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# TEST BED CONSIDERATIONS FOR THE EVALUATION OF EMP PROTECTION MEASURES FOR DEFENSE ELECTRONICS INSTALLATIONS

Georgia Institute of Technology  
Georgia Tech Research Institute  
Atlanta, Georgia 30332

31 May 1981

Final Report for Period 1 May 1980-31 May 1981

CONTRACT No. DNA 001-80-C-0292

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20. ABSTRACT (Continued)

This study also addressed the concept of, and the need for, a programmatic approach to identifying and resolving those technical issues and voids which currently inhibit the formulation of well-defined EMP hardening principles and practices.

Program results and conclusions were derived from information and data obtained from a literature review, several visits to cognizant agencies, and an EMP Workshop. Many technological voids were identified which will require some form of test bed capability for their resolution. These voids are considered symptomatic of several larger issues related to EMP hardening technology. For this reason, it is recommended that an EMP Technology Program be established by DNA to provide a more coordinated and structured approach to the resolution of deficiencies in current EMP hardening principles and practices. A test bed facility might well be a part of such a program, but it is premature to decide on its form until a plan is formulated for addressing the major issues.

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## PREFACE

The work described in this report was sponsored by the Defense Nuclear Agency (DNA) under RDT&E RMSS Code B3630 80464 099QAXCB20603 H2590D as Contract DNA 001-80-C-0292, "Evaluation of EMP Protection Measures for Defense Electronics Installations." The work was done under DNA Program Element D 62704H, Project 099QAXC, Task Area B206, and Work Unit 03. The program was monitored by Major Blair Williams of DNA. The overall goal of DNA in the support of this investigative effort is to determine how best and most cost-effectively to implement and maintain protective measures in defense electronics installations.

This project was directed by Mr. E. E. Donaldson, Project Director, under the general supervision of Mr. F. L. Cain, Director, Electronics and Computer Systems Laboratory (ECSL) of the Georgia Tech Engineering Experiment Station. Technical supervision was provided by Mr. H. W. Denny, Head of the Electromagnetic Compatibility Division. The analysis described in this report was performed by personnel of the Electronics and Computer Systems Laboratory. The report was coauthored by Mr. Donaldson, Mr. Denny, Mr. J. K. Daher, Mr. B. B. Wise, and Mr. J. A. Woody, and edited by Ms. B. S. Rice.



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## SECTION I

### INTRODUCTION

#### 1-1 PROGRAM OBJECTIVE

The study summarized in this final report was performed under Contract No. DNA 001-80-C-0292, "Evaluation of EMP Protection Measures for Defense Electronics Installations." The overall objective of the program was to assist the Defense Nuclear Agency (DNA) in defining the need for, and the issues which should be addressed by, a test bed facility or other testing capability to evaluate EMP protection measures. To accomplish this objective, major efforts were directed to:

1. The identification of technology voids which currently inhibit the formulation of well-defined EMP hardening principles and practices for defense electronics installations, and
2. An evaluation of the test bed facility concept as a means of resolving these voids.

As the program progressed, it was concluded that (1) the identified voids are symptoms or elements of the more fundamental issues of EMP hardening technology (design, testing, analysis, documentation, etc.) which must be resolved if cost-effective EMP protection measures are to be realized, and (2) while some form of test bed facility may be needed to improve the investigative capability of the EMP community, the facility in itself is not the answer to current or future shortcomings in EMP hardening technology. It was further concluded that a more structured and systematic approach will be required to properly address and resolve the fundamental issues of concern. Based on these conclusions, program efforts were directed to the concept, structure, and basic elements of an EMP Technology Program--a program which would (1) identify the fundamental issues of concern, (2) define the assets available or needed to resolve these issues, and (3) establish the optimum approach to organizing and utilizing these assets to bring about an efficient and timely resolution of the issues.

#### 1-2 BACKGROUND

Under the proper circumstances, a nuclear explosion will generate a very high energy electromagnetic pulse (EMP). The EMP from an exo-atmospheric



burst can disrupt or damage unprotected electronics over an area as large as the continental United States. Until adequate protection is provided, many of the nation's defense system facilities will remain susceptible to this EMP threat. Independent studies have identified several hundred defense facilities whose mission is sufficiently critical to require protection against EMP.

Those same characteristics which render a facility potentially vulnerable to EMP also tend to make it susceptible to Electromagnetic Interference (EMI) and sensitive to lightning damage. In addition to needing protection against these electromagnetic influences, electrical safety must be achieved. Since all of these electromagnetic influences are inherently interactive, protective measures designed to address only one of the EM concerns run the risk of being at variance with other EM requirements. Thus, in the development of appropriate measures for EMP protection of critical facilities, the various EMI, lightning, and safety requirements also need to be considered concurrently in order to meet all the requirements in the most cost-effective manner. Unfortunately, the responsibility for meeting these various requirements lies with various organizations and individuals. The net result is that measures designed for protection against one form of EM influence are frequently implemented independently of concern for other EM influences.

Effective protection against EMP combines basic electromagnetic interference (EMI) protective measures, such as grounding, bonding, and shielding, with elements of lightning protection technology, such as the use of surge suppression. The great intensity and very fast rise and fall times of the EM pulse, however, require that a higher than normal degree of emphasis be placed on certain aspects of these more common procedures. For example, the predominately magnetic field characteristic of the pulse means that materials of higher permeability, such as steel, and of heavier gauge than are necessary for protection against EMI must be used to provide effective EMP shielding. A great deal of attention also must be paid to achieving and maintaining high quality joints and seams in shields, enclosures, cables, and connectors. This results in a significantly greater use of welding than is normally employed for EMI or lightning protection.

Because the rise time of an EMP is so short, its energy can reach susceptible components before the typical lightning suppressor has time to energize. Since standard lightning suppressors are generally not sufficient to protect circuits and devices from the currents induced on signal, control, and power lines by EMP, specialized suppression devices must be used. These devices

must be chosen very carefully so as not to degrade the normal operating characteristics of the protected devices. In addition, mounting techniques, placement, and lead dress assume even greater roles of importance. Therefore, because of the unique properties of the EMP threat, considerable attention must be paid to implementing and maintaining EMP protection on critical vulnerable systems.

A frequently suggested approach to the EMP hardening of electronic systems is to enclose them entirely in a metal shield, preferably one constructed of heavy gauge steel. Where the total volume is small, as for an individual circuit or equipment, total enclosure is compatible with standard practices, and, though requiring care in design and construction, does not extravagantly inflate the per-unit costs of the protected circuit or equipment. Where the volume to be protected is large, such as a room or an entire structure, however, the cost of an adequate EMP shield markedly increases the normal cost of construction. As an example, a study funded by the Defense Nuclear Agency indicates that enclosing an entire structure in a steel shell offering greater than 100 dB shielding effectiveness would approximately double (at 1979-1980 wage rates) the cost of construction of the building. For a building eighteen meters wide by sixty-one meters long by six meters high, which is a representative structure for a typical C<sup>3</sup> facility, construction estimates variously range from \$1.25 million to \$1.75 million. Application of such per-unit costs as these to the large number of defense facilities needing EMP protection indicates the relatively high costs associated with the total shielding approach to EMP hardening. In view of such high costs for total EMP shield implementation, it would be desirable to be able to identify alternative means for achieving effective EMP protection.

