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STUDENT REPORT

THE USE OF COMMERCIAL OFF-THE-SHELF EQUIPMENT AND ITS IMPACT ON C^3 EMP SURVIVABILITY

MAJOR MELVIN D. HOKE, JR. 88-1250

"insights into tomorrow"

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TITLE THE USE OF COMMERCIAL OFF-THE-SHELF EQUIPMENT AND ITS IMPACT ON C^3 EMP SURVIVABILITY

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The President's Blue Ribbon Commission on Defense Management has recommended that the military should make greater use of off-the-shelf components, systems, and services (also know as non-developmental items or NDI). This recommendation, if blindly implemented, could have an adverse impact on the survivability of critical command, control, and communications assets. The study evaluates how the electromagnetic pulse (EMP) survivability of a strategic, time-urgent, fixed, ground-based, command, control, and communications (C^3) facility would be impacted by the use of off-the-shelf C^3 equipments. The study concludes that to have a quantifiable measure of confidence in the facility's EMP survivability, the piece of off-the-shelf equipment under consideration will first have to be subjected to some degree of EMP testing.

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PREFACE

The survivability/availability of our command, control, and communications (C^3) systems in times of conflict is an issue that concerns commanders at all levels. C^3 survivability in the presence of a nuclear electromagnetic pulse (EMP) is dependent upon the conscientious application of sound engineering principles to "harden" the system to the effects of EMP. If a piece of equipment is used that has not been properly "hardened" to the effects of EMP, then the entire C^3 systems' EMP survivability is placed at risk.

In todays environment of tight budgets and pressures to reduce the cost of defense, recommendations are being made that are seen as ways to save funds but that also have the effect of placing our C^3 survivability at risk. A case in point is the recommendation of the President's Blue Ribbon Commission on Defense Management that more off-the-shelf components, systems, and services be used in place of those developed using military specifications. While this recommendation may have application in some areas of Department of Defense (DoD) procurement, it should be followed with extreme care when attempting to apply it to equipments and systems that are part of our strategic, time-urgent, C^3 systems. In particular, our fixed, ground-based, facilities that are a part of that system may have their EMP survivability compromised by the use of such equipment.

During my assignment to the Defense Nuclear Agency (DNA), I was placed in charge of a program to develop EMP hardening standards and specifications for application to strategic, time-urgent, fixed, ground-based C^3 facilities. I was frequently approached by people who would ultimately have to implement the standards and specifications I was developing with problems they perceived would arise from the use of commercial off-the-shelf equipment in an EMP hardened C^3 facility. In this paper, I have discussed the standards that are used by commercial C^3 equipment manufacturers and how they relate to the EMP standards and specifications being developed at DNA. Furthermore, I have provided some recommendations for consideration by managers who are faced with the task of using off-the-shelf equipments in an EMP hardened C^3 facility where mission performance is dependent upon the survivability of that piece of equipment.

I wish to thank several people for their help to me in completing this paper: Dr. George Baker, Lt Col Richard Smith, and Maj Clinton Gordon for their support and assistance in obtaining data; and to my wife Chris for her patient typing (and retyping) and understanding during long periods of my absence to conduct the research.

ABOUT THE AUTHOR

Major Melvin D. Hoke, Jr. received his Air Force commission through the Officer Training School in 1974 after completion of two years as an enlisted member. After his commissioning he was assigned to the Air Force Armament Laboratory at Eglin AFB, FL as an electromagnetic compatibility engineer evaluating aircraft electromagnetic interference and compatibility problems. Three years later he was transferred to the Armament Division at Eglin AFB where he was a mine electronics design engineer on the GATOR Mine System. From 1979 to 1982 he again worked aircraft electromagnetic interference and compatibility problems but this time while assigned to the Aeronautical Systems Division at Wright-Patterson AFB, OH. From here, Major Hoke went to a Flight Systems Manager job in the C-5B System Program Office at Wright-Patterson AFB before being moved to the Defense Nuclear Agency (DNA) in 1983. While at DNA, Major Hoke managed several programs involving the electromagnetic pulse (EMP) hardening of aircraft, ships, and ground-based command, control, and communications (C^3) facilities. It was the experience he gained while at DNA that formed the basis for this paper. He is presently a student at the Air Command and Staff College, Maxwell AFB AL, having previously completed the Air Force's Squadron Officer School. He holds the B.S. in Electrical Engineering from the University of Denver, and the M.S. in Electrical Engineering from the University of Florida.

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I. Purpose: To investigate the impact of using off-the-shelf components and equipment (sometimes referred to as non-developmental items or NDI) in strategic, time-urgent, fixed, ground-based, command, control, and communications (C^3) facilities that have a requirement to survive and operate through all phases of a nuclear electromagnetic pulse (EMP) event.

II. Problem: Commanders at all levels have become dependent upon their C^3 assets for the successful waging of war. Anything that puts their C^3 capability at risk must be dealt with appropriately. The pulse of electromagnetic energy resulting from a high altitude nuclear explosion is generally viewed as something that can put our C^3 capability at risk and steps must be taken to decrease the susceptibility of our C^3 system's to EMP. The Defense Nuclear Agency has initiated a program to develop a set of military standards and specifications that, when properly applied, will insure the EMP survivability of our fixed, ground-based C^3 facilities and systems. However, when components and equipments with unknown EMP survivability (ie. off-the-shelf items or NDI) are used in a C^3 facility that otherwise meets the requirements of DNA's standards, the entire facility's EMP survivability may be put at risk.

III. <u>Discussion:</u> The EMP survivability of a fixed, ground-based, C^3 facility is predicated upon the comprehensive application and validation of sound EMP hardening techniques. In an effort to save program resources, it has been recommended that off-the-shelf components and equipments be used in place of those developed using military standards and specifications (including EMP standards). Although off-the-shelf communications equipments may have numerous standards and specifications applied to them, those published by the Federal Communications Commission (FCC) and Underwriters Laboratories (UL) are commonly applied. The FCC standards apply to the controlling of spurious emissions that might interfere with other equipments. The UL standards focus of user safety issues. Although the FCC and UL standards may indirectly provide some measure of EMP immunity, they do not require any testing that quantifies it and therefore do not provide any useful measure of the equipment's EMP survivability.

