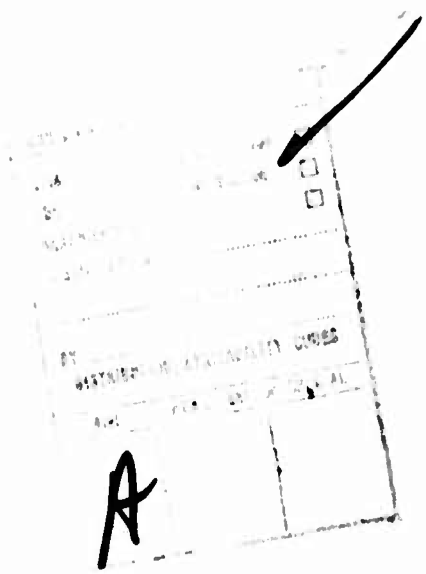
ELECTROMAGNETIC PULSE AND CIVIL PREPAREDNESS: An Overview

DEFENSE CIVIL PREPAREDNESS AGENCY

Washington, D. C. 20301

Contract DAHC20-73-C-0217
Research Work Unit 2213I

MAY 21, 1975



May 21, 1975

ELECTROMAGNETIC PULSE AND CIVIL PREPAREDNESS: An Overview

By:
James W. Kerr
Defense Civil Preparedness Agency

Jack E. Bridges
IIT Research Institute

Summary of a Seminar held at
IIT Research Institute, Chicago, Illinois
May 29-30, 1974. Sponsored by the
Defense Civil Preparedness Agency and the
Defense Nuclear Agency

DCPA REVIEW NOTICE

This report has been reviewed in the Defense Civil Preparedness Agency and approved for publication. Approval does not reflect the views and policies of the Defense Civil Preparedness Agency

Contract DAHC20-73-C-0217
Research Work Unit 2213I

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

Electromagnetic Pulse and Civil Preparedness: An Overview.

5. TYPE OF REPORT & PERIOD COVERED

~~Proceedings of Seminar~~

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

James W. Kerr
Jack E. Bridges

8. CONTRACT OR GRANT NUMBER(s)

DAHC20-73-C-0217

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Defense Civil Preparedness Agency
Washington, D. C. 20301

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

~~Work Unit 2213I~~

11. CONTROLLING OFFICE NAME AND ADDRESS

Defense Civil Preparedness Agency
Washington, D.C. 20301

12. REPORT DATE

May [redacted] 75

13. NUMBER OF PAGES

38

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

Summary rept.

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

EMP
Civil Preparedness
Electromagnetic protection

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

State of knowledge and degree of applicability of threat from and countermeasures against electromagnetic pulse from nuclear weapons is examined from the civil systems viewpoint. Environmental aspects are adequately researched, but practical measures are less well comprehended, especially for application by the layman. This report is expected to be the normative EMP program document for U.S. civil preparedness for the foreseeable future.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

390 342

1. INTRODUCTION

1.1 Background

The considerable advances in both knowledge and technology in the past five years led DCPA to sponsor a classified two-day seminar-workshop at IIT Research Institute, 29-30 May 74. Participants included government, industry, and the scientific community (See Appendix B). The purpose of the meeting was to present an overview of the civilian EMP problems, to note aspects transferable from military developments, to obtain the viewpoints of affected industries, and to identify future needs and implementation requirements. Unclassified presentations on the first day, with attendant discussion periods, were followed the next day by a much smaller workshop at classified levels.

1.2 EMP Environment and Effects

Of basic importance is the nature of the radio-frequency electromagnetic radiation from a nuclear burst. Over the last few years, sufficient information has been released in unclassified form from reliable sources[1,2,3,4,5] to permit intelligent susceptibility analyses and hardening programs for civil defense purposes. The subsequent discussion in this section briefly summarizes some of the more important aspects of this environment and, also, serves to introduce the problem area.

Under the proper circumstances, a significant portion of the energy released during a nuclear detonation can appear as an electromagnetic pulse. The spectral components of this pulse include the same frequencies as those employed by commercial radio and military system equipments. When the British first became aware of this particular phenomenon, they more appropriately called it the "radio flash".

The EMP from a nuclear detonation is dependent on the weapon burst point and location of possible affected systems. There are two weapon burst points of significance to civilian systems. In one case, the weapon is burst within the atmosphere near the target, and in the other, the weapon is burst just above the atmosphere. In the first place, the atmosphere or air has a containing effect on the EMP generation mechanisms; and as a result, any possible EMP damage is concomitant with other types of close-in nuclear weapons effects damage such as blast and fire. In addition, the EMP arising from detonations within the atmosphere close to the earth's surface is generally not of great significance in relation to other nuclear weapons effects.

On the other hand, if a high yield weapon is detonated just outside of the atmosphere, the EMP generation mechanisms are such that a fairly efficient conversion of the nuclear energy into the electromagnetic radio frequency spectrum occurs. This electromagnetic energy is radiated from the upper atmosphere downward to the earth's surface and can illuminate a very substantial fraction of the earth's surface. This radio-frequency-spectrum electromagnetic pulse illumination can occur at very high field intensities and with very unusual waveshapes. It is not accompanied by any other prompt nuclear weapons effects such as blast, thermal, dust, debris and biological effects. Owing to the very high levels of intensities and unique waveform, the EMP has the capability to affect, at great distances, the operation of electrical and electronic equipments which have not been hardened. Typical ranges for the maximum ground coverage are illustrated in Fig. 1.