In addition to high construction costs, additional lifetime costs can be expected for the maintenance of the high degree of protection initially provided by a total steel enclosure. Unless rigid measures (which are just now very early in the process of being defined) are imposed, the relative hardness of a facility will tend to degrade with time. This degradation results in part from natural aging effects, such as component deterioration, corrosion, and wear. A more significant, albeit less tractable, factor is the tendency of a facility or structure to continually evolve over its lifetime in purpose, arrangement, and complexity. This evolution is caused by such events as the introduction of new equipment, changes in wiring and cabling, rearrangement of equipment, and even physical alterations to the building itself. In the absence of stiff hardness control measures, there is a natural tendency for the original level of protection to

become significantly compromised. This tendency is perhaps most acute where the success of the total "line of defense" depends upon maintaining the integrity of one "hard" protection barrier (i.e., a steel shell). It is possible that the success of a protection philosophy embodying multiple "soft" barriers (i.e., the implementation of layered hardening) would be less critically dependent upon maintaining a particular barrier at its original designed-in level of protection, although certainly the loss of a barrier would result in some weakening of the total hardness. The relative trade-offs between maintaining one outer "hard" shell versus maintaining multiple layers of "soft" protection need to be evaluated.

At the present time, it is difficult to decide which of the approaches to hardening electronics facilities against the EMP threat is most cost effective because substantiated data does not currently exist as to the relative (and achievable) performance levels that can initially be expected for other than the total metallic enclosure approach. Nor does data exist for either approach concerning life-cycle costs to maintain levels of hardness. Just as critically lacking is performance data on various ground conductor and signal cable network configurations, equipment locations and arrangements, earth electrode configurations and placements, cable and equipment shielding practices, signal cable grounding, surge arrestor locations, effects of structural support and reinforcement conductors, and other design aspects which influence the EMP susceptibility properties of an electronics facility. In each of these areas, both relative and absolute data is needed which can be used as the basis for design and trade-off decisions and as a reference against which performance can be compared both for initial facility acceptance and for continuing hardness maintainance assessment.

The need for data to support engineering decisions and to substantiate the selection of a particular hardening methodology for a facility strongly points to the desirability of a testing capability that would facilitate evaluation of the performance of alternate approaches to EMP hardening under controlled conditions. Consequently, DNA identified the potential need for a test bed facility (a mockup structure equipped with an EMP simulator) that would permit simulation of actual conducting networks and equipment arrangements. In such a facility, various networks and equipment would be exposed to representative EMP waveforms, and measurements of induced currents and voltages would be made at critical locations throughout the networks and at highly sensitive points in equipment. From the measurements made before and after various hardening

2  
measures were taken, the relative effectiveness of each measure could be assessed. Coupled with cost estimates for implementation, decisions could then be made as to the most cost-effective approach to EMP hardening for a particular type of facility.

### 1-3 REPORT SUMMARY AND ORGANIZATION

This report summarizes the research activities performed and the results obtained concerning the determination of the need for an EMP test capability and the identification of EMP-related issues which could be addressed by a test capability. The major elements which would be needed in a plan that would provide such a capability are also indicated.

The material which follows in this report is organized into five major sections, Section 2 through Section 6. Section 2 describes the technical approach that was followed in acquiring information and data to establish the need for, and potential applications of, a test bed facility. Section 3 summarizes the specific voids in the EMP technology areas which were identified. These voids are indicative of a strong need for a test bed facility or other capabilities to provide a means for their resolution. Section 4 discusses the identified voids in terms of major issues of concern in the current state-of-the-art in EMP hardening principles and practices. Section 5 presents the conclusions which have been drawn from the program efforts, and Section 6 recommends an approach to filling the identified voids and resolving the major issues of concern in a cost-effective manner.

## SECTION 2 TECHNICAL APPROACH

The overall approach established for accomplishing the project objective was to assemble and review information and data which were derived from three primary sources of information. First, some information was gained from existing documentation, including several relevant reports by agencies involved in EMP-related research activities. These reports proved to be helpful in identifying various voids that currently exist in the EMP database. Also identified in these reports were a number of tests which could be performed in order to fill these voids. Second, visits to three agencies, two of which are actively involved in EMP simulation testing, provided a substantial amount of information. These visits also allowed a first-hand look at several operational EMP simulators and associated test sites. Finally, an EMP Workshop was held at the Georgia Institute of Technology which provided a means of exchanging concepts and ideas pertaining to the need, utilization, and characteristics of a test bed facility.

### 2-1 LITERATURE REVIEW

A library of EMP-related documentation was scanned to determine the availability of information and data which describe the characteristics of EMP protective measures. The documentation proved to be very useful in determining the potential need for a test bed facility. A review of this material indicated that information is lacking in several areas, and identified various tests which should be performed at a test facility.

A few of the documents reviewed specifically address current EMP technology voids and recommended approaches to filling these voids. For example, a recent study by Georgia Tech ("An Investigation of the Relationship Between EMP Grounding Practices and MIL-STD-188-124," J. A. Woody and H. W. Denny, 28 February 1979, Contract No. DNA 001-78-C-0390) identifies differences between EMC and EMP grounding and shielding requirements and indicates the need for obtaining quantitative data to resolve these differences. Investigations by the Stanford Research Institute (SRI) ("Definition of Requirements for a Test Facility for the Unification of Electromagnetic Specifications and Standards," W. Graf, J. E. Nanevicz, E. F. Vance, 27 June 1980, Contract No. DNA 001-79-C-0206) have identified tests and test

methodologies that need to be evaluated to establish the compatibility of various specifications and standards. This latter report also presents a description of a proposed test facility, a brief listing of some typical equipment necessary for the validation tests, and a description of how an EMP environment could be simulated. A recent study by the Illinois Institute of Technology Research Institute (IITRI), ("Shielded Enclosure Test Bed Requirement," L Valcik, T. A. Martin, I. N. Mindel, 30 April 1980, Contract No. DNA 001-79-C-205) indicates the need for a dedicated test bed facility to obtain additional data to aid in the design and testing of shielded communications facilities. This report identifies specific inadequacies in shield design information and data, the lack of a meaningful definition of and simplified procedures for measuring shielding effectiveness, and the effects of magnetic saturation on a ferromagnetic shield.

Numerous other documents in the library were also identified as being particularly relevant to program efforts. These documents address various aspects of EMP hardening (design, test, analysis, etc.) which are directly pertinent to the definition of the facilities and capabilities necessary to resolve the EMP-related voids and issues of concern. Examples of these documents are:

1. AFWL and GE-TEMPO/DASIAC "Joint EMP Technical Meeting (NEM 1973): Proceedings," GE TEMPO for Defense Nuclear Agency, Contract No. DNA 001-74-C-0014, Vols. II, III, IV, and V, June 1975.
2. Ammer, H. G., and Meiggs, J. D., "Technical Management Plan for Site Defense Facilities EMP/RFI Protection in the Prototype Demonstration Project," Kaman Sciences Corporation, for Corps of Engineers, CE-HND, Contract No. DACA 87-74-C-0098, Nov. 1974.
3. Bevensee, R. M., Cabayan, H. S., Deadrick, F. J., Martin, L. C., and Mensing, R. W., "Probabilistic Approach to EMP Assessment," Lawrence Livermore Laboratories for U. S. Department of Energy, Contract No. W-7405-ENG-48, Aug. 1979.
4. Bevensee, R. M., Cabayan, H. S., Deadrick, F. J., Martin, L. C., and Mensing, R. W., "Characterization of Errors Inherent in System EMP Vulnerability Assessment Programs," Lawrence Livermore Laboratories, Livermore, CA, Oct. 1980.
5. Bodsén, D., "EMP, Lightning and Power Transients: Their Threat Relevance to EMP Protection Standards for Telecommunication Facilities," NCS Technical Information Bulletin 78-1, August 1978.
6. Dairiki, S., and Scharfman, W. E., "Study of EMP Testing of Satellites," Stanford Research Institute for Defense Nuclear Agency, Washington, DC, Contract No. DNA 001-74-C-0105, Sept. 1975.
7. Deadrick, F. J., Cabayan, H. S., Kunz, K. F., Bevensee, R. M., Martin, L. C., and Egbert, R. W., "EMP Coupling to Ships," Lawrence Livermore Laboratories, Livermore, CA, Jan. 1980.

