widespread.

Within nanoseconds (billionths of a second) of a nuclear detonation, any electrical system is threatened by EMP. Because of the potential damage by EMP, let's briefly look at how it is produced.

EMP is caused by the rapid release of gamma radiation from a nuclear detonation. The release of these particles at the speed of light (300,000,000 meters per second) will produce regions of negative/positive charges as atmospheric molecules are stripped of their electrons. These charges will propagate (travel) through the air at the speed of light and can have significant effects on all electromagnetic signals within line of sight of the nuclear detonation (NUDET).

The energy generated by the nuclear burst and its propagation towards the earth is characterized as an EMP waveform. The waveform has been broken down into three segments:

- The first is called early-time EMP and is the most devastating segment of the waveform. During early-time EMP, maximum levels of energy are produced in a very short time. Because of the intensity of the energy and the speed of the waveform, unprotected circuitry will be damaged or destroyed.
- The succeeding segment is called the intermediate-time portion of the waveform. This section is superseded in systems effects by the early-time and late-time EMP, as early-time EMP effects will overwhelm equipment and late-time EMP will expose long communications lines with continued low-level EMP.
- The final segment is called late-time EMP (also known as magneto-hydrodynamic EMP). Late-time EMP will occur at about one second after generation and can last up to 1000 seconds. During late-time EMP, low levels of energy are induced into the varying magnetic fields in the earth, which results in electrical fields being determined by the earth's surface resistance. This energy can pose a threat to long land lines such as telephone, power and submarine cables.

One significant factor in EMP effects is the amount of coverage desired. The area of exposure will depend on the size of the yield and the altitude of the burst. Based on the line of sight factor, the higher the burst altitude, the greater its coverage. Because of this factor, High-altitude Electromagnetic Pulse (HEMP) is the highest concern, as the entire electronic spectrum could be affected.

High-Altitude Electromagnetic Pulse (HEMP)

The gamma rays produced from a high-altitude nuclear burst will travel rapidly outward from the burst. The gamma rays traveling toward the earth will collide with the atmosphere at altitudes between 20 and 40 km. This collision will produce a gamma deposition layer, or EMP source region, where gamma energy is converted to a downward moving electromagnetic wave. A high-altitude burst can produce large-amplitude EMP fields over thousands of kilometers. Peak energy fields can reach levels of 50 kilovolts per meter. The peak levels can be reached very quickly and will have a large broad-band frequency coverage extending from Direct Current (DC) to 100 MHz frequencies. It is assessed that a nuclear burst at an altitude of approximately 500 kilometers can affect electromagnetic transmissions within the continental United States (CONUS).

While HEMP field strengths can be significant out to the tangent radium, the exact field strengths, as a function of ground position, can vary. Burst observer geometry is significant because HEMP is produced by an electron motion transverse to the earth's magnetic field. Other factors involved are the height of burst, weapon yield (particularly gamma yield) and geomagnetic field. The Earth's magnetic field strength is weaker and the orientation will vary near the equator. Therefore, peak EMP fields will be smaller and the field strength will be different.

EMP Protection Program

EMP is a critical issue in the survivability of all weapon systems and all three services have established regulations and organizations to examine and develop procedures to neutralize this threat. Such programs examine technology requirements, procedures and training programs for implementation.

From a technology standpoint, shielding a ground-control facility is required for EMP survivability. The ideal shielding would be made of steel and completely enclose the facility. However, this is an unrealistic method, as operations would not be possible. To create an EMP survivability facility, it should be shielded as much as possible. Furthermore, all openings to the facility need to be filtered and protected. The facility also needs to be isolated from any external electric EM propagation in the earth.

The effects of a nuclear detonation on a satellite system will also interfere with communication transmissions that are required for the maintenance of the satellite constellation. Effects, which would interfere with communications, are scintillation and absorption/blackout. Both have the effect of preventing or interrupting any communications between a ground station and the spacecraft.