The waveform of electromagnetic fields and associated spectra of the EMP differ from those of other natural, more commonly used man-made sources. A typical EMP test waveform which is used to evaluate equipment responses has a rise time on the order of 10 nanoseconds (10^{-8} seconds), a peak value of 50,000 volts per meter, and an exponential fall time on the order of 500 nanoseconds. This waveform has a much greater amplitude and a much faster rise time than the fields radiated from a nearby lightning stroke, as shown in Fig. 2. Another important point is that the very intense EMP fields occur nearly simultaneously over large areas of the surface of the earth. Very high amplitude natural or man-made fields are usually quite localized. The EMP occupies a spectrum roughly from very low frequencies well into the lower microwave band, whereas most man-made fields are confined spectrally as well as spatially. This is indicated in Fig. 2. EMP is sufficiently different than any other normally occuring high-level electromagnetic environment that the usual protection devices, such as surge arrestors and filters, do not always provide sufficient protection without the addition of other measures.

The understanding of how EMP is generated has reached a point where good agreement exists between the theoretical results

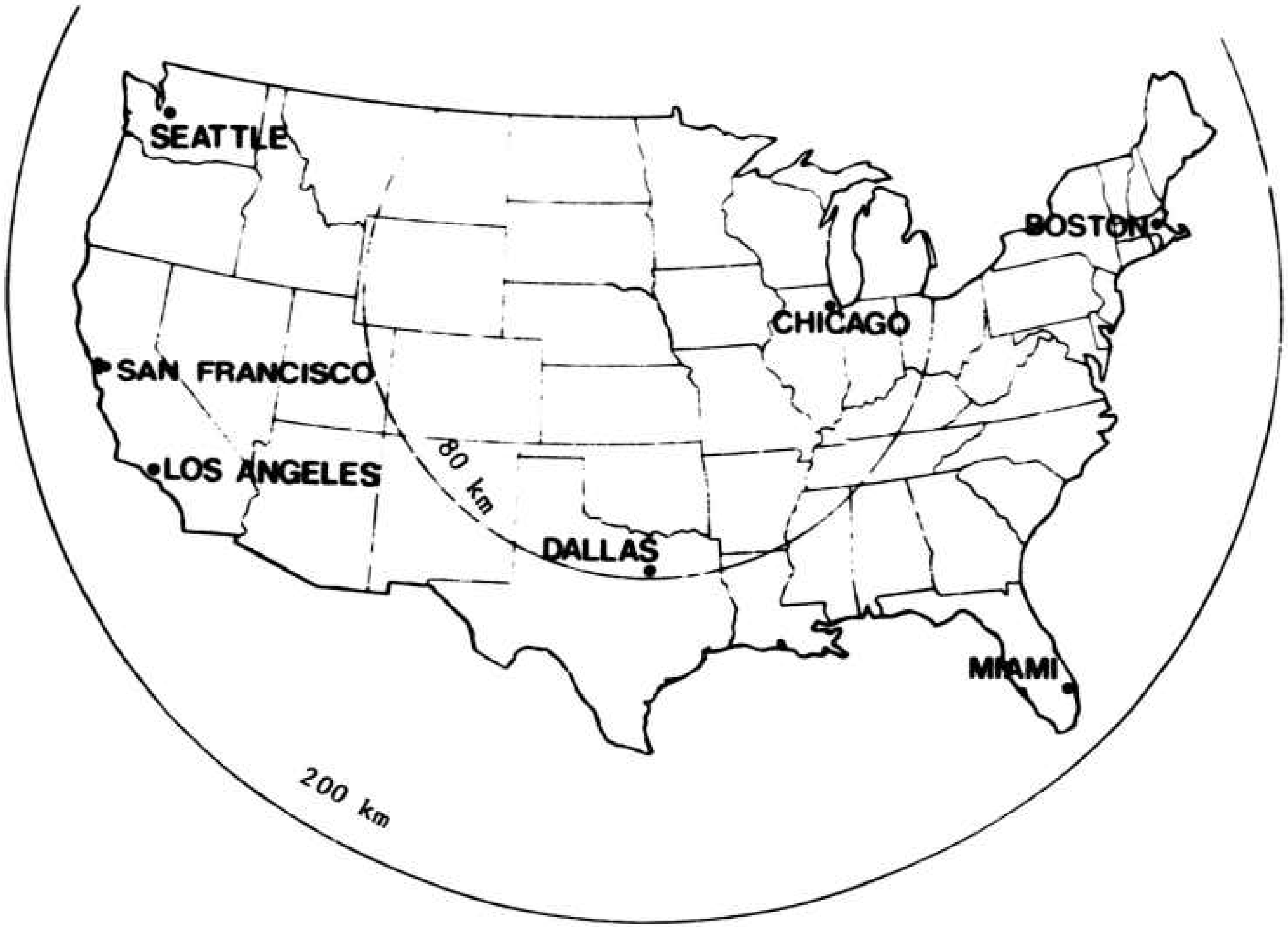


Figure 1 MAXIMUM GROUND COVERAGE OF HIGH ALTITUDE BURSTS FOR BURST HEIGHT OF EIGHTY AND 200 KILOMETERS

(Note that field intensity can vary within each area.)