IV. <u>Conclusions:</u> The EMP survivability of a fixed, ground-based, C^3 facility is dependent upon the use of components and equipments with known EMP survivability. The use of off-the-shelf components and equipments introduces an unknown into the facility's EMP survivability and places its capability to perform its mission at risk when subjected to an EMP.

V. <u>Recommendations:</u> In those instances where off-the-shelf (or NDI) equipment is being considered for use in fixed, ground-based C^3 facilities with EMP survivability requirements, there are several options to be considered. The common factor to be considered when choosing the option is how much risk of not surviving an EMP are you willing to accept. If EMP survivability is not a firm requirement, then the use of off-the-shelf equipment is probably acceptable. However, where EMP survivability is a firm requirement, the unknown survivability characteristics of NDI may present an unacceptable risk. The option then becomes to not use off-the-shelf components and equipments or take steps to quantify and possibly reduce their EMP susceptibility. This can be done by subjecting the NDI to a series of tests to quantify its susceptibility. If the item being considered has no or limited susceptibilities, then an informed decision can be made about the risk of using the NDI. In some cases, the NDI may need to be modified by incorporating some EMP hardening measures to reduce its susceptibility to an acceptable level. The bottom line is that where EMP survivability is a firm requirement, the use of off-the-shelf

CONTINUED

components and equipments without testing and/or hardening modifications injects an unknown risk into system survivability that is not acceptable.

INTRODUCTION AND OVERVIEW

The way in which we wage war is a constantly evolving process that is accelerating at an ever increasing rate as the technology explosion is brought to bear on our means of conducting war. We have gone from the primitive spear and club to the highly complex and sophisticated "smart weapons" of mass destruction; from battles where it was every man for himself to highly orchestrated and controlled engagements of staggering complexity requiring a "team effort". It is this last aspect of a "team effort" that may well prove to be the achilles' heel of our next major war. The ability to organize and direct the team by means of our command, control, and communication (C^3) capabilities through all phases of armed conflict will weigh heavily upon the final outcome. Central to our C^3 capability are the ever increasingly complex and technologically advanced communications equipments that we rely on for the directing of our military forces. These equipments, by virtue of the fact that they are electronic, are susceptible to the effects of a pulse of electromagnetic energy that is generated by a high altitude nuclear explosion. This pulse of energy, commonly referred to as an electromagnetic pulse (EMP), is sufficient to cause component damage and/or circuit upset. It is not my intent in this paper to argue the merits of this susceptibility as a potential kill mechanism worthy of exploitation (for an excellent treatment of this subject see the referenced report by David H. Stone). It is my contention that the risk of disrupting or losing our C^3 capabilities is sufficient to warrant our doing something to preclude it. It is this point and the fact that there is a congressional push to use "off-the-shelf" (sometimes referred to as non-developmental items or NDI) communication equipment with no known survivability to the effects of EMP, that presents a threat to our ability to successfully maintain our C^3 capability during nuclear conflict. Therefore, this paper will focus on what I perceive to be an incompatibility of requirements, i.e. EMP survivability of C^3 and use of NDI for C^3 equipment, and some possible solutions to this problem.

Chapter 1 will provide a basic framework for the understanding of EMP and its effects on electronics. My discussion will be very general in nature as there are many excellent resources on EMP generation, EMP coupling, and electronics susceptibility to EMP available to those interested. My intent is to give the reader who may be unfamiliar with the subject an appreciation for what EMP is, how it can have deleterious effects on electronics, and what measures can be taken to protect equipment from these effects. In Chapter 2 I will discuss the criticalness of maintaining our C^3 capability when subjected to EMP. I will put special emphasis on our strategic, time-urgent, fixed, ground-based C^3 facilities, and the efforts of the Defense Nuclear Agency (DNA) to address this problem. Chapter 3 will then address the NDI issue. What is NDI? Who advocates its usage? What impact does it have on the survivability of our C3? How does it impact the DNA program? Finally, in Chapter 4 I will put forth what I believe are the alternatives for reconciling the incompatibilities between the need to protect against EMP and the use of NDI. It is my goal in this paper to make the reader aware of the problems NDI communications equipment can present to the EMP survivability of our C^3 capabilities without being so pragmatic as to leave the reader with a feeling of despair that there are no solutions.

Chapter One

THE WHAT AND HOW OF EMP

A basic understanding of EMP is essential to understanding the problem that NDI equipment presents to the survivability of electronic equipment and thus to C^3. In a very cursory fashion, I will cover the following: (a) What is EMP and how is it generated, (b) How does it eventually end up inside (couple into) a piece of electronic equipment, (c) What effect can it have on a piece of electronic equipment, and (d) What can be done to protect equipment from damage/upset due to EMP? Since this is intended to be only a basic treatment of this subject, the reader who desires more complete information is referred to either the DNA EMP Course Study Guide (5:--) or the DNA EMP Engineering Handbook for Ground Based Facilities (3:--).

WHAT IS EMP

EMP is a term used loosely to describe what is, in fact, four different but related EMP environments. The first type, and the one most commonly being referred to when using the term EMP, is the high-altitude EMP or HEMP. This type of EMP occurs when a nuclear detonation occurs at altitudes above 30 km (5:18). The second type of nuclear detonation, air-burst EMP (5:38) occurs at altitudes of from 2 km to 30 km. The third type is known as a surface-burst EMP and occurs when the detonation is between the earth's surface and 2 km (5:26). The fourth type of EMP is the result of the high energy photons released by a nuclear detonation interacting directly with the material of a piece of equipment and is called system generated EMP (SGEMP) (5:44). This is in contrast to the other types of EMP that are produced by the interaction of the high energy photons with the air which produces an electromagnetic field that then interacts with a system or piece of equipment. This distinction in the way the electromagnetic field is generated requires different protection techniques. The area of SGEMP (its generation mechanisms, effects, and protection measures) is beyond the technical expertise of the author and the scope of this paper. In addition, SGEMP is not currently being considered in the DNA program for the EMP hardening of fixed, ground-based, C^3 facilities. Therefore, SGEMP will not be discussed in any further detail.

Table 1 below summarizes the characteristics of the other types of EMP.