8. Department of Defense "EMP Protection for Emergency Operating Centers," Report No. TR-61A, May 1971.
9. Duncan, L., "Prototype HEMP Design Practice Handbook," IRT Corporation for Defense Communications Agency, Washington, DC, Contract No. DCA 100-77-C-0040, May 1978.
10. Holst, D. W., "Suitability of ARES for Simulating Tactical Burst EMP Environments," Mission Research Corp. for Defense Nuclear Agency, Contract No. DNA-001-80-C-0076, April 1980.
11. Merewether, D. E., Cooper, J. A., and Parker, R. L., "Electromagnetic Pulse Handbook for Missiles and Aircraft in Flight EMP Interaction 1-1," Sandia Laboratories for Air Force Weapons Laboratory, Contract Nos. DO AF(29-601)-64-4457 and FY7617-71-10270, Sept. 1972.
12. Monroe, R. L., "EMP Shielding Effectiveness and MIL-STD-285," U. S. Army Material Command, Harry Diamond Laboratories, Washington, DC, Contract No. HDL-TR-1636, July 1973.
13. Roberts, H. A., and Capobianco, J., "Safeguard Buried Conduit Studies," U. S. Army Electronics Research and Development Command, Harry Diamond Laboratories, Adelphi, MD, Contract No. HDL-TR-1850, Sept. 1978.
14. SV&H Programs "EMP Assessment Methodology Program EMP Vulnerability Assessments Using PRESTO Computer Code," Boeing Aerospace Co. for Defense Nuclear Agency, Contract No. DNA 001-79-C-0219, Sept. 1979.
15. Sherman, R., DeMoss, R. A., Freeman, W. C., Greco, G. J., Larson, D. G., Levey, L., and Wilson, D. S., "EMP Engineering and Design Principles," Bell Laboratories, Whippany, NJ, 1975.
16. Stansberry, C., "Requirements for Federal EMP Protection Standards for Telecommunications Facilities and Equipment," NCS Technical Information Bulletin 80-4, June 1980.
17. Stansberry, C., "EMP Vulnerabilities of Telecommunications Facilities and Their Relevance to EMP Protection Standards," NCS Technical Information Bulletin 80-3, June 1980.
18. U. S. Army Corps of Engineers, "EMP/RFI Facilities Acceptance Construction/Installation Test Summary Report," Report No. HNDDSP-73-122-ED-R, Sept. 1977.
19. U. S. Army Corps of Engineers, "Protection Instructions," Report No. HNDDSP-72-145-ED-R, Dec. 1974.
20. U. S. Army Corps of Engineers, "NEMP Protection Inspection Guide," Report No. HNDDSP-71-42-SE, May 1971.
21. Whitson, A. L., and Vance, E. F., "Bolted Lapped-Joint EMP Shields," SRI International for Defense Nuclear Agency, Contract No. DNA 001-76-C-0386, June 1977.

## 2-2 VISITS TO AGENCIES

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In conjunction with the literature review, visits were made to three separate organizations, and discussions were held with various personnel who are currently involved with, or have experience in, facility EMP hardening design. On 17 July 1980, Mr. E. E. Donaldson and Mr. J. A. Woody visited Mr. J. E. Nanevicz and Mr. W. Graf at SRI International in Menlo Park, California. The issues discussed with these individuals concerned the need for a test bed facility (TBF), the tests which should be conducted at the TBF, some recommended design and construction features, and potential locations for the test facility.

On 11-12 December 1980, Mr. J. K. Daher and Mr. J. A. Woody visited with Dr. C. B. Williams, Dr. T. W. Buckman, Mr. M. A. Rose, and Mr. B. Harlacher at IRT Corporation in San Diego, California. The discussions with these individuals encompassed many pertinent areas, including EMP simulators for use with a TBF and the credibility of data and conclusions obtained from particular simulators. In addition to these topics, opinions were expressed on the role of analysis in testing, the validity of scale modeling, the specific characteristics and capabilities likely to be needed in a facility, a recommended approach to simulating an actual facility and potential problems to be avoided, the types of tests that should be performed at a facility, and the use of continuous wave (CW) versus pulse testing.

On 15-16 December 1980, Mr. Daher and Mr. Woody visited the Air Force Weapons Laboratory, Kirtland AFB, to obtain information on AFWL's test facilities, sources, and simulators. Meetings were held with Dr. Bill Page, Capt. Bill Clark, Mr. Bill Kehrer, and Dr. Carl Baum. Tours of the following AFWL EMP sources and simulators were conducted by the indicated personnel:

TRESTLE -- Capt. Jerry Ferguson  
HPD (Horizontally Polarized Dipole) -- 1st Lt. Larry Teverbaugh  
VPD (Vertically Polarized Dipole) -- 1st Lt. Larry Teverbaugh  
ALECS -- Mr. Lloyd Reeves

These tours were very beneficial in providing a familiarity with existing EMP sources, simulators, and test facilities. Following the tours, a discussion with Mr. C. A. Aeby provided useful information and recommendations from the perspective of C<sup>3</sup>I facilities.



### 2-3 EMP WORKSHOP

As a result of the literature review and the visits to the aforementioned agencies and organizations, it was concluded that the assembly of the information and data necessary to accomplish the project objectives could best be achieved by obtaining inputs from as many as possible of the organizations and individuals who are cognizant of the current needs and deficiencies related to EMP protective measures. Various individuals and organizations which currently are or recently have been involved in EMP analysis, testing, hardening, and evaluation were identified as points of contact for obtaining pertinent information. Rather than making separate visits to each individual organization, a two-day EMP Workshop was held as a more cost-effective approach to obtaining the desired information. The purpose of this workshop was to provide a mechanism by which the individual and collective expertise of the various organizations could be assembled to exchange ideas and viewpoints on the needs and requirements for a test bed facility.

The EMP Workshop was held at Georgia Tech on 10 and 11 February 1981. A total of twenty-four individuals representing fifteen organizations (see Table 1) participated in the workshop. Each participant was asked to present information which in his opinion would aid in identifying existing voids in hardening design data, in identifying tests for filling these voids, and in designing a test bed facility for accommodating these tests. After each presentation, a discussion was held, and at the end of the Workshop a working session was held.

The participants in the EMP Workshop provided many suggestions, recommendations, and individual conclusions concerning the needs and requirements for a test bed facility and a test capability. The resulting discussions illustrated that in some instances there were controversies within the EMP community as well as between the EMP community and other disciplines. The information gained from the EMP Workshop, the literature review, and the visits was consolidated to provide some tentative thoughts and conclusions as to the needs and requirements for a test capability.

Table 1. EMP Workshop attendees.