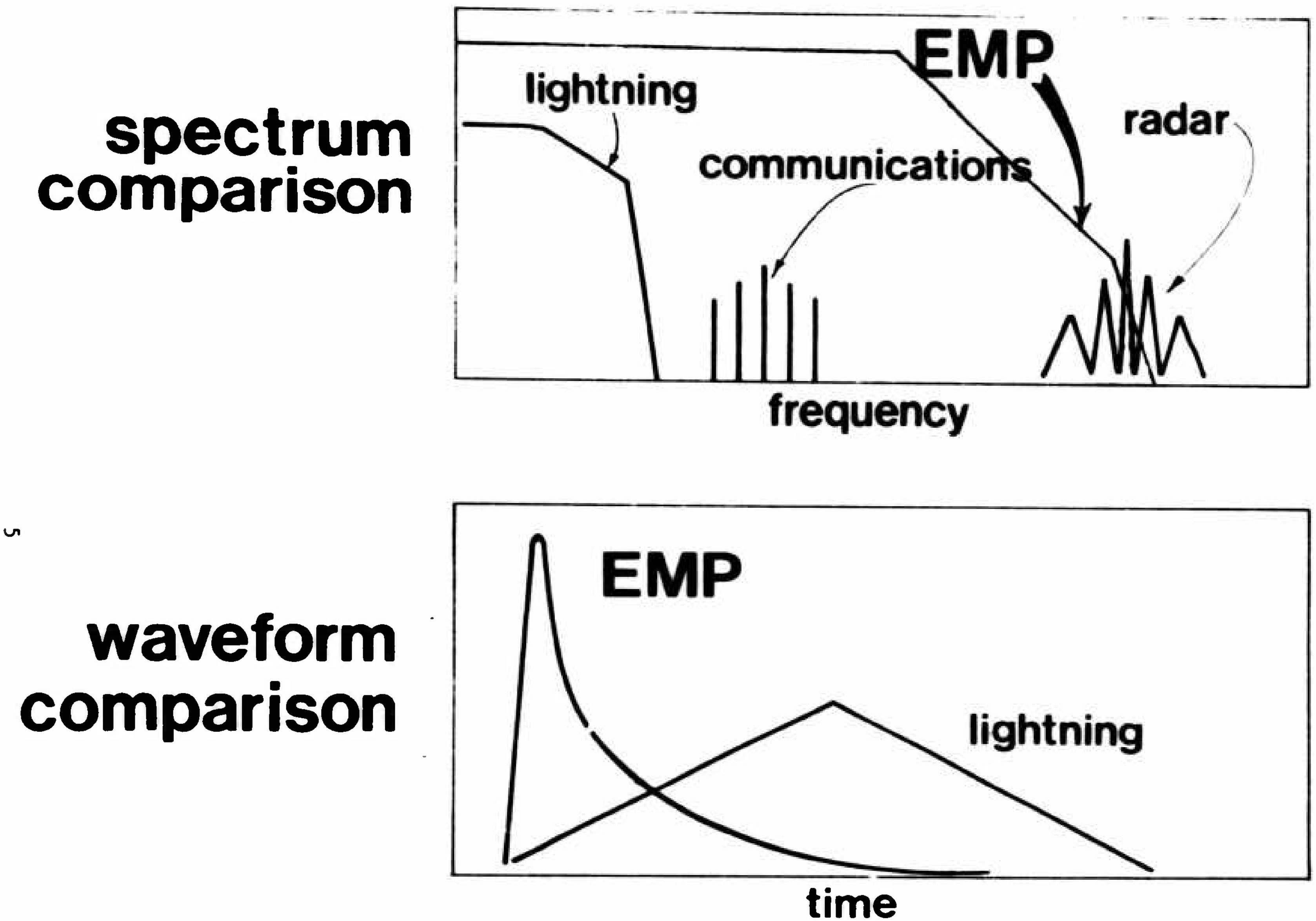


Fig. 2 COMPARISON OF NORMALLY OCCURRING HIGH-LEVEL EM ENVIRONMENTS WITH EMP

and observed measurements taken during the atmospheric tests. As a consequence, EMP waveform parameters of known significance can, for the most important cases, be described within a factor of two, and for the more unusual situations well within a factor of ten.

Numerous examples of EMP induced damage or disruptions were observed during the atmospheric test programs. Such examples range from damaged cables due to arc-overs to the false tripping of street light systems from the EMP which arose many hundreds of miles away from the weapon detonation point.

Similar results have been observed for modern, sophisticated equipment exposed to EMP simulated by non-nuclear techniques. These equipments, if not otherwise protected, exhibit a very high probability to be operationally upset at a very low level of EMP illumination. For example, the data in a digital computer can be scrambled at field intensities as low as a few hundred volts per meter. Wholesale burnout of large numbers of components has not been noted; however, functional damage to a few critical elements attached to exposed cables or antennas can occur, often in unexpected ways. In general, the more modern and sophisticated equipments show a high potential for EMP degradation than the older, more simple units.

1.3 DCPA Programs

For over ten years, DCPA and its predecessor agencies have pursued a low-level program of research and action in the EMP field. The list of contributors is impressive, and includes most of the individuals and organizations that have known competence in the field, including an advisory committee of the National Academy of Sciences.

Early efforts were hampered by two basic problems. First, virtually all EMP data and reports were highly classified, whereas few civil systems users or operators had clearances. Secondly, the state of knowledge regarding civil system's vulnerability and feasible low-level countermeasures was indeed poor. It was thus necessary for DCPA to "piggyback" on military programs, in an attempt to glean material that would be declassifiable and translatable into civil guidance. In the late 1960's, the first such material appeared, and efforts have continued to produce credible and relevant manuals and procedures for use by the civil preparedness community at federal, state and local levels.

It is necessary to distinguish a rather striking contrast between civil and military approaches. While the nearly universal military approach has been to harden systems of interest, this is not a feasible civil measure. Civil preparedness systems can afford to be out of action for periods running from minutes to days, but cannot afford the cost of hardening the tens of thousands of installations in CONUS against anything approaching threat level. Thus, the civil approach has been one of upgrading through low-cost prudent plans or modifications. The attempt made is to build some EMP resistance into new hardware and systems, to retrofit slowly, and to harden actually only the few existing or planned blast-hardened facilities.

The earlier classified studies led to the now-famous Oak Ridge conference of 1969 that produced the conclusions shown in Appendix A. At the same time, studies were in progress on radio, power, and other civil systems of concern. These produced a series of guidance documents that now enjoy a world-wide audience, and have had a major impact on upgrading of the basically vulnerable civil installations. These documents are listed in Appendix C.

As work has progressed and the field broadened, greater opportunities for disagreement in detail have likewise arisen. This has provided partial motivation for the seminar reported in this document. Obviously, universal agreement is not feasible, but all inputs have had their impact on this summation. It is anticipated by DCPA that the content of this report, especially Section 3.0, will serve DCPA as a normative reference for at least the next five-year period.