TYPE	FEATURES	SYSTEMS IMPACT
HEMP	Large extent, large amplitude, wide frequency band, plane wave	Nearly simultaneous EMP stressing of an entire system
SURFACE BURST		
Source Region	Large amplitude, limited spatial extent	Important for systems protected aginst other nuclear effects
Radiated Region	Large amplitude varies inversely with distance	Can supersede HEMP if vertical orientation or low frequencies are important
AIR BURST		
Source Region	Similar to surface burst	Important for systems protected against other nuclear effects
Radiated Region	Amplitude less than HEMP	Coverage much less than HEMP

Table 1. Characteristics of EMP environments (3:1-25).

As stated in the table, the systems impact of surface burst and air burst EMP is a function of the system's location relative to the blast, whether or not the system is protected against other nuclear effects (blast, shock, thermal, etc.), orientation, and frequency. On the other hand, HEMP has a very broad area of coverage, a wide frequency band, and is a plane wave. Since HEMP is the more general type of EMP, and the only one being addressed at this time by the DNA Standards and Specifications Program, I will restrict my attention to it for the remainder of this paper. Also, any further use of the term EMP will mean HEMP.

The high-altitude EMP is actually composed of three components referred to as the early-time, intermediate-time, and late-time (also referred to as magnetohydrodynamic EMP, or MHD-EMP) components (4:36; 5:10-11). These three components are generated when a nuclear detonation occurs above the earth's atmosphere (above 30 km) and a series of complex physical reactions are set in motion. Basically what happens is the gamma rays which are produced by the explosion travel radially outward from the detonation point. Those gamma rays directed toward the earth eventually reach the earth's atmosphere and collide with air molecules. These collisions generate what are called Compton recoil electrons. The electrons are propelled toward the earth and are turned by the earth's magnetic field to produce a downward traveling electromagnetic wave. This all occurs within the first 10^{-6} seconds after the explosion and is referred to as the early-time component (5:12-13). The intermediate time component is a product of collisions between neutrons and gamma rays that have been scattered by earlier collisions with air molecules (5:12-13). The late time interaction of the fireball with the earth's magnetic field gives rise to the MHD-EMP and occurs after one second has elapsed. The MHD-EMP is the result of further ionization of the earth's atmosphere and the interaction of this ionized air with the earth's magnetic field (5:20-23). The resulting composite electromagnetic pulse that is seen on the earth's surface is one that has a high peak amplitude, a very fast rise time (which equates to a large frequency content) a long pulse duration, and a very broad area of coverage (see figures 1,2,3*) (5:58-59). All of these attributes of the HEMP contribute to the problems that have to be dealt with when the pulse is coupled into a piece of electronic equipment.

*NOTE: The figures used are the unclassified forms. For a more accurate representation see DoD-STD-2169A, High Altitude Electromagnetic Pulse (HEMP) Environment (U), SECRET.

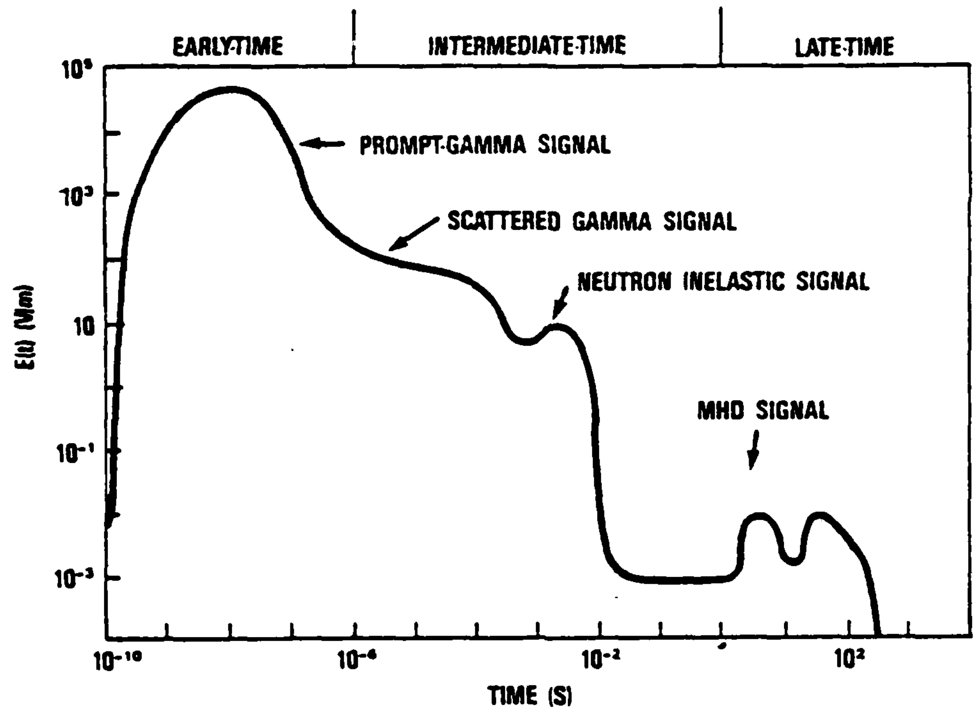

Figure 1. Qualitative time domain plot of high-altitude EMP (3:1-13).