Maj. R. Blair Williams  
Headquarters  
Defense Nuclear Agency  
EMP Effects Division  
Washington, D.C. 20305  
(202) 325-7016

G. H. Baker  
Headquarters  
Defense Nuclear Agency  
EMP Effects Division  
Washington, D.C. 20305  
(202) 325-7016

Sam Colombo and Robert L. Carney  
Nuclear Survivability Projects  
Boeing Aerospace Company  
P.O. Box 3999  
Seattle, Washington 98124  
(206) 251-4677

Maurice Sancer  
R & D Associates  
P.O. Box 9695  
Marina del Rey, CA 90291  
(213) 822-1715 X426

Joan Pierre  
Naval Research Laboratory  
Code 4707  
Washington, D.C. 20375  
(202) 767-3278

C. William Bergman  
D.C.E.C. Code R302  
1860 Wighle Avenue  
Reston, VA 22091  
(703) 437-2169

A. Thomas Bolt  
U.S. Army Engineer Division  
Box 1600  
Huntsville, AL 35807  
(205) 895-5670

Thomas W. Buckman  
IRT Corp  
P.O. Box 81087  
San Diego, CA 92141  
(714) 565-7171

Werner J. Stark  
MRC, P.O. Box 7816  
Colorado Springs, Colorado 80907  
(303) 635-7755

Werner Graf  
Electromagnetic Sciences Lab  
SRI International  
333 Ravenswood Avenue  
Menlo Park, CA 94025  
(415) 859-3094

Melvin W. Dill  
Sylvania Systems Group  
CSD  
GTE Products Corp  
189 "B" Street  
Needham Heights, MA 02194  
(617) 449-2000 X2936

Joseph Miletta and Louis Lebelo  
Harry Diamond Laboratories  
2800 Powder Mill Road  
Adelphi, MD 20783  
Attn: DELHD-NW-EA  
(202) 394-3010/394-3011

Irving M. Mindel  
IIT Research Institute  
10 W. 35th Street  
Chicago, IL 60616  
(312) 567-4487

E. F. Vance  
SRI International  
333 Ravenswood Avenue  
Menlo Park, CA 94025  
(817) 478-5653

G. E. Morgan  
Autonetics Statagic Systems Division  
R-2777 Mail Code GB-17  
3370 Miraloma Avenue  
Anaheim, CA 92803  
(714) 632-1903

E. L. Arnold  
Kaman Tempo (Consultant)  
10 Windflower Court  
Hilton Head Island, S.C. 29928  
(803) 785-6085

Table 1 (continued). EMP Workshop attendees.

H. W. Denny  
Engineering Experiment Station  
Georgia Institute of Technology  
Atlanta, Georgia 30332  
(404) 894-3535

Ernest Donaldson  
Engineering Experiment Station  
Georgia Institute of Technology  
Atlanta, Georgia 30332  
(404) 894-3535

J. A. Woody  
Engineering Experiment Station  
Georgia Institute of Technology  
Atlanta, Georgia 30332  
(404) 894-3535

David P. Millard  
Engineering Experiment Station  
Georgia Institute of Technology  
Atlanta, Georgia 30332  
(404) 894-3535

G. Bruce Melson  
Engineering Experiment Station  
Georgia Institute of Technology  
Atlanta, Georgia 30332  
(404) 894-3535

J. K. Daher  
Engineering Experiment Station  
Georgia Institute of Technology  
Atlanta, Georgia 30332  
(404) 894-3535

### SECTION 3 IDENTIFIED TECHNOLOGY VOIDS

Based on the information obtained from the literature review, from the visits to cognizant agencies and organizations, and from the EMP Workshop described in Section 2, a large number of specific needs or voids in the EMP technology areas were identified. Table 2 outlines these voids. A number of comments are pertinent to the organization and significance of the information in this outline. First, although not specifically included, cost effectiveness is considered implicit in all of the voids identified in the table. Second, no attempt was made to prioritize the voids in terms of their impact on the capability for achieving an EMP-hardened facility; however, it is likely that some of the voids are of more immediate concern than others. Third, although the voids were identified by a representative body of the EMP community, there is considerable controversy over the significance of the voids and the actions necessary for their resolution. Fourth, although the test bed facility was initially envisioned as a means for satisfying voids such as those identified in the table, there is generally no consensus as to what form or characteristics such a facility should have or what role it should play in addressing those needs. Fifth, it is both obvious and highly significant that the identified voids not only encompass all of the EMP technology areas (design, testing, analysis, documentation, etc.), but that a multitude of needs or voids exist in each of these areas. The number and extent of identified voids and the considerable controversy which exists over their significance and methods for their resolution indicate that considerably more study and investigation will be required before a consensus approach to the EMP protection of ground-based facilities can be achieved.

Finally, it is important to recognize that the voids identified in Table 2 are only elements or subelements of the more fundamental concerns of EMP hardening technology -- design, testing, analysis, documentation, etc. While the significance of the voids identified in this section is not questioned, their resolution is not necessarily sufficient to satisfy these more fundamental concerns. It is thus strongly felt that any actions which are taken to improve or advance the state-of-the-art in EMP technology should address more definitized goals than those indicated in Table 2.

**Table 2. Technological voids.**

1. Voids pertaining to hardening techniques and devices.
  - o The relative effectiveness of various techniques and devices.
  - o The transient response of hardening devices (filters, transient protection devices, etc.).
  - o The most effective shield design; specific voids pertain to:
    - meaningful definition of shielding effectiveness
    - relationship between shield design and construction and internal fields
    - relationship between shield design and construction and internal coupling
    - improved (simplified) procedures for measuring shielding effectiveness
    - effects of apertures and penetrations
    - effects of magnetic saturation
    - shielding effectiveness of composite materials
  - o The effectiveness of protection schemes where the scheme cannot be implemented perfectly, e.g., effect of different pigtail lengths, use of a rack as part of the path to ground, etc. A system solution including overhead and underground lines, transformers, etc. also needs to be evaluated.
  - o The protection against penetration from large current pulses (greater than 5 kA) which can be obtained when a facility has no overall shield, as is the case for many existing facilities; in particular, an effective scheme for protection of high data-rate lines is needed.
2. Voids in the database for hardening design; these can be filled by testing a sufficient number of devices and techniques so as to obtain a statistically significant characterization for a variety of each "type" of device or technique.
3. Voids in criteria for designing hardened facilities; these should address cost, performance, maintenance, and verification.

**Table 2. Technological voids. (Continued)**

4. Voids pertaining to the impact of EMP hardening on other design practices; these can be filled by evaluating various concepts and practices to determine if they satisfy not only EMP requirements, but EMI, EMC, NEC, lightning, and COMSEC requirements, also. In addition, there is a need to demonstrate compatible techniques as convincingly as possible.
5. Voids pertaining to EMP analysis and modeling techniques.
  - o Data which could verify or aid in development of coupling models, such as:
    - determination of transients induced through cable shields
    - determination of coupling into cables from current on conduits
    - determination of leakage through typical apertures
    - estimation of induced voltages and currents on internal cables
  - o The relative merits of statistical vs. closed-form models.
  - o Data pertaining to susceptibility:
    - determination of upset levels of various equipment
    - determination of burnout thresholds of various equipment
6. Voids in the area of EMP-related documentation.
  - o EMP design and engineering handbooks.
  - o EMP specifications and standards.
7. Voids pertaining to hardness degradation; this includes data pertaining to the effects of degradation under controlled conditions. This data should examine the degradation effects of time, corrosion, missing finger stock, etc.
8. Voids pertaining to different methods of testing.
  - o Data pertaining to the effectiveness of bounded wave vs. open radiator vs. hybrid HEMP simulation.
  - o Data comparing planar vs. nonplanar (near-field vs. far-field) results.