2. SUMMARY OF SEMINAR PRESENTATIONS

2.1 Civil Defense Communications Systems

2.1.1 Introduction

A very hostile environment consisting of radiation, fallout, fires and the direct effects of blasts will exist over much of the nation during and following a nuclear attack. State and local governments must be prepared to provide the necessary emergency services to insure national survival and eventual recovery. To this end, communications are essential.

Telephone and telegraph common carrier communications are the principal means considered to be available to all elements of Civil Defense operations.[5] Many elements of these common carriers may be damaged by the direct effects of nuclear blast. In the event that these land links are not available, a variety of two-way radio links are available.[5] An Emergency Broadcast System (EBS)[5,6] employing selected AM broadcast stations is also available which is largely dependent on signals derived from carrier services. State and regional emergency operating centers (EOC's) have the primary function of coordinating and controlling Civil Defense operations across local boundaries. To provide these functions, the EOC's become a focal point for a number of communication links.

2.1.2 Telephone and Telegraph Common Carrier

The effect of EMP on the telephone land-line communications has been the subject of a number of investigations conducted by Bell Telephone Laboratories, both in-house and on projects sponsored by the Military Departments. The AT&T telecommunications system is complex, extensive, and represents a formidable enterprise in developing its EMP vulnerability. Numerous analyses and some dozen different laboratory and field test programs have been conducted. Based on these limited numbers of tests, on laboratory analysis, and on engineering judgment, it is the opinion of AT&T that there appears to be no need to retrofit the existing system to increase the EMP margin of protection for voice communications. (In some special military digital data situations, DoD may consider it necessary to increase this margin). Based on this assessment, AT&T is no longer conducting any large-scale analysis and testing programs of current Bell System equipment. However, some future testing of selected AT&T components may be conducted by Military Departments.

To assure that future Bell System equipment is EMP resistant, Bell Telephone Laboratories is developing an EMP hardening handbook for telephone circuit and equipment designers and building engineers. This will assure that the necessary protection is incorporated, as far as practicable, into future Bell System installations. In addition, simple laboratory test procedures will be initiated to assure adequate EMP resistance in new designs.

The inherent hardness of the AT&T network is due, in large part, to the electromagnetic protective measures already incorporated to protect against other high level electromagnetic interaction effects, such as power line switching surges, lightning currents, and radio interference. Specifically, the availability of batteries and emergency generator power sources not only isolates the essential circuits in telephone switching centers from the massive EMP surge appearing in power lines, but also provides an independent power source for Bell System equipment in the event of a commercial power blackout.

It should be noted that most of the analyses and tests by AT&T were conducted on facilities of military interest. The EMP behavior of local exchanges whose circuits might interface with state and local civil defense units has not been tested or analyzed directly. It is, however, the opinion of AT&T that local service will probably not be significantly affected by EMP at the presently agreed on threat level.

2.1.3 Two-Way Radios

The available two-way radio communications for state civil defense operations are primarily those communication networks that can provide state-wide coverage. Such networks are those of the state and local civil defense organizations, state police, forestry, park and highway departments, radio amateur emergency services (RACES), state-wide utility companies' corps of engineers, as well as others.

Local governments have the primary function of providing the necessary emergency services to save lives, limit damage, and speed recovery. Public and private resources could also be called upon to assist in local civil defense operations.

Immediately following a nuclear attack, essential actions required by the local governments are those related to countering the threats to life and property by radiation fallout or fires. The two-way communications associated with a radiological defense (RADEF) and the fire department nets will be likely to have large communication traffic requirements during the early periods following the attack.

Other services, such as police, medical, rescue and evacuation, and welfare will be provided as the environment permits. The primary two-way radio communications associated with these services are those that are normally used by these agencies.

On a longer time frame, the post-attack recovery of the public power utilities system, water supplies, sewage treatment, fuel delivery, rail, truck, and bus traffic, and aircraft control are similarly dependent on the two-way radio communication.

Programs have been conducted which investigated the effect of EMP on small portable radios or systems used in the police and fire safety networks [5,6,7] Typical radio receivers or transceivers were exposed to simulated EMP test waveforms. Various forms of damage were observed in a large fraction of the tested units

Small, portable, battery-operated AM broadcast receivers, of the shirt pocket size, suffered no damage unless placed near very high current-carrying cables. This observation is of importance regarding the use of the Emergency Broadcast System described in Section 2.4. The susceptibility of TV receivers to EMP exposure remains to be developed.

A significant fraction of the more modern, up-to-date VHF and UHF receiving systems suffered some form of damage. This damage was associated with components attached to exterior conductors such as antennas or cables Whether damage occurred or not was a function of a number of design details, with the resistance to damage increasing generally with the higher frequencies where the shorter antennas are normally employed

The trend toward incorporation of integrated circuits led to the possibility of additional potential vulnerability being built into the more modern day receivers. For example, an integrated circuit in a Motorola transceiver was burned out by EMP picked up by the microphone cord Initially, this appeared to be an improbable failure mode and came as somewhat of a surprise

It was also experimentally demonstrated that repetitive EMP-induced power line surges could damage receivers drawing power from the 60 Hz lines having surge protected distribution transformers.[8] This suggests a higher susceptibility for base stations than for mobile units. Where backup power is available, the automatic control system which switches over to the emergency generator may be highly susceptible. Resetting circuit breakers and making other adjustments to counter an EMP exposure during an attack period also poses certain human problems, especially if the qualified personnel are normally in protected shelters during the attack period.

Hardening techniques and components are available, but often require careful engineering analysis and test before installation.[5,9] For example, the zener diode surge arresters used to protect the sensitive input circuit's communication receiver exhibit a very large shunt capacity, which will degrade normal reception

The test results on the very small sample of transceivers and receivers vital to important civil defense missions leaves much to be desired from a decision-making viewpoint If nearly all had been damaged, an extensive hardening of all two-way radio communications equipment could be strongly recommended Unfortunately, higher levels of susceptibility are increasingly being built into the more recent equipment by the incorporation of very damage-prone integrated semiconductor circuits. The promulgation of an EMP hardening specification is a possible solution for new equipments, but an intelligent basis for this which will not radically increase costs remains to be established In the case of existing equipment, further investigations might be useful to minimize the component cost and retrofit problems

2 1.4 Emergency Broadcast System

The principal means for emergency communication with large masses of people is by the Emergency Broadcast System (EBS) To provide for essential communications to the large number of people, certain AM radio broadcast stations are designated to broadcast directly to the public. These stations derive their information from land line networks leased from common carriers, chiefly, AT&T.