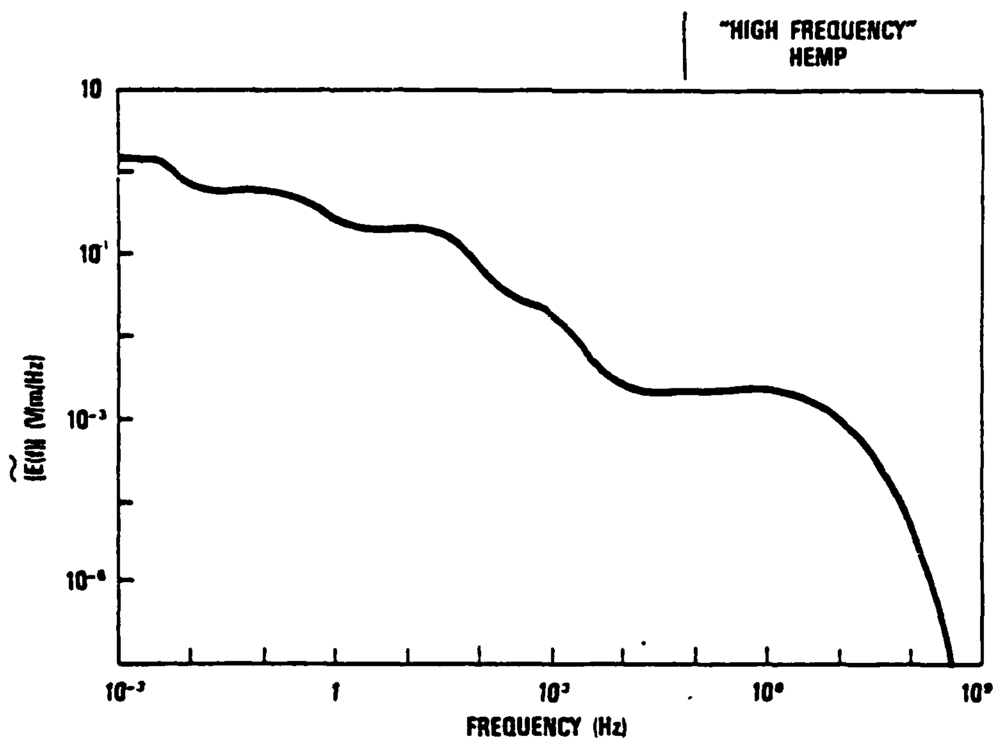

Figure 2. Qualitative frequency domain plot of high-altitude EMP (3:1-13).

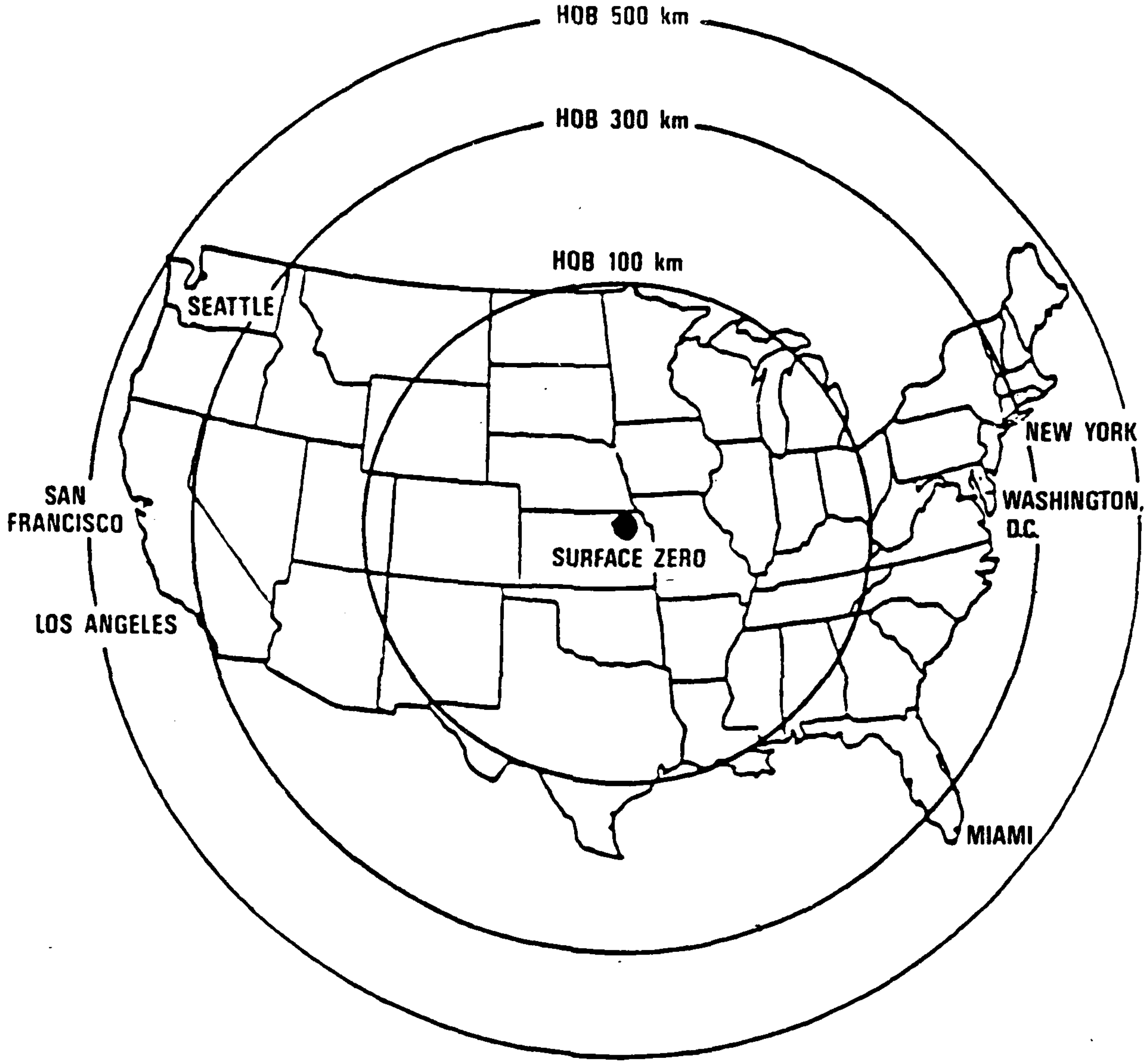

Figure 3. EMP coverage as a function of height of burst (HOB) (3:1-9).

COUPLING

The process whereby the EMP induces transient currents and voltages in conductors is generally referred to as coupling (5:58). This is a rather complex process and literally volumes have been written trying to explain and analyze it. However, by recognizing the fact that all conductors act as antennas for collecting the EMP, a basic understanding of the process can be achieved. The theory behind how electromagnetic waves (i.e. an EMP) cause currents in conductors is tied to antenna theory, which for the purposes of this paper can best be understood in terms of two basic principles.

> One principle is that the amplitude of the induced current depends on the size (effective length) of the conductor. An EMP will induce larger currents in a large conductor than in a small one.
>
> The second principle is that conductors respond better to some frequencies than others. For example, an induced current will travel to the end of a conductor (like an aircraft fuselage) and be reflected and return to its original position. If the time it takes for the current to take a complete round trip matches the frequency of the incident electromagnetic wave, the wave and current will strengthen one another and the response will be very strong. This condition is called half-wave resonance, and is similar to the condition which produces a dominant frequency for a vibrating string. Just as longer strings produce lower frequency tones, larger conductors will tend to respond more strongly to lower frequency electromagnetic waves. Most systems do not have uniform shapes but instead have complicated geometries, with each attachment and projection responding with its own resonant current, so the total current is the net of all these contributions and the current wave shape may be quite complex (4:48).