**Table 2. Technological voids. (Continued)**

- o Data to verify the scale model approach by comparing scale model results with full-scale results.
  - o Data comparing threat-level test results with lower level testing plus analysis results; the following items in particular should be investigated:
    - the effects of nonlinearities
    - saturation effects
  - o Data quantifying the limitations of CW systems by comparing threat-level pulse system with CW system results.
  - o Quantitative data on nonlinear effects.
  - o Quantitative data on errors due to truncated frequency spectrum.
  - o Data pertaining to the characteristics and wave shape of coupled energy for use in direct injection testing.
  - o Data establishing the best combination of CW and pulse illumination and/or CW and pulse injection testing.
9. Voids pertaining to system-level considerations:
- o Evaluation of different grounding schemes, with emphasis upon:
    - the effects of different internal ground configurations on induced signals
    - the effects on induced transients of various earth electrode systems (ring, star, etc.)
  - o Evaluation of zonal shielding approach.
  - o Data pertaining to the effects of the number and location of penetrations.
  - o Data pertaining to the importance of configuration control.

**Table 2. Technological voids. (Continued)**

10. Voids in the area of hardness maintenance and monitoring approaches.
- o Data pertaining to optimal assessment and monitoring methods.
  - o Data comparing the effectiveness of various maintenance practices and procedures.
  - o Data correlating maintenance criteria to level of degradation.



## SECTION 4 TECHNICAL AND PROGRAMMATIC ISSUES

The previous section has identified a multitude of specific voids which must be filled in order to bring about an improvement in EMP hardening principles and practices for defense electronics installations. The fact that the existence of these voids was confirmed by a representative body of the EMP community leaves little doubt that the voids represent realistic shortcomings in current EMP hardening technology. There is also little doubt that a test capability will be needed to collect the information and data necessary to resolve these voids in a non-controversial manner. However, before any action is taken to establish a program for addressing the identified voids, and before the test bed facility concept is pursued to the point of defining specific facility requirements and characteristics, several questions of paramount importance must be addressed. These questions deal with the fundamental issues of facility hardening and with the optimum approach for resolving these issues. The first question can best be illustrated through the use of Table 3. This table depicts some of the fundamental issues and subissues which must be addressed in the acquisition of an EMP-hardened facility. The table is not intended as a complete or precise definition of all of the EMP hardening issues, but rather is presented to show that there is a delineation between the fundamental concerns of the EMP hardening process and the subissues or subelements which contribute to these concerns. In other words, there is a distinct difference between Table 2 and Table 3. Table 2 is a listing of technological voids which are subelements of the fundamental issues of EMP hardening which are listed in Table 3. Based on this illustration, the first question might thus be phrased as, "If the voids identified in Table 2 are addressed and resolved, will the fundamental concerns of facility hardening be resolved?" Another way of phrasing the same question is, "Should actions taken to improve EMP hardening principles and practices be directed solely to the voids of Table 2, or should these actions be directed to the fundamental issues of EMP hardening with the recognition that the identified voids are subelements of these issues?" The goal of any actions taken should be to resolve the fundamental issues. Any approach which would result in the strong probability that such fundamental questions as "How do we harden?" or "How do we test?" would go unanswered would not be logical.

A second set of questions involve the concept of a test bed facility. Is a test bed facility needed, what form or characteristics should the facility have, and how should the facility be applied in resolving the identified voids and

**Table 3**

- I. How to Establish Hardness Requirements?
  - A. Should Performance be Specified?
    1. Establish Environment
      - a. What are maximum field strengths at facility level?
      - b. What are maximum voltage and current levels on penetrating conductors?
      - c. What are maximum voltages, currents, and field strengths at system/equipment/component levels?
    2. Establish Susceptibility of Systems/Equipment/Components
      - a. What criteria should be used?
        - o burnout
        - o upset
        - o system noise
      - b. How should susceptibility levels be determined?
        - o measurements
        - o analysis
    3. Establish Safety Margins
      - a. How should appropriate values be determined?
  - B. Should Design Procedures be Specified?
    1. Which design steps should be specified?
    2. How should the specifications be determined?
  - C. Are established requirements compatible with requirements of other EM disciplines?
    1. Are the end goals the same?
    2. Are compromises required?
    3. How should compromises be resolved?
      - a. What are priorities?

**Table 3 (continued)**

- II. How to Harden to Meet the Requirements?
  - A. What is the relative effectiveness of the various basic concepts?
    - 1. Total shielding
    - 2. Zonal approach
    - 3. Tailored approach
  - B. What is the relative effectiveness of the various mitigation techniques for use in each concept?
    - 1. Shielding
      - a. meaningful definition of shielding effectiveness
      - b. level of shielding effectiveness required
      - c. relationship between shield design/construction and internal fields
      - d. relationship between shield design/construction and internal coupling
      - e. effects of equipment inside shielded region versus empty region
      - f. improved (simplified) procedures for measuring shielding effectiveness
      - g. effects of apertures and penetrations on shielding effectiveness
      - h. effects of magnetic saturation
      - i. shielding effectiveness of composite materials
      - j. type or types of metal to be used
      - k. amount of metal required
    - 2. Grounding
      - a. Effectiveness of different grounding schemes
        - o effects of various internal ground configuration on induced currents/voltages
        - o effects of earth electrode system configuration on induced transients
      - b. Compatibility with grounding schemes of other EM disciplines
        - o identification of appropriate compromises
        - o effects of compromises on all disciplines
        - o resolution of differences
    - 3. Treatment of penetrating conductors
      - a. What are the effects of the number and location of penetrations?

**Table 3 (continued)**

- o single point entry
- o random entry points
- o all entries near earth electrode system
- b. How should penetrations be hardened?
  - o What is the effectiveness of the various types of treatments?
    - filters
    - TPD's
    - grounding
  - o How should appropriate treatments or combination of treatments be selected?
    - for penetrations of good shields
    - for penetrations of imperfect shields
    - for penetrations of facilities/boundaries with no metal shields
    - for penetrations (e.g., high data-rate lines) where the treatment may affect desired signals
- 4. Bonding
  - a. Effectiveness of various techniques
  - b. Selection criteria
  - c. Effects on non-EMP requirements
- 5. Treatment of Apertures
  - a. Effectiveness of various types of treatment
    - o Quantify coupling to internal systems/equipments with no aperture treatment
    - o Quantify improvement resulting from the use of each type of treatment
  - b. Criteria for selection of most appropriate treatments
- 6. Configuration Control
  - a. Effects of no configuration control
  - b. Effects of various degrees of configuration control
  - c. Selection criteria for different circumstances

Table 3 (continued)

- C. What are the relative costs of the various hardening techniques and devices?
    - 1. For various circumstances, what is the relative importance of cost?
    - 2. For various hardening techniques and devices, quantify relative cost versus effectiveness.
  - D. What is the relative effectiveness of various hardening concepts and mitigation techniques and devices when they must be implemented imperfectly?
    - 1. Imperfect shields at any level
    - 2. Effects of pigtail lengths
    - 3. Compromised ground schemes
    - 4. Partial retro-fixes
  - E. Are the EMP hardening concepts and techniques compatible with those of other EM disciplines?
    - 1. Are the goals compatible?
    - 2. Are the methods for achieving common goals compatible?
    - 3. Are compromises required?
    - 4. How should compromises be resolved?
- III. What is the Role of Analysis?
- A. What is the relationship between analysis and testing?
    - 1. Both required to support each other?
    - 2. One required and the other not required depending on the circumstances?
  - B. When is analysis required?
    - 1. Design
      - a. prior
      - b. during
      - c. post