As it stands, cost effective EMP hardening measures exist to solve all known problems in present broadcast station equipment.[3,6] Surge arrestors can be employed to protect the transmitter output stages from surges induced in the broadcast antenna. Supplementary shielding is probably required to protect the interior unshielded electronic equipments. An EMP protected emergency power station also appears desirable, assuming the use of adequate disconnects and switch-over circuits from the public service utilities distribution network. The increasing use of solid state devices worsens the EMP problem in broadcast station equipment. The interfaces between the telephone system and the EBS might well be a problem area.

Small, shirt-pocket sized AM battery operated receivers have been experimentally found to be invulnerable to EMP Because these intrinsically EMP hard receivers are available in almost every household, the EBS system appears especially attractive as a primary and back-up communication method with large masses of people.

It appears that the EBS will continue to have a role in the state and local operations. However, as now configured, the EBS is unreliable vis-à-vis the EMP, owing to lack of rigorous application of cost effective EMP hardening measures. To assure complete reliability of the EBS system, the telephone network should be supplemented by a preplanned hardening radio relay for state and local use. The EBS system can also supply clarifying information to the public, possibly necessary after the activation of the acoustical warning sirens of an impending attack. During the attack, the warning system could well be damaged (although this remains to be studied) and the EBS could be used to provide guidance to the public during the attack and recovery periods.

2.1.5 Emergency Operations Centers

The Emergency Operating Centers (EOC's) contain the electronic equipment necessary for warning of a possible impending nuclear attack, as well as communications equipment vital during the postattack recovery period. This equipment, if not protected, might well be susceptible to possible EMP effects. To provide a basis for hardening of emergency operating centers, a number of studies were conducted which resulted in numerous hardening guidance documents.[4,10,11,12,13,19]

Presently, DCPA is hardening Federal Regional Operating Centers against EMP. In one this is done by means of a completely welded steel shield which envelopes the entire facility. In the rest, limited sections of the communications rooms are shielded, with "clean" engineering applied to other segments and all leads.

An exemplary program to harden one state emergency operating facility has just been completed. The basic hardening approach relies on the use of prefabricated EM shielding enclosures to protect the more critical electronic and electrical equipments. Based on the design of this system, consideration is being given to hardening the radio communication centers of the remaining state emergency operating centers.

In addition to the basic hardening technique of shielding employed for both the Federal and State emergency operating centers, connecting cables have generally been run in ferrous conduits with electromagnetically treated threaded couplers. All electronic-electrical wires penetrating the enclosures were made through a solid steel entry panel on the wall of the enclosure. Individual terminal protective measures are then applied.

A test program to validate the incorporated hardening is currently under way.

2.2 Electrical Power Systems

2.2.1 Introduction

The power system is a very complex and diverse utility. While there are many superficially common features, such as the use of transmission lines and transformers, technical aspects of each power company can differ considerably in important details from others. For example, some of the southwest coastal utilities have not required the use of lightning protection for their power distribution transformers, whereas in other regions of the United States where lightning activity is more intense, the use of lightning protection is mandatory.

The complexity and sophistication of the modern interconnected power systems and related components probably exceeds that of either a strategic missile system or the Bell Telephone System. As a consequence, the research which has been conducted to date is only sufficient to begin to identify the problems and the necessary coutermeasures. The results, therefore, should be considered both interim and incomplete. It is probably more appropriate to describe the behavior of the power system in terms of the specific components or equipments as having either a high susceptibility or low susceptibility, rather than to speak of the more deterministic overall vulnerability of the power system.

The effects of EMP on power systems have been considered in a half-dozen programs concluded or in progress.[6,14,15,16,17,18]

The subsequent discussion considers: first, the general EMP effects on power transmission and distribution portion; second, the behavior of the supervisory and control elements; third, network aspects; fourth, countermeasures for power systems; and fifth, response of user equipment and resultant hardening.

2.2.2 General Response of Transmission and Distribution Lines

The results to date indicate the EMP from a high altitude nuclear explosion will induce a current and voltage surge throughout the electric power system.[6,14] The voltages and currents will be induced on the transmission and distribution lines as well as other portions of the power system, such as control circuits. These will be characterized by very fast rates of rise, high peak values, and short time durations. The peak values of the current pulses depend on the orientation and geometry of the lines, and can be as great as 10-30 kilo-amperes. Although these values are somewhat less than the total current of an average lightning stroke, it is greater than the average lightning current appearing in the lightning arrestors. Voltages developed by EMP illumination can rise to values in the order of several megavolts.

These EMP induced pulses differ from lightning in several ways. First, the rise time of the pulses may be up to 10 or more times faster than the rise times associated with lightning. Second, these pulses can appear simultaneously throughout the entire power system.

This universal illumination aspect of the high altitude EMP-induced pulses means that the system will be thoroughly tested for its weakest components. This is in contrast to lightning-induced pulses which analogously only "spot check" the system for weaknesses. Furthermore, in any attack there may be many high altitude explosions. This means that the power system will be subject to repeated universal tests by EMP induced surges.

It is virtually certain that the weak points will be found. Those points in the system which are not adequately protected against lightning induced pulses are especially vulnerable, but adequate lightning protection does not guarantee adequate protection against EMP. In particular, overhead ground wires offer little protection against EMP. In addition, limited experimental tests have indicated a higher susceptibility of insulation in power equipment to EMP waveforms than might be inferred from experiments employing lightning-induced waveforms.[8] This appears to be a critical but controversial point, and further work is needed to resolve it.