Although these two principles seem pretty straightforward, applying them to actual systems can be extremely difficult. This is especially true in the case of a fixed, ground based facility. These facilities are frequently made up of several subsystems, spread over several acres, and interconnected by numerous conductors including telephone and electric power cables. The result is that the entire facility acts as a collector of EMP (5:64). The problem is further complicated by such factors as

(1) what the buildings are constructed of (typically wood or concrete which are transparent to EMP), (2) buildings may be located above or below ground, (3) ground reflection and absorption alter the EMP, (4) ground based facilities, especially communications facilities, have a large variety of antennas covering the entire frequency band, and a host of other factors.

The point of all this is that given a high altitude nuclear explosion, the resultant EMP will be picked up by many different conductors, or antennas, that are connected to a fixed, ground-based C^3 facility. The question is, what happens when all the collected energy arrives at the facility?

EFFECTS OF EMP

What happens to a communications facility, and in particular the electronic equipment within the facility, once the EMP couples into it has been a topic of concern and debate for years. The damaging effects of EMP were first experienced during early near-surface tests before the partial test ban treaty. During these tests, "hundreds" of EMP effects examples were noted and documented. The systems affected by the EMP were diagnostic systems, control systems, and power systems. The actual damage reported consisted of blown fuses, damaged electronics, burned and welded relays, burned cable insulation and conductors, damaged meters, and disruption of the power system. Similar problems were noted during low altitude testing over Johnston Island in the Pacific during 1962. It was during this testing that the famous incident of street lights going out and burglar alarms being set off on the Hawaiian Island of Oahu (some 800 miles away) occurred. All of these effects were noted before the advent of semiconductor electronic components which are generally believed to be even more sensitive to the effects of EMP (4:42-44).

In addition to these early observed effects of EMP, attempts have been made to test various systems to the effects of EMP by using laboratory simulators. System effects observed during these tests have been many and varied. Many excellent reports on these tests are available through the Defense Nuclear Agency, Electronic Effects Division, for those interested in pursuing the subject. Most of the reports are classified and cannot be treated here, but results of the tests are consistent with what was experienced during the early above-ground nuclear tests. Electronic equipment experienced component damage and upset, and in the case of newer semi-conductor devices, the problem is even greater. All this points to the need to protect equipment from the effects of a HEMP or suffer the consequences.

PROTECTION

The choices available for protecting a system against the effects of an EMP (generally referred to as EMP hardening) are basically limited to three options. These are to reduce the incident EMP environment, increase the systems threshold or immunity level, or a combination of both (4:92). Beyond these fundamental choices the problem becomes much more complex in terms of how to actually tackle the problem. Only the basic principles involved in these choices will be covered in this paper. For more detailed information, the reader is referred to Section 2 of the DNA EMP Engineering Handbook for Ground Based Facilities, Volume 2 (3:--).

Reducing the EMP environment experienced by a system involves placing a barrier to the EMP between the system to be protected and the EMP environment, the ideal solution here being a solid, conducting volume which completely surrounds the system of concern (4:98,99). For a fixed, ground based facility, this might translate to a building made of solid steel on all six sides with absolutely no holes or imperfections. Obviously, this would not work because the system being protected in all probability needs to "communicate" to the outside world. It is here that the problem gets complicated. Anytime that perfect six-sided volume gets a hole in it, say for a door, a signal line, a power cable, etc., the effectiveness of the shield in reducing the EMP environment is compromised. Some of these imperfections, or penetrations as they are commonly called, can have the effect of totally eliminating the barrier's effectiveness (4:98,99). Consequently, steps must be taken to "plug the holes" so to speak. This is done by a variety of means such as filters and transient suppressors, wire mesh and honeycomb, specially designed doors, fibre optics, and a host of other techniques. The final goal is to approach that perfect shield so the equipment being protected is subjected to a much less intense EMP that it can survive (3:2-1 - 2-41; 4:110-125).

This brings us to the second general EMP protection approach: increasing the system's threshold or immunity level. The concept involved here is to do things to the various components of the system to make them more tolerant to EMP. This involves three basic processes. First, using specially designed components (semi-conductors, switches, etc.) that are able to stand high level currents and transients. Second, using circuit design techniques that can reduce the EMP before it reaches more sensitive components. Finally, to minimize the functional consequences of EMP by changing the system's response from a major upset to something tolerable. This can be accomplished by both hardware and software techniques (4:127-133).

The whole concept of EMP generation, coupling, and hardening is far more complex than I have presented here. The lesson to be learned though, is that EMP does exist, that it presents a threat to the operability/survivability of electronic equipment, and to protect against it requires the careful application of various hardening techniques.

Chapter Two

C^3 AND EMP SURVIVABILITY

> *Key military leaders fear that command, control, and communications in a nuclear war may be the Achilles' heel of U.S. strategic forces (2:74).*

The United States (US) defense is built around a reliable and survivable command, control, and communications (C^3) network. This fact is nowhere more evident than in the area of strategic, time-urgent communications, such as communications involving attack warning/attack assessment (AW/AA), emergency action message (EAM) dissemination, and National Command Authority (NCA) conferencing. It is here, during the very first few moments of hostilities that the survival of our defenses and our nation depends upon our ability to communicate. Once we detect an action which indicates that we are about to come under attack, we have to get that information to the proper people who in turn can alert our defense forces.

> Without communications, sensors can detect, but cannot warn. Command centers are impotent if they cannot provide their critical warning information to the national command authorities and the unified and specified commands. Worse yet, unreliable communications means a loss of credibility in warning information passed to national decision makers. Without valid, credible warning information, U.S. leaders will not be able to make timely decisions in a crisis. Poor warning communication increases response time, reduces flexibility, and ultimately reduces deterrent capability. To ensure the flow of information throughout the wide range of conflict, survivable communications networks must be used (1:86).

It is our various C^3 facilities that will be depended upon to make sure the information does flow and that it does so through all levels of conflict and in all environments -- including HEMP.