Other Nuclear Effects

The effects of scintillation on a radio frequency are the disruption or breakup of the signal. For example, when the signal is transmitted through the contaminated area, characters in the transmission will be lost and only part of the message will be received. As for absorption/blackout, the layers of charged electrons trapped will prevent the transmission of the signal through the layer. However, these effects are frequency dependent. Disruption can last from just seconds to days. The lower end of the radio frequency spectrum will be affected by absorption and the higher level will encounter scintillation effects. HF communications can be affected the most, as potential outages may last for hours to days (depending upon reflection off the ionosphere). Mitigation techniques being currently used are avoidance, crosslink and signal manipulation.

Avoidance, as the word implies, means not using the satellite and ground control station within the affected area. This technique can be used with large constellations and worldwide ground-control networks. Crosslink capability allows the constellation to communicate with a satellite that is within the contaminated area via another satellite. Signal manipulation is designed to compensate for the loss of signal characters during the transmission. This is accomplished by inserting extra characters in the transmission.

Effects on Space Assets

Perhaps a more threatening challenge to our commercial satellite constellations is that from enhanced trapped radiation that results from delayed nuclear effects. These enhanced effects depend on a number of factors: the yield and number of bursts and, to a certain extent, the details of the bomb design; the latitude (and to a lesser extent the longitude); and height of the burst(s) and, of course, the "kind" of orbit the satellite is in-low earth orbit (Landsat, Teledesic, and Iridium, for example), medium earth orbit (Global Positioning Satellite (GPS) and Odyssey, for example) or geosynchronous earth orbit (Anik, Galaxy, and GOES, for example).

Direct radiation or thermal radiation effects are greater at altitudes above 40 km. Because of the lack of atmosphere, energy that would be converted to blast and shock (normally about 50% of the energy) is converted to thermal radiation (about 85% of the energy). The effects of this energy on a satellite are dependent on the distance of the spacecraft from the NUDET. Damage could range from simple computer logic changes to total destruction.

Prompt radiation can be described just like early-time EMP; it hits the satellite very quickly with maximum levels of energy. This charge of energy can be devastating to the satellite's health. Skin-charge effects are like intermediate EMP; they destabilize the energy fields and lead to the generation of internal EMP, which is similar to late-time EMP. The generation of internal EMP is the result of the satellite attempting to equalize the energy fields within itself. These charges collect on the cables, and high voltages are sent to various components, causing effects ranging from simple logic changes or circuitry disruptions to total component burnout.

Ground Segment Attack

Physical attacks and/or sabotage can be used against the critical ground facilities associated with US space systems in an effort to disrupt, deny, degrade, or destroy the utility of the space system. Satellite communications, data reception, command and control, launch, and assembly facilities, and their supporting infrastructures, are all potential targets. In cases where the neutralization of a single site effectively negates an entire space service, this method is more appealing; however, where there are many targets, this technique is less appealing. Many fixed US satellite communications, data reception, and control facilities are described in open source materials.

Once located, facilities deployed in a military theater can be attacked using conventional military assets, including aviation, cruise and ballistic missiles, special operations forces, and conventional ground forces. Facilities inside the United States or in a large, friendly country can be attacked by long-range bombers, submarine-launched ballistic missiles, intercontinental ballistic missiles, special operations forces and agents, and terrorists and paramilitary groups. Space launch facilities are also susceptible to attack or sabotage. A single incident or a small number of incidents could impact our space systems for years. Sabotage of satellite subsystem hardware or software could also be employed at the assembly plant or the location of a subcontractor.

Electronic Attack

US space systems could be functionally neutralized by jamming or spoofing the electronic equipment on the satellites or at their ground facilities. Jammers usually emit noise-like signals in an effort to mask or prevent the reception of desired signals, while spoofers emit false but plausible signals, for deception purposes, that are received and processed along with desired signals. All military and commercial satellite communication systems are susceptible to uplink and downlink jamming or spoofing. However, the jammer must operate in the same radio band as the system being jammed. Downlink jammers have a significant range advantage over the space-based emitter, so they can often be much less powerful and still be effective.

The targets of downlink jammers are ground-based satellite data receivers, ranging from large, fixed ground sites to handheld GPS user sets. Downlink jamming is generally easier than uplink jamming since very low power jammers are often suitable, though their effects are local (from tens to hundreds of miles, depending on the power of both the jammer and downlink signal).