2.2.3 Supervisory Control

Higher degrees of susceptibility appear to lie in the supervisory control equipment of the power system. Investigations to date[15] have considered the following entry points into the supervisory control system:

1. Induction of EMP currents into current transformer monitoring lines.
2. Direct induction of EMP currents in exposed outdoor relay circuits, and
3. Direct induction of EMP currents in relay circuits contained in control houses.

Damage to relays connected to the above circuits was assessed. It was found that if the relays were entirely electromechanical, damage which would prevent their continued functioning was extremely unlikely. Nor is it likely that the current induced in the circuits feeding the relays will cause them to operate falsely because of their great mechanical inertia. On the other hand, if the relays are constructed in part from semiconductor components, damage and false operation was very likely. Limited experimental tests confirmed the high susceptibility of these circuits employing semiconductors.

2.2.4 Power Network

The dynamic effect of an EMP or a series of EMP bursts on the entire power system was considered during a rather limited and preliminary study.[16] It was concluded that there is a possibility that an EMP or a series of EMP's can introduce serious perturbation on the distribution networks, causing a large portion of the transmission network in the perturbed area to lose synchronization, and resulting in an immediate and massive power failure. Further study is needed to develop specific ranges of probability for this to occur.

Another problem area is the possible high susceptibility of consumer equipment which would require rapid load shedding procedures. However, even if the consumer equipment is adequately protected, a distribution system might well be able to recover from the effects of a single EMP pulse or from a series of such pulses spaced more than a few minutes apart. If, however, more than a few pulses occur in a period of a few minutes, successive opening and reclosing of breakers may take place until a large-scale lock-open of many breakers occurs, giving rise to a power failure.[14]

Studies to date on the impact of EMP on a regional power pool show that computer controlled operation may deteriorate, but that the system can "coast" long enough to permit human operation and non-catastrophic shut-down, if needed.[17] For this to be successful, training of personnel and other countermeasures discussed in the succeeding section are needed. In addition, various communication links such as leased common carrier, privately owned microwave and two-wave radios are vital to the possible non-catastrophic shut-down and rapid reconstruction of services.

2.2.5 EMP Countermeasures for Power Systems

Methods to cope with the possible, but as yet undetermined, vulnerability of the power systems to EMP do not lie, because of expense, in the extensive physical hardening of electric power systems (such as by the use of extra shielding, filtering, and surge arrestors). It does seem desirable, however, where these features can be incorporated economically and as part of other requirements, to do so from an EMP hardening viewpoint as well. This appears to be desirable in the supervisory control equipment, and especially those circuits and subsystem elements necessary to reconstitute the system after a possible massive power outage.

Also, as an interim measure, it appears to be desirable to provide sufficient guidance to the power companies so that they can develop the necessary procedures to cope with the possible EMP effects. An EMP disaster plan similar to the disaster plans currently developed to provide quick recovery from physical damage due to earthquakes, windstorms or hurricanes seems highly desirable.

To implement this, extensive interaction with the power companies is needed by means of a comprehensive educational program at both managerial and technical levels. Interaction via technical societies to include EMP, as well as lightning and switching surge requirements in standard test bench acceptance procedures for equipment might also be productive. For maximum effectiveness, more complete data--especially experimental--on the susceptible elements of power system and benefit of various countermeasures would be needed.

2.2.6 EMP Effects on Consumer Equipments and Countermeasures

In addition to the direct coupling of EMP into the transmission and distribution lines, up to one-third of the voltage in the primary may be passed on to the secondary by capacitive coupling into consumer circuits.[8,14] This means that transformers will not offer substantial protection against such pulses coming into the equipment of the consumer. Such voltage pulses may reach peak values of 10-70 kilovolts and they will damage consumer equipment unless protective measures are taken. Such protective measures include the use of lightning arrestors and surge absorption capacitors installed near the user equipment. Power transformers which incorporated electrostatic shields were suggested as a means to counter this feed-through problem. Recent tests, however, disclosed that this technique is of little benefit.[8]

Some sort of emergency procedures also are necessary for equipments for critical consumers. Such vital equipments might include water pumping stations, sewage treatment plants, fuel distribution systems, lighting systems, hospitals, and air traffic control equipment. The most direct method of protection of such equipment would be by means of disconnecting it from the public utility system. Other techniques, such as the combined use of surge arrestors, filters, and shielded enclosures, are also possibilities. Techniques to protect consumer equipment are expected to be summarized in the forthcoming handbook[18] and some of these have already been noted.[13]

However, the efficacy of a number of these protective techniques remains to be experimentally demonstrated. This should be noted if the type of protection is in the higher cost category or if the equipment is critical. The most serious technical problem appears to be that of providing a satisfactory disconnect from the power system. In certain circumstances, the pickup along distribution lines will be in the order of megavolts. Providing switches, surge arrestors and filters which can withstand this voltage may be expensive.

2.3 Relevant Military Efforts

The defense Nuclear Agency is providing documentation and dissemination of pertinent EMP hardening information. For security reasons, much of the material is classified. The DNA EMP

Awareness Course Notes,[1] the PEM note series,[19] and Preferred Test Procedures are available for distribution for civil defense uses. Unclassified versions of the DNA EMP Course have been presented to key members of the power utilities. More and more of the results of various programs are being made available on an unclassified basis. For example, funded efforts are underway to develop an effective surge arrestor which can be installed with a minimum of engineering costs.

The more confidential aspects of EMP efforts in the military concern development of the EMP environment, the non-nuclear simulation of the EMP fields for test purposes, generation of special test environments by underground nuclear detonations, and analyses of important systems. Most of these results are documented on a general basis in the DNA EMP Handbook. A compilation of EMP interaction computer programs is being assembled for DNA by Lawrence Livermore Laboratories, and a library of EMP related documents is maintained for DNA by General Electric at Santa Barbara, California. A note series on various aspects of EMP--interaction, environment, simulation and mathematics--is available at the Air Force Weapons Laboratory. A number of military facilities, such as HDL, AFWL and NOL maintain analytical, simulation and data-bank capabilities.