As stated in Chapter 1, HEMP poses a threat to the operability and survivability of electronic equipment. This is no less true in the case of our C^3 assets which we will be depending upon. The need to take action to protect our strategic C^3 network from the effects of HEMP has been known for some time. However, it was not until the Under Secretary of Defense, Research and Engineering (USDRE) tasked the DNA in December 1981 to develop a DoD HEMP standardization and specification program that the problem received the needed visibility and support to start solving the problem (15:--). Following DNA's development of a recommended program, the Assistant to the Secretary of Defense for Atomic Energy (ATSD(AE)) was designated as the focal point for the overall DoD HEMP standardization program. He then tasked the services (Army, Navy, Air Force), the Defense Communications Agency (DCA), and the Defense Nuclear Agency (DNA) to accomplish various portions of the overall program. The task for developing military standards and specifications for fixed, ground-based C^3 facilities was given to the DNA (10:--). The ultimate objective of the program, and in particular DNA's program, was to develop standardized methods for designing, building, and testing HEMP hardened and survivable C^3 facilities, thus ensuring that C^3 is not the Achilles' heel of nuclear war (14:3-7).

As required by the ATSD(AE) tasking, the DNA has developed a program to develop the requisite military standards and specifications. The program has as it's foundation the development of five inter-related standards: (1) Top-Level Standard, (2) Facilities Stress Control Standard, (3) Electronic Subsystem Strength Standard, (4) Facility HEMP Hardness Verification Standard, and (5) HEMP Handbook (14:App. A). The Top-Level Standard, as the name implies, is an overview standard. It will acquaint the user (System Program Officer, etc.) with the other documents and serve as a roadmap to their application. It will also provide reference to other related documents (14:App. A). The Facilities Stress Control Standard will establish HEMP hardening requirements for the facility that will house the specific C^3 equipment, the focus of the document being to control/reduce the HEMP stress experienced by the equipment (13:--; 14:App. A). The Electronic Subsystem Strength Standard complements the Facilities Stress Control Standard. The facilities standard requires reduction of the HEMP stress to a specified level. The subsystem standard then uses that level to establish a known level that the equipment inside the facility must be able to withstand (14:App. A). The fourth standard, or Facility HEMP Hardness Verification Standard, details the requirements for the functional HEMP hardness verification testing of the total facility. This is the "proof of the pudding" document which ensures that when you integrate the previously tested facility and subsystem, you have not missed or invalidated something (14:App. A). The last document in the series is not a standard but a HEMP handbook. It will provide the user with practical how-to information so that he can comply with the other four standards' requirements (14:App. A). This group of documents form links in a chain that connects our C^3 facilities with HEMP survivability. By taking each of the DNA standards and applying them as specified, we can ensure the HEMP survivability of our fixed, ground-based C^3 facilities. If we remove or weaken one of the links, then HEMP survivability is at risk.

Chapter Three

NDI AND ITS IMPACT ON HEMP SURVIVABILITY

The Federal Government, and in particular the Department of Defense (DoD), is constantly being asked to cut the cost of doing business. President Reagan underscored this need when in July, 1985 he "established his Blue Ribbon Commission on Defense Management to `study the issues surrounding defense management and organization, and report its findings and recommendations'" (6:xi). Less than one year later the Commission published its findings and recommendations in a report to the President commonly referred to as the Packard commission report. Among their findings for ways to improve the military's organization and procedures for acquiring new equipment, and thereby save resources, was the recommendation that the military should expand their use of commercial products. Specifically, "rather than relying on excessively rigid military specifications, DoD should make greater use of components, systems, and services available 'off-the-shelf'" (6:60). The use of "off-the-shelf," or NDI as it is frequently referred to, is seen as one means of cutting the cost of equipment that the DoD buys. The practice of buying products that are "developed uniquely for military use and to military specifications" has resulted in products that "cost substantially more that their commercial counterparts" (6:60). The commission's bottom line is that the DoD should use the less expensive NDI equipment over specially developed "militarized" equipment whenever it exists.

The concept of saving funds by using NDI sounds appealing, but what would be the impact of such a decision on the EMP survivability of our strategic, time-urgent C^3 capabilities? To answer that question, several other questions must be answered first. Is there a place for NDI equipment in strategic, time-urgent, command, control, and communications? If there is, do equipment manufacturers subject commercial equipment to any EMP, or EMP related, tests? How do these tests compare to the EMP threat? Finally, what can be said about the NDI equipment's EMP survivability and therefore the survivability of our strategic, time-urgent C^3 systems that might use NDI?

THE ROLE OF NDI IN STRATEGIC, TIME-URGENT C^3

The system used to transmit strategic, time-urgent messages is composed of a network of several different communication paths. Some of these communication paths make use of the public telephone system. This would, of course, imply that NDI in the form of commercial telephone equipment is already a part of our strategic, time-urgent C^3 network. However, the DoD is aware of the public telephone systems' potential vulnerability to EMP and has a program underway to investigate it. (This program is being managed by the Defense Communications Agency (DCA), Washington, DC, and could be the subject of a research project itself. Anyone interested in pursuing this subject should contact DCA.) Since there is already a program looking at the EMP survivability of the public telephone system and ways to EMP harden it, no further discussion of it will be included in this paper. There are, however, other communication paths besides the public telephone system, that are a part of the strategic, time-urgent message distribution system. The particular systems utilized in these paths are currently all "militarized" systems and there are no commercial or NDI equipments used (12:--). Therefore, the problem of NDI degrading the EMP survivability of the system does not currently exist. However, there are commercial HF, VHF, UHF, satellite, and microwave communication systems and equipments that could conceivably be used in place of the current military systems/equipments. If the recommendations of the President's commission are to be followed (and laws may soon be enacted that require it), any future changes would have to consider the use of NDI systems/equipments as a cost reducing alternative to developing yet another specialized military system/equipment (6:61). Therefore, the requirement to at least consider NDI for future use dictates the need to understand the ramifications of using NDI in these currently "militarized" systems.