On the other hand, the targets of uplink jammers are the satellites' radio receivers, including their sensors and command receivers. Uplink jamming is more difficult, since considerable jammer transmitter power is required. However, its effects may be global, since the satellite or space system would be impaired for all users. Furthermore, if false commands can be inserted into a satellite's command receiver (spoofing), they could cause the spacecraft to destroy itself.

Space Segment Attack

There are attacks other than nuclear that can target the space segment. Antisatellite (ASAT) systems can exploit a number of susceptibilities to disrupt, deny, degrade, or destroy satellites. For example, kinetic impact weapons cause structural damage by impacting the target with one or more high-speed masses-either warhead fragments or the ASAT itself. Chemical weapons (surface coating or reacting) can damage thermal control materials, surfaces, optical sensors, solar panels, and antennas. Laser fluence can damage exposed surfaces through heating or mechanical (pulsed laser only) effects. Lasers can also damage electro-optical sensors. Intense radio-frequency energy can couple to and disable sensitive satellite electronic components. What makes this all the more threatening is that technologies applicable to the development of some ASAT weapons are proliferating. An adversary only needs intent to use this capability.

Another area in the ASAT arena is interceptors, which can be divided into two currently basic categories-ground or air. Low-altitude direct-ascent ASAT interceptors are launched on a booster from the ground or from an aircraft into a suborbital trajectory that is designed to intersect that of a low Earth orbit (LEO) satellite. Low-altitude co-orbital ASAT interceptors are launched from the ground into an orbit from which they maneuver to intercept a low Earth orbit. High-altitude, short-duration ASAT interceptors are launched from a large space launch vehicle into a temporary parking orbit, from which an interceptor maneuvers to engage a high-altitude (MEO, GEO, or HEO) satellite, typically within 1-12 hours. Finally, long-duration orbital ASAT interceptors are launched into a storage orbit, where they await the command to engage a target satellite.

Directed energy ASAT weapons tend to be more sophisticated than ASAT interceptors. The directed-energy weapon's greatest advantage is that it can engage multiple targets, whereas interceptors tend to be single-shot systems. Ground-based high-power lasers could damage the thermal control, structural, and power generation components of the satellite. Additionally, they may also affect electro-optical sensors. Low-power antisensor lasers could blind or damage specific satellite-borne electro-optical sensors. Airborne high-power lasers could also damage components on LEO satellites. What gives the airborne laser an advantage over the ground-based laser is the airborne platform allows the ASAT to operate above inclement weather, which can shut down a ground-based laser.

CONCLUSION

In this chapter we have reviewed the effects of a nuclear burst on a satellite system, and how these effects can threaten all three segments of satellite systems. Equally important, we know that the technology to assure survivability exists; however, DOD personnel need to be more aware of the importance of maintaining facility-hardened levels for EMP. Since modern warfare and governmental duties are dependent on the availability of these systems for day-to-day operations, it is imperative that all possible means are employed to ensure survivability. We have also looked at other threats against our space systems. These have been broken down into the ground segment, link segment, and space segment.

The United States has three ongoing efforts to address the EMP threat that are underway as part of the DOD's Reliance program. The Science and Technology (S&T) directorate of the Office of the Under Secretary of Defense for Acquisition and Technology (OUSD (A&T)) established the Reliance program as a mechanism for coordinating and integrating DOD-wide S&T programs, reducing redundant capabilities, and eliminating unwarranted duplication. Although Nuclear Technology investments are addressed in the Defense S&T Reliance processes, the nuclear technology programs are unique in the level of integration built into the program. Currently all DOD Nuclear Technology S&T programs are accomplished under a single DOD component, the Defense Threat Reduction Agency (DTRA), which began operations on October 1, 1998. DTRA's establishment was one of the primary actions directed by the Defense Reform Initiative in November 1997.

The nuclear threat against our space systems has always been a primary concern because of the massive amount of damage that it would cause. However, our ground segment is more vulnerable because of the easier availability. Ground systems are much easier to attack than space systems. Moreover, the electronic attack against the link segment is a much more technologically achievable target than a nuclear explosion in space for many of our potential adversaries. In conclusion, our space systems must be regarded as a system made up of multiple parts-ground segment, link segment, and space segment, which are all integral to the accomplishment of the space mission.

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