In general, the basic "tools" needed to harden a system are being actively developed by the military. These have been and can be expected to be made available in appropriate format for civil defense purposes.

3. ANALYSIS AND FINDINGS

3.1 Introduction

The attendees discussed the present state of the art in the general frame of reference of the findings of the 1969 conference (Appendix A). While none of those findings has been invalidated in the intervening years, a number have been overtaken by events or by the many important advances in knowledge. The formulation which follows reflects the comments and debates of 1974. The general statements enjoy broad if not unanimous support; some of the more detailed remarks juxtapose several, sometimes divergent points of view.

3.2 The EMP Environment

There remains no reasonable doubt as to the nature and general description of the threat of the EMP environment to civil systems. For these applications, the environment can be described within better than an order of magnitude. For any given location the actual problems are highly scenario dependent.

3.3 Testing, Simulation, and Analysis

In general, civil systems are much less demanding than military systems in level of confidence as to level of performance and in overall survivability. Systems users must use available guidance material and specify such factors as performance standards and acceptable down time if evaluation by testing and analysis is to be relevant and interpretation of results meaningful. A scenario approach is often useful, allowing the correlation of system sensitivity to a range of credible scenarios and the establishment of criteria for tolerance to mission interference. This approach also provides a partially quantitative appreciation for what, at basic levels, is largely a qualitative judgment.

Numerous systems and devices that produce a credible EMP field for test purposes are available. Their use is costly and scheduling is sometimes critical. Use of the less costly injection technique usually provides adequate insights for evaluation of civil systems where pretest analysis has been applied. Computer codes that can aid in test design through reasonable description of the EMP environment are numerous though not uniformly relevant or obviously interrelated. Codes for coupling into many systems are also available, but their suitability for use in evaluating civil systems is questionable because an associated test program is usually required, and where required is usually very expensive. Damage assessment by means of computer analysis remains unfeasible at the system level.

The feasibility of assessing the vulnerability of civil systems varies widely; it is usually more difficult to assess a "soft" system than an inherently "hard" one. Preliminary identification of likely problem areas (the "weakest link") is usually feasible, thereby facilitating test design and often reducing the costs that are otherwise demanded by the "worst case" approach. Quantitative appreciation of the benefit derived from "weak link fixes" remains problematic. Adequate insights into system vulnerability can often be derived from the application of nominal threat criteria, provided additional analysis is carried out at other suitable stress levels.

3.4 System Vulnerability and Countermeasures

Economic factors coupled with lack of a well defined survivability requirement have generally forced the omission of EMP resistance from procurement specifications for civil systems, notably governmental systems. This means that the appraisals of their vulnerability and suggestions for upgrading must be viewed in a much different light from their military counterparts. It also means that "hardening" to any absolute standard is neither appropriate nor cost-effective. Rather, the civil approach must be to upgrade resistance to EMP with adequate discrimination to assure that the costs are commensurate with anticipated gains. Insofar as practicable, this should be done without recourse to testing except as a verification and quality control measure. Significant benefits can also be achieved through planning of alternative employment of existing systems and exploitation of new technology.

Sound engineering practice (to include EMP considerations), if properly conceived, faithfully carried out, and rigidly maintained and enforced, represents the most noteworthy protection for civil systems; in some cases it is the only protection needed. Operational modifications to otherwise resistant installations, unless done with equal EMP rigor, are notorious for degrading resistance to EMP.

Retrofitting is usually the most expensive and least satisfactory approach; however, a "brute force" approach to upgrading critical systems can be effective if suitably organized. Cost analysis at early planning stages can often help choose between built-in or added-on upgrading measures.

The add-on approach to upgrading vulnerable systems is well understood and is now the main EMP action program in DCPA; its effectiveness is not easy to evaluate. Guidance in this technique is available for application to control centers, broadcast radio, public-safety communication networks, and, to a lesser extent, to power systems and logic circuits. Limited testing (still underway) and the application of engineering judgment to existing voice-grade wire systems have led the common carriers to qualitative conclusions as to reasonable survivability; the extent and complexity of such systems makes full demonstration of survivability infeasible.

Free-field EMP wartime pulses offer no direct threat to people. Direct evidence is lacking, but it appears that isolated casualties could result in cases of people touching "long" (hundreds of meters) exposed conductors. The usual laboratory discretion in dealing with high voltage electricity is needed in testing programs.

3.5 <u>Requirements</u>

A general federal policy on EMP is both feasible and necessary. Classification is no longer a bar to such a pronouncement, nor is lack of technical data. (More and more military EMP publications are issued in unclassified form).

Civil preparedness programs are highly sensitive to the availability of electric power. If, as recently concluded on a policy basis, planning for local operations must assume absence of power, ventilation problems for below-grade shelter spaces must be dealt with using alternative approaches. An equivalent evaluation of telephone, radio, fire, water and other specialized systems is needed.

A low-cost, layman-oriented methodology (not using testing) for appraising vulnerability of unimproved facilities, such as local operating centers in unprotected structures, is also urgently needed. Coupled with simple upgrading guidance, developed in parallel with a limited program of experimentation and testing, such an application of engineering judgment offers the greatest hope for civil system improvement. This becomes especially true if DCPA does not maintain a significant EMP program for the immediate future.

APPENDIX A

IMPLICATIONS OF EMP FOR CIVILIAN SYSTEMS

As part of their conclusions regarding EMP effects, the (1969) seminar participants agreed on the following 13 points and recommended that these points be disseminated.