EMP AND EMP RELATED TESTING OF NDI

Commercial equipment, much like military equipment, is subjected to numerous inspections and tests to ensure that the product will meet certain specifications. The question is, can any of the tests or inspections normally done on a commercial communication system be related to EMP testing? Major communication equipment manufacturers employ a variety of industry standards as well as company peculiar tests and inspections (16:--). The Institute for Electrical and Electronic Engineers (IEEE) and the Electronic Industries Association (EIA) publish numerous standards for testing and inspection. Standards by these organizations are frequently used for commercial equipment but not in any consistent fashion (16:--). Therefore, each piece of equipment would have to be considered on a case by case basis, and no general conclusions can be drawn. There are also standards published by the Federal Communications Commission (FCC) and Underwriters Laboratories (UL) that are applied almost universally (16:--). Since the IEEE and EIA standards are not always applied, they will not be considered further, as their applicability would be dependent upon the specific piece of equipment under consideration. However, since the FCC and UL standards are almost always applied, they need to be reviewed further.

The FCC has a variety of standard tests and inspection requirements they impose on the manufacture of commercial communication equipment. However, "in all cases, the technical requirements in the rules are intended to limit the amount of radio frequency interference the device will be capable of causing to radio communications" (9:1; 18:--). In other words, the rules or standards imposed by the FCC are designed to control what the piece of equipment transmits, not to ensure its survivability when exposed to electromagnetic interference such as an EMP.

The other set of requirements normally met by commercial equipment are those contained in various UL standards for safety. In particular, UL standard UL813, "Standard for Commercial Audio Equipment," and UL1414, "Across-the-line, Antenna-coupling, and Line-by-pass Capacitors for Radio- and Television-Type Appliances" apply to commercial communication equipments (17:--). UL813 is the broader of the two standards and references UL1414 in section 16, "Capacitors". The focus of both standards is user safety (17:7,8). The standards are used to test the construction and design of audio equipment to ensure that the user will not be injured during normal use of the equipment, which, of course, does not include use during a nuclear EMP event.

The conclusion to be reached at this point is that off-the-shelf components and equipment that have only been tested to the FCC and UL requirements have no known EMP survivability. This does not mean that in designing a piece of equipment to comply with the FCC and UL requirements that its EMP survivability has not also been improved. In fact, design measures taken to ensure its compliance with the FCC and UL standards will probably enhance its EMP survivability. For example, filtering techniques are frequently used to suppress spurrious emissions in order to comply with FCC requirements. These same filters, working in reverse, can help to suppress the EMP signal picked up by the equipment's antennae. Unfortunately, how much survivability has been gained and how it relates to the EMP stresses the DNA standard requires it to survive cannot be quantified without further testing. An example of this problem can be seen in the application of UL Std. 1414. Sections 8 through 11 of the standard describe testing of across-the-line capacitors. In the test, a 5 Kilovolt pulse from a dumping capacitor is applied to the capacitor under test. The acceptance criteria is that cheesecloth wrapped around the capacitor under test does not glow or flame and that parts of the capacitor not be expelled outside the equipment enclosure (8:F-8 - F-12). There is no requirement for the equipment to function following the test which is the major pass criteria for EMP testing. Indeed, some EMP testing of consumer electronics has been done on equipment that meets FCC and UL requirements which has shown that the equipment can not withstand an EMP (11:--).

The conclusion at this point is that where EMP survivability is a requirement, use of "off-the-shelf" equipments is probably not acceptable due to the equipment's unknown EMP survivability. However, the recommendation of the President's commission that the military use more "off-the-shelf" equipment remains valid. The next chapter will present some possible solutions to this apparent incompatibility of requirements.

Chapter Four

CONCLUSIONS AND RECOMMENDATIONS

At this point it would seem that there is no way to comply with the presidential commission's requirement to use commercial "off-the-shelf" equipment if there is also a requirement for EMP survivability. In the strictest sense, that may be true. However, I believe there are several alternatives to choose from that comply with the intent of the commission's recommendation -- i.e. to reduce the cost of equipment. The alternatives range from doing nothing and accepting the risk that the system may fail when subjected to an EMP event, to running a complete series of tests on the NDI to quantify and then fix any EMP susceptibility of the equipment. The advantages and/or disadvantages of the different alternatives are based on the assumption that there is a requirement to survive in an EMP environment with some level of confidence. These alternatives and what I believe are the implications of each will be covered in the remainder of this chapter.

USING NDI "AS IS"

The first alternative is to use the desired piece of commercial "off-the-shelf" equipment just as it is. As stated in the previous chapter, using NDI straight off the shelf carries the risk of the equipment failing when exposed to an EMP. A thorough review of any qualification test data available from the contractor may help to reduce the risk of failure but, as mentioned earlier, the amount of EMP data available that can be related to EMP survivability is likely to be minimal or non-existent and not contribute to a significant reduction in risk. For this to be an acceptable option, the requirement for EMP survivability cannot be of high priority. Otherwise, one could not justify accepting the risk of using equipment with essentially unknown survivability characteristics. This is obviously the least desirable option since it means either reducing EMP survivability requirements, or accepting a high risk of not meeting the requirements.

There are, however, some people within the communication and EMP communities who feel that if you design the facility so that it provides a high level of EMP stress reduction, then NDI equipment could be used inside it with a low risk of the equipment being damaged. This concept is generally referred to as the "low risk" EMP hardening approach. The problem with this approach lies with determining how much facility hardness is enough to reduce the risk of disrupting the C^3 capability to an acceptable level. Unless you know something about what the piece of NDI equipment can tolerate without damage and upset, you don't know how much facility shielding is needed to reduce the EMP stresses to that level. Again, this variation of using NDI "as is" carries an unquantified level of risk that the system will not meet its EMP survivability requirements. Although the risk might be "low", there is still some unquantified risk that exists and it may be unacceptable. If our strategic, time-urgent C^3 capability is dependent upon the NDI equipment working without damage or upset due to an EMP, then any amount of unknown risk is likely to be unacceptable unless the EMP survivability requirement can be relaxed. The "bottom line" is--using NDI "as is" for strategic, time-urgent C^3 is probably unacceptable due to the unknown risks of system failure that is involved and, therefore, other options should be considered.