Table 3 (continued)

2. Evaluation
    - a. prior
    - b. during
    - c. post
  - C. What Analysis Techniques Should Be Employed?
    1. Deterministic
      - a. when appropriate
      - b. when required
    2. Probabilistic
      - a. when appropriate
      - b. when required
- IV. How Should Testing Be Performed?
- A. When is Testing Required?
    1. In conjunction with analysis
    2. Instead of analysis
  - B. What Method of Testing Should Be Used?
    1. Threat-level
      - a. Type of simulator
        - o bounded wave
        - o open radiator
        - o hybrid radiator
      - b. Effects of near field radiation
      - c. Scale model versus full-scale
      - d. Quantify errors due to truncated frequency spectrum
      - e. Errors due to shot-to-shot repeatability
      - f. Appropriateness of radiated plus lower level direct injection
    2. Less than threat-level
      - a. Pulse versus CW

**Table 3 (continued)**

- o correlation of results
- o criteria for use
  - pulse
  - CW
  - combination
- o improvements in CW
- b. Radiated versus direct injection
  - o correlation of results
  - o criteria for use
    - radiated
    - direct injection
    - combination
- c. Type of simulator
- d. Scale model versus full-scale
- e. Effects of nonlinearities
- f. Effects of saturation

V. What Documentation is Needed?

A. Cataloged Data Bases Which Are Statistically Significant

1. Transient Responses of Discrete Devices
  - a. Filters
  - b. TPD's
  - c. Capacitors
  - d. Solid State Components
2. Effectiveness of various hardening concepts and techniques
3. Relative cost of various hardening concepts and techniques
4. Environment data at various points within facilities, systems, and equipment.
5. Susceptibility data of systems and equipment
6. Threat-level versus lower level tests

**Table 3 (continued)**

- 5
7. Scale model versus full-scale tests.
  8. Fields and effectiveness of various HEMP simulators
  9. Results of previous analyses and tests
- B. Specifications and Standards
  - C. Design Guides and Handbooks
    1. Hardening concepts
    2. Specific hardening techniques
    3. Relationships between EMP hardening and hardening for other EMP disciplines
      - a. Considerations that must be recognized
      - b. Compromises that are necessary
      - c. Trade-offs between various alternatives
  - D. Management Guides
    1. Program Plans
    2. Control Plans
  - E. Test Procedures
  - F. Maintenance Procedures
- VI. How Should Hardening Be Monitored and Maintained?
- A. What preventative maintenance is required?
    1. Effects of hardness degradation
    2. Acceptable level of degradation
    3. Specific preventable maintenance steps
      - a. to minimize degradation
      - b. to detect unacceptable degradation



**Table 3 (continued)**

- B. How should hardness be monitored?
  - 1. Built-in, automatic monitoring
  - 2. Periodic retests
- C. What remedial actions are appropriate to correct unacceptable degradation?

issues? To help answer these questions related to the need, characteristics, and potential utilization of a test bed facility, the following guidance principles are proposed: First, the test bed facility concept should not be viewed as the "solution" to EMP-related hardening deficiencies; rather, the test bed facility should be considered as an additional investigative tool which will complement other test capabilities within the EMP community. This consideration leads to the concept of a test bed capability rather than a test bed facility. This test bed capability would be comprised of all of the EMP testing capabilities which currently exist; new or different test facilities would be required only for those needs which cannot be handled with currently available facilities.

A second consideration deals with the type of facilities which will be necessary to form the test bed capability needed to address voids such as those indicated in Table 2. Although the specific facility requirements and characteristics which will be necessary are as yet undetermined, it can reasonably be stated that three basic types of facilities will be required. The first type will be small laboratory facilities for basic EMP hardening investigations, i.e., investigations of improved methods for defining and improving shielding effectiveness, injection testing to determine the transient response of filters, etc. Standard laboratory instrumentation should be sufficient for the type of tests envisioned for these facilities. The second type of facility will generally be characterized by a radiated test capability which will simulate the characteristics of an EMP environment (in the time domain, frequency domain, or both), except that threat-level testing will not be required. This type facility will have the capability for addressing most of the voids listed in Table 2. The third type of facility will be characterized by a threat-level capability. Threat-level testing will be required to investigate the possible effects of magnetic saturation of shields, the nonlinear characteristics of terminal protection devices, and other EMP-related questions which can only be answered through the use of high-level environments. More importantly, however, threat-level testing provides the only means at present for verifying that a hardening design (device, technique, configuration, facility, etc.) is sufficient to withstand the EMP from an actual nuclear burst.

It is to be noted that many facilities of the three types defined above already exist. These facilities do not necessarily preclude the need for an additional test bed facility; however, as was emphasized earlier, care should be taken to ensure that such a facility complements rather than duplicates those testing capabilities which currently exist.

A third question is multi-faceted in nature and deals with the approach to be established to address the identified issues and voids. Specifically, are the fundamental issues involved in the acquisition of a hardened facility adequately defined, and have all of the voids which cause or contribute to these issues been identified? What priorities should be given to resolving the identified voids? What specific tests and test facilities should be utilized to address the voids? Are present test capabilities adequate, or are additional test facilities needed? Is testing alone sufficient to resolve the voids, or could their resolution best be handled through an optimum mix of testing and analysis? What is the most cost-effective approach to resolving the issues and voids? How should any actions which are taken be organized and scheduled to achieve results in a timely manner? Are the issues being addressed in a manner which will eliminate controversy? Who will define, direct, and control the actions necessary to achieve resolution of the issues?

Questions such as those formulated above lead to the conclusion that a programmatic approach must be established to properly address the identified issues and voids. A well-defined and properly planned program will not only provide an orderly and efficient means of attacking the issues, but more importantly, will also provide a cost-effective means of matching the voids to those assets needed for their resolution. It is important to recognize that, with proper utilization, the existing assets of the EMP community are probably sufficient to resolve most of the current deficiencies in EMP principles and practices.

## SECTION 5 CONCLUSIONS

From the results of project efforts to date, the following conclusions can be drawn regarding the current state-of-the-art in EMP hardening technology, the need for a test bed facility, and the actions which should be taken to resolve current and future issues and voids related to the EMP hardening of defense electronics installations.

It should first be emphasized that project efforts have identified a multitude of voids in EMP technology areas which must be addressed if consistent, reliable, and cost-effective EMP design practices are ever to be realized. These voids are evidenced by a lack of reliable information and data in essentially all areas of EMP hardening design (i.e., testing, analysis, hardening criteria, and hardening techniques and devices), by controversies over existing EMP hardening approaches and practices, and by conflicts between the EMP community and other EM disciplines.

Second, it can definitely be stated that some form of a test bed facility will be required to collect the information and data necessary to satisfy the voids identified in Table 2. At this time, however, the specific form or characteristics of a test bed facility which will satisfy these voids is still in question; perhaps it is more appropriate to state that a need exists for a test bed capability.

Third, it is Georgia Tech's opinion that the concept of a test bed facility would be viable only if such a facility were the responsibility of a specific government agency. This agency would be responsible for the development, management, and control of the facility, and would serve as a focal point for EMP-related facility life-cycle development activities. Most importantly, however, the responsible agency would act as the driving force to ensure the effective utilization of the facility to advance the state-of-the-art in EMP-related technology, resolve controversies, assimilate data, etc. The test bed facility concept should not be envisioned simply as another test facility, but should be considered as a longer term, well managed, goal-oriented investigative and data-gathering tool.

In conjunction with the above comment, it is strongly felt that a major goal of the test bed facility should be to resolve prevailing controversies within the EMP community. These controversies encompass essentially all areas of EMP

hardening (testing, analysis, and hardening approach) and also involve other EM disciplines. It is doubtful that these controversies will ever be adequately resolved without proper impetus and direction from a central organization.

Fourth, it was indicated during the EMP Workshop that the design of a test bed facility should be derived from, and based on, the requirements of specific tests which would be identified as necessary to satisfy current technological voids. It is felt, however, that caution should be exercised to prevent the design and construction of a costly facility which would serve only short-term objectives which might be relatively narrow in scope. Although current questions regarding EMP technology are of prime concern, it is doubtful that the resolution of these questions would terminate the need for further investigative efforts. In fact, a "successful" test bed facility would likely promulgate and enhance the advancement of the state-of-the-art in EMP technology. Thus, it is felt that any test-bed facility concept should be viewed in terms of a highly flexible, long-term resource which would serve as a focal point or center for EMP-related program support.

Fifth, it is important to recognize the significant capabilities which already exist for EMP-related research. The concept of a test bed facility does not necessarily imply a totally new, unique facility, but rather may embody the assembly and integration of current capabilities in a manner so as to realize identified goals. It is felt that current EMP testing capabilities, which range from small laboratory facilities to large facilities which require an open field site, may be sufficient to address many of the voids listed in Table 2. A new or different test bed facility should be considered only for those needs which cannot be handled with current capabilities.

Finally, although Georgia Tech concurs with the test bed facility concept, it is felt that such a facility is not necessarily the primary key to the resolution of either current or future problems in EMP technology areas. What is needed is a broad and comprehensively defined EMP technology program, structured and organized to resolve fundamental concerns by addressing identified needs and voids in a manner which would make the most effective use of all assets of the EMP discipline. Under the framework of this program, a test bed capability would serve as one element, tailored to be compatible with the structure, elements, and goals of the program.

## SECTION 6 RECOMMENDATIONS

### 6-1 EMP TECHNOLOGY PROGRAM

It is recommended that an EMP Technology Program be established to coordinate and promote advancements of the state-of-the-art in EMP hardening principles and practices for defense electronics installations. The overall objective of the EMP Technology Program would be to establish cost-effective EMP protection for such installations. A major thrust of the program would thus be to resolve those voids of current concern as defined by the EMP community, i.e., the voids identified in Table 2. More importantly, however, the program would be structured and organized to address the more fundamental concerns of EMP hardening--how to establish hardening requirements, how to harden, how to test, how to analyze, and how to identify and generate required documentation, i.e., the issues discussed in Section 4. It is to be emphasized that the voids identified in Table 2 are symptoms of the more fundamental concerns, and that the primary goal of the program should be to address these fundamental concerns, rather than individual symptoms.

It should be emphasized that the recommended EMP Technology Program is not intended to be a totally new or different approach in the area of EMP hardening technology. Rather, it is intended to be a mechanism to identify (1) what problems should be addressed to resolve current and future shortcomings in EMP hardening principles and practices, (2) what assets are available or are needed to resolve these problems, and (3) what is the optimum approach to organizing and utilizing these assets so as to bring about an efficient and timely resolution of these problems. It is felt that a well-defined program, which will provide a systematic approach to resolving technological deficiencies, is mandatory if current as well as future issues and controversies in EMP hardening technology are ever to be resolved, and if the objective of providing cost-effective EMP protection for defense electronic installations is to be realized.

### 6-2 MAJOR PROGRAM CONSIDERATIONS

It would be premature at this time to attempt to describe in detail the nature, structure, and elements of the recommended EMP Technology Program. The proper formulation of this program will require that careful consideration be given to the program objective, the specific tasks and subtasks required to

accomplish this objective, and the program structure and management necessary to accommodate the tasks. However, it is possible at this time to indicate some of the major considerations which should be a part of the program. A brief discussion of these major program considerations is presented below.

Program Management - Proper management will be the key to the success of the program. An effective management philosophy, organization, and structure must be implemented in order to provide the necessary direction, control, and coordination of program tasks if the program objective is to be realized.

Program Goals - To satisfy the overall program objective, the goals of the program should be to clearly delineate and resolve the fundamental issues and subissues of concern in EMP hardening technology. Examples of these fundamental issues and subissues are illustrated in Table 3.

As is indicated in Table 2, a multitude of technical voids may need to be filled in order to properly address these issues; however, these technical voids should not be misconstrued as the basic issues to be resolved. Any program which did not properly address and resolve these fundamental issues would not be considered successful.

Identification of Needs - Once the fundamental issues are clearly defined, the next major step is to identify what is needed (knowledge, information, data, test techniques, analysis techniques, documentation, etc.) to resolve these issues. An identification of needs will inherently lead to a determination of what voids must be filled. Many of the existing technical voids have already been identified in Table 2.

Identification of Assets - Prior to defining the approach and tasks necessary to satisfy the identified needs, the assets (expertise, facilities, analyses and modeling capability, data, etc.) available within the EMP community must be identified. This step is extremely important in order to prevent a "reinvention of the wheel." It is felt that many of the voids which have already been identified can be filled by utilizing existing facilities and capabilities available in the EMP community. For example, it is already known that the answers to some of the data voids indicated in Table 2 can be obtained using small laboratory facilities. Every effort should be made to exclude the requirement for new and costly programs or facilities except where absolutely necessary.

Program Approach and Tasks - Once the EMP technology needs and voids and the assets available or required to meet those needs have been identified, the specific approach and required tasks for addressing these needs can be

defined. Major concerns will be (1) the optimum mix and utilization of assets to meet the identified needs in the most effective manner, (2) the prioritizing of needs to insure that those needs which are most critical to the resolution of fundamental issues are addressed first, and (3) the scheduling and coordination of program tasks to maximize the timely output of useful results. Specific tasks to be performed will depend upon the nature of the particular need which is being addressed. In general, task efforts may involve testing, analysis, data analysis and reduction, and/or developmental studies as required.

Program Output - As was emphasized previously, the ultimate objective of the program is to provide cost-effective EMP protection for defense electronics installations. Thus, the program tasks must be specifically directed to, and culminate in, program results which permit the firm resolution of underlying issues. As the results of the program tasks become available, each issue should be addressed, and the approach to, the rationale behind, and the "proof" of its resolution should be fully documented. In this manner, current controversial issues can be resolved and information and data voids filled.

### 6-3 PROGRAM PLAN

A detailed plan will be necessary to implement and provide direction to the EMP Technology Program. This plan must establish the program goals, identify and prioritize the issues to be addressed, define the tasks necessary to resolve the identified issues, and establish a logical, efficient program task structure for performing the tasks. The plan must also provide a detailed description of the approach to be followed and the assets to be utilized in accomplishing the tasks. Of particular importance in the plan will be the organization, coordination, and monitoring of program efforts which will be necessary to insure that program outputs are driven to meet the program goals.

It is anticipated that a significant portion of the efforts of the EMP Technology Program will involve testing. The program plan thus must address in detail the specific tests to be performed, the test method to be used, and the facilities to be utilized in performing the tests. If additional test facilities are required, the plan must define the approach to determining the specific requirements and characteristics of these facilities.



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Naval Air Systems Command  
ATTN: AIR 350F

Naval Electronic Systems Command  
ATTN: PME 117-21

Naval Intelligence Support Ctr  
ATTN: Code 41

Naval Ocean Systems Center  
ATTN: 7309, R. Greenwell  
ATTN: Code 8123, S. Lichtman

Naval Ordnance Station  
ATTN: Standardization Division

Naval Postgraduate School  
ATTN: Code 1424, Library

DEPARTMENT OF THE NAVY (Continued)

Naval Research Laboratory  
ATTN: Code 6624  
ATTN: Code 1434, E. Brancato  
ATTN: Code 2627, D. Folen

Naval Surface Weapons Center  
ATTN: Code F30  
ATTN: Code F32, E. Rathbun

Naval Surface Weapons Center  
ATTN: Code F-56

Naval Weapons Center  
ATTN: Code 233

Naval Weapons Evaluation Facility  
ATTN: Code AT-6

Office of the Chief of Naval Operations  
ATTN: NOP 981  
ATTN: OP 981N1

Strategic Systems Project Office  
Department of the Navy  
ATTN: NSP-43  
ATTN: NSP-2342, R. Coleman  
ATTN: NSP-230, D. Gold  
ATTN: NSP-27334  
ATTN: NSP-2701, J. Pitsenberger

DEPARTMENT OF THE AIR FORCE

Aeronautical Systems Division  
Air Force Systems Command  
ATTN: ASD/ENESH, P. Marth  
ATTN: ASD/YEYF  
ATTN: ASD/ENFTV

Aerospace Defense Command  
Department of the Air Force  
ATTN: DEE

Air Force Aeronautical Sys Div  
ATTN: ASD/ENAMA, J. Corbin

Air Force Weapons Laboratory  
Air Force Systems Command  
ATTN: CA  
ATTN: NTYE, J. Castillo  
ATTN: NT  
ATTN: NTYEE, C. Baum  
ATTN: NTYEP, W. Page  
ATTN: ELXT  
ATTN: SUL  
ATTN: NTYC, M. Schneider  
ATTN: NXS  
ATTN: NTN  
ATTN: ELP

Air University Library  
Department of the Air Force  
ATTN: AUL-LSE

DEPARTMENT OF THE AIR FORCE (Continued)

Air Logistics Command  
Department of the Air Force  
ATTN: OO-ALC/MMETH, P. Berthel  
ATTN: OO-ALC/MM  
ATTN: OO-ALC/MMEDO, L. Kidman

Ballistic Missile Office/DAA  
Air Force Systems Command  
ATTN: ENSN, J. Allen

Headquarters  
Electronic Systems Division  
Department of the Air Force  
ATTN: YSEA

Foreign Technology Division  
Air Force Systems Command  
ATTN: TQTD, B. Ballard  
ATTN: NIIS, Library

Northern American Air Defense Treaty  
Department of the Air Force  
ATTN: J5YE, P. Castleberry

Rome Air Development Center  
Air Force Systems Command  
ATTN: TSLD

Sacramento Air Logistics Center  
Department of the Air Force  
ATTN: MMEAE, C. Howard  
ATTN: MMCRS, H. Delmastro  
ATTN: MMCREB

Space Division  
Department of the Air Force  
ATTN: IND

Space Division  
Department of the Air Force  
ATTN: YKA

Space Division  
Department of the Air Force  
ATTN: YLXT

Strategic Air Command  
Department of the Air Force  
ATTN: XPFS, F. Tedesco  
ATTN: INT, E. Jacobsen  
ATTN: NRI, G. Matzke  
ATTN: DEL  
ATTN: NRI-STINFO, Library

OTHER GOVERNMENT AGENCIES

Central Intelligence Agency  
ATTN: OSWR/NED  
ATTN: OSWR/STD/MTB, A. Padgett

Department of Transportation  
ATTN: Sec Div ASE-300

OTHER GOVERNMENT AGENCIES (Continued)

Federal Emergency Management Agency  
ATTN: State & Local Prog Support

Federal Preparedness Agency  
ATTN: ESTE, M. Murtha

DEPARTMENT OF ENERGY

Department of Energy  
Albuquerque Operations Office  
ATTN: WSSB  
ATTN: CTID

Department of Energy  
ATTN: Office of Utility Systems, L. O'Neill

DEPARTMENT OF ENERGY CONTRACTORS

Lawrence Livermore National Lab  
ATTN: L-96, T. Donich  
ATTN: Technical Info Dept Library  
ATTN: L-156, H. Cabayan  
ATTN: L-10, H. Kruger

Los Alamos National Laboratory  
ATTN: B. Noel  
ATTN: C. Benton

Sandia National Lab  
ATTN: R. Parker  
ATTN: E. Hartman

DEPARTMENT OF DEFENSE CONTRACTORS

Aerospace Corp  
ATTN: I. Garfunkel  
ATTN: J. Reinheimer  
ATTN: C. Pearlston  
ATTN: C. Greenhow  
ATTN: Library

Agbabian Associates  
ATTN: Library

American Telephone & Telegraph Co  
ATTN: W. Edwards

AVCO Research & Systems Group  
ATTN: Library A830

Battelle Memorial Institute  
ATTN: E. Leach

BDM Corp  
ATTN: F. Agee  
ATTN: Corporate Library  
ATTN: J. Klebers

BDM Corp  
ATTN: Library  
ATTN: J. Schwarz

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Bendix Corp  
ATTN: Document Control

Bendix Corp  
ATTN: M. Frank

Bendix Corp  
ATTN: Dept 6401

Boeing Co  
ATTN: H. Wicklein  
ATTN: D. Kemle  
ATTN: D. Egelkroust  
ATTN: V. Jones  
ATTN: Kent Technical Library  
ATTN: B. Hanrahan

Boeing Wichita Co  
ATTN: L. Weller

Booz-Allen and Hamilton, Inc  
ATTN: R. Chrisner  
ATTN: Technical Library

Calspan Corp  
ATTN: Library

Charles Stark Draper Lab, Inc  
ATTN: TIC MS 74  
ATTN: K. Fertig

Cincinnati Electronics Corp  
ATTN: C. Stump  
ATTN: L. Hammond

Computer Sciences Corp  
ATTN: A. Schiff

Cutler-Hammer, Inc  
ATTN: E. Karpen

Dikewood Corporation  
ATTN: L. Davis  
ATTN: Technical Library

E-Systems, Inc  
ATTN: J. Moore

Effects Technology, Inc  
ATTN: Technical Info Acq, S. Clow

EG&G Wash Analytical Svcs Ctr, Inc  
ATTN: C. Giles

Electro-Magnetic Applications, Inc  
ATTN: D. Merewether

Ford Aerospace & Communications Corp  
ATTN: K. Attinger

Franklin Institute  
ATTN: R. Thompson

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

General Dynamics Corp  
ATTN: Research Library

General Dynamics Corp  
ATTN: Research Library

General Electric Co  
ATTN: J. Andrews

General Electric Co  
ATTN: C. Hewison

General Electric Co  
ATTN: Technical Library

General Research Corp  
3 cy ATTN: Technical Information Office

Georgia Institute of Technology  
4 cy ATTN: Res & Sec Coord for H. Denny  
4 cy ATTN: Res & Sec Coord for E. Donaldson  
4 cy ATTN: Res & Sec Coord for J. Woody  
4 cy ATTN: Res & Sec Coord for J. Daher

Grumman Aerospace Corp  
ATTN: L-01 35

Harris Corporation  
ATTN: V. Pres