1. Electromagnetic environments of significance to civilian systems can be described within a factor of 2 or, at worst, an order of magnitude.
2. The most sensitive hardware of a given system can be selected with acceptable confidence for further study.
3. Experimental simulator programs are not yet understood or developed well enough, nor are facilities sufficiently numerous to permit general testing prior to reasonably rigorous systems analysis.
4. EMP retrofit for existing soft systems is feasible in many cases but usually much less economical than EMP protection incorporated in the design and construction of new facilities.
5. Capability for systems analysis of projected systems now exists.
6. Future efforts should be directed toward selected systems studies, costing and identification of hardening options, description of selection criteria, and generally upgrading the technological

base for supporting agency or government-wide policy making.

7. Coupling of EMP into, and its effects on, many hardware systems can be determined, but sufficiently generalized vulnerability information does not yet exist to permit formulation of damage-assessment computer programs.

8. The free field EMP presents no known direct personnel hazard.

9. The nature and extent of EMP damage to U.S. civilian systems cannot now be described well enough to declare with any certainty that a given system will or will not function transattack or post-attack or to state degrees of partial effectiveness. Experience indicates that component upset or damage may occur unless appropriate countermeasures have been taken.

10. Planning and analysis should focus on "worst case" contingencies until more specific information is available.

11. Study of technological, economic, and institutional factors for a federal policy pronouncement on EMP is feasible and should be started now.

12. System description and input to EMP analysis must include estimates of required reliability and tolerable downtime. Where possible, this estimate must come from those operationally responsible

13. The conflicting requirements for information on EMP and for classification of EMP data in the national interest should be weighed in order that sufficient protection against EMP can be afforded to vital civilian systems.

APPENDIX B

ATTENDEES

Adams, Major William E.
Defense Nuclear Agency

Alfonte, Mr. William
DNA-Information and Analysis Center
General Electric Company-TEMPO

Anderson, Mr. Robert A.
Lawrence Livermore Laboratories
University of California

Beckham, Mr. Claud
Government Com. Mgr.
A. T. & T. Company

Bostak, Mr. Ron
Harry Diamond Labs

Christensen, Mr. K.
DCPA

Cikotas, Mr. Bron
U. S. Air Force Weapons Lab.

Clark, Mr. Don B.
Naval Civil Engineering Lab.
Navy Construction Battalion Center

Conolly, Mr. Merton
Commonwealth Edison Co.

Hess, Mr. Ed. G.
A. T. & T. Company

Jero, Mr. Leroy
Motorola, Inc.

Karzas, Dr. William
R. & D. Associates

Kerger, Mr. Robert
Commonwealth Edison

Kerr, Mr. James
DCPA

Nelson, Dr. David
Oak Ridge National Lab.

Roderick, Mr. Harry
DCPA

Swingle, Mr. Theodore
TVA

Vance, Edward F.
Stanford Research Institute

Wengrovitz, Mr. S.
DCPA

Wouters, Dr. Louis
Lawrence Livermore Lab.
University of California

Yeskoo, Mr. R.
Government Com. Mgr.
A. T. & T. Company

Bridges, Mr. Jack E.
IIT Research Institute

Dabkowski, Dr. John
IIT Research Institute

Mindel, Mr. Irving
IIT Research Institute

Weber, Dr. Erwin
IIT Research Institute

REFERENCES

1. DNA EMP Awareness Course Notes, Second Edition, DNA 2772T, August 1973, Headquarters Defense Nuclear Agency, Washington D.C., 20305.

2. EMP Directory for Shelter Design PME Note #2, Defense Nuclear Agency, Washington, D.C. 20305.

3. "The Effects of Nuclear EMP on AM Radio Broadcast Stations in the Emergency Broadcast System," TM-2830, published by the Oak Ridge National Laboratory (ORNL), January 1971.

4. "EMP Threat and Protective Measures," Office of Civil Defense (DCPA), TR-61, August 1970.

5. "The Effects of Electromagnetic Pulse on State and Local Radio Communications," Final Report, October 1973, and ORN-4873 published by Oak Ridge National Laboratory.

6. "EMP Threat and Countermeasures for Civil Defense Systems," IIT Research Institute Project No. E6120, Contract DAHC20-68-C-0198, November 1968, Work Unit 2213A, for the Office of Civil Defense.

7. "The Effect of EMP on Portable Transistor Receivers," Civil Defense Memorandum No. 1-74, Scientific Advisory Branch and Directorate of Telecommunications, the Home Officer, Horster House, Dean Rylestreet, London SW1, England, February 1974.

8. "EMP Susceptibility Tests on Power Equipments," IITRI Project E6216 for ORNL A7(11-1)-578 Task Order 91, April 1972.

9. "EMP Protection Hardware," IITRI Project E6227 for DCPA, DAHC-20-72-C-0282, October 1972.

10. "Architectural EMP Criteria for the Civil Defense Combined Regional Operating Center No. 2," IITRI, for the U.S. Army Corps of Engineers, Contract DACA-31-67-G-0079, December, 1967.

11. "Unclassified EMP Guide for Shelter Designers," Office of Civil Defense via produced university subcontract OCD-PS-66-3, April 1968.

12. "EMP Protection for Emergency Operating Centers," Office of Civil Defense, TR-61-A, May 1971.

13. "EMP Protective Systems," Office of Civil Defense, TR-61-B, November 1971.

REFERENCES (Cont.)

14. "Effects of Electromagnetic Pulse on a Power System," Final Report, ORNL-4836, December 1972.

15. "The Effects of Electromagnetic Pulse EMP on the Supervisory Control Equipment of a Power System," Final Report, ORNL-4899, October 1973.

16. "The Effects of Nuclear Electromagnetic Pulse on the Synchronouse Stability of the Electric Power Transmission and Distribution Systems," (in process), Oak Ridge National Laboratory.

17. "Power System Study," IIT Research Institute, Project E6278 (in process).

18. "Electromagnetic Pulse Handbook for Electric Power Systems," Stanford Research Institute, DNA Contract 001-73-C-0238, (draft copy), May 1974.

19. Protection Engineering and Management Notes (PEM note series), published by Lawrence Livermore Laboratories under contract to Defense Nuclear Agency, Washington D.C. 20305.