USING NDI "AS IS" BUT TESTING

For this alternative, the selected piece of NDI would have to be subjected to a series of tests to accurately determine its susceptibility to an EMP. A minimum number of tests would need to be selected in order to keep the cost down as testing can quickly become a big cost item. By thus quantifying the equipment's EMP survivability, the risks of using the NDI can be stated. In some cases, the equipment may have no susceptibility and there would be no risk. Here again, trade-offs may have to be made between EMP survivability requirements and the risk of the equipment being subjected to the defined EMP environment. However, the final decision can be made based on known risk factors and the willingness to accept those risks.

USING NDI "AS IS" BUT TESTING AND FIXING

The final alternative builds upon the previous. In this instance, testing is conducted to determine any EMP susceptibility and the equipment is then modified to eliminate the susceptibility. Modification could take the form of added

EMP suppression components or perhaps a new enclosure. The final fix would be determined by the test results, costs of various fixes, and any other constraints identified. The point is that only the minimum modifications necessary to ensure compliance with the EMP survivability requirements and acceptable risk factors would have to be made. This option is obviously the most desirable for ensuring the system's survivability. The more economical NDI could be used with a minimum of added cost due to testing and possibly modification to eliminate or reduce susceptibility. More importantly, the decision maker would have all the information needed to make an informed and justifiable decision.

In all the preceeding alternatives, using NDI is seen as a basic requirement. The differences come in making trade-offs between using NDI with varying levels of known EMP survivability and the risk of not complying with stated EMP survivability requirements. The final decision on how much testing and/or EMP hardening is required would, of course, depend on the system under consideration, and its EMP survivability requirements. The alternatives I have presented are what I perceive to be some options available for consideration and some of the risks a decision maker would have to address.

In summary, the need to conserve resources will continue to be a pressing need for the foreseeable future. Non-developmental item (NDI) communication equipment remains a viable means of conserving valuable program funds. However, for those applications where EMP survivability is a requirement, trade-offs will have to be made between using NDI, meeting EMP survivability requirements, and saving money. I have attempted to identify some of the issues surrounding EMP survivability and the use of NDI. I have also put forth some alternatives and their associated risks for using NDI when EMP survivability is a requirement. Hopefully, what I have presented here will be of use to those who have to try to resolve any incompatibilities between these two requirements.

BIBLIOGRAPHY

A. REFERENCES CITED

Articles and Periodicals

1. McMillan, Raymond V., Brig Gen, USAF, and Dennis P. Johnson, Lt Col, USAF. "Integrating C^3I: NORAD's Number One Challenge." Defense Electronics, Vol 18 (January 1986), pp. 80-89.

2. Tamashiro, Howard. "The Danger of Nuclear Diplomatic Decapitation." Air University Review, Vol 35 (September-October 1984), pp. 74-79.

Official Documents

3. Booz-Allen and Hamilton Inc. DNA EMP Engineering Handbook for Ground-Based Facilities: Vol 2 Design and Engineering, DNA-TR-86-60-V2. Defense Nuclear Agency, Washington DC, 15 November 1986.

4. Dittmer, P., et al. DNA EMP Course Study Guide: Vol 1, Overview, DNA-H-86-68-V1. Defense Nuclear Agency, Washington DC, 27 May 1986.

5. -----. DNA EMP Course Study Guide: Vol 2, Detailed Discussions, DNA-H-86-68-V2. Defense Nuclear Agency, Washington DC, 27 May 1986.

6. Packard, David, et al. A Quest for Excellence: Final Report by the President's Blue Ribbon Commission on Defense Management. Washington DC: Government Printing Ofice, June 1986.

7. Underwriters Laboratories Inc. Standard for Commercial Audio Equipment, UL813, Fifth Edition. Northbrook, Illinois: Underwriters Laboratories Inc., September 1983.

8. -----. Standard for Across-the-Line, Antenna Coupling and Line-By-Pass Capacitors for Radio- and Television-Type Appliances, UL1414. Northbrook, Illinois: Underwriters Laboratories Inc., September 1983.

9. U S Superintendent of Documents, The FCC Equipment Authorization Program for Radio Frequency Devices, OET Bulletin No. 61. Washington D C: Government Printing Office, May 1987.

Unpublished Materials

10. Deputy Secretary of Defense Memorandum. "Military Standards and Specifications for Electromagnetic Pulse (EMP)." Washington D C, 9 December 1982. CONFIDENTIAL. Classified by ATSD(AE). Declassify on OADR.

11. Haas, Pete. "Environmental Assessment--Installation and Operation of Transportable Electromagnetic Pulse Simulator." Defense Nuclear Agency, Washington D C, 4 October 1977.

12. JCS Memorandum 2010/635-1. "Identification of C^3 Systems Subject to DoD Standard for High Altitude EMP Environments." Washington D C, Revised 18 June 1985. SECRET. Classified by Director C3S. Declassify on OADR.

13. SRI International. "High-Altitude Electromagnetic Pulse (HEMP) Protection of Fixed, Ground-Based Command, Control, and Communications Systems: Volume 2, Facility Design, Construction, and Stress Control." Topical Report 5, Defense Nuclear Agency, Washington D C, 10 April 1987.

14. -----. "Project Plan for DNA Specification and Standards Support (Second Revision)." Defense Nuclear Agency, Washington D C, 10 April 1987.

15. USDRE Memorandum. "Military Standards and Specifications for Achieving, Validating, and Maintaining EMP Protection, Survivability, and Endurance." Washington D C, 9 December 1981. CONFIDENTIAL. Classified by DUSD(C3I). Review on 12 November 1987.

Other Sources

16. Byers, John T., Vice President and Area Manager for Federal Government Market, Motorola Inc., Landover, Maryland. Telecon, 17 December 1987.

17. Dryer, Dave, Engineering Group Leader, Electrical Department, Underwriters Laboratories Inc., Northbrook, Illinois. Telecon, 25 September 1987.

18. Robinson, John T., Deputy Chief, Authorization and Standards Division, Office of Science and Technology, Federal Communications Commission, Columbia, Maryland. Telecon, 29 October 1987.

B. RELATED SOURCES

DoD-STD-2169A, High Altitude Electromagnetic Pulse (HEMP) Environment. 1 December 1987. SECRET. Classified by Multiple Sources. Declassify on OADR.

Stone, David H., Maj, USAF. "The Case Against Electromagnetic Weapons." Research study prepared at the Air Command and Staff College, Air University, Maxwell Air Forec Base, Alabama, April 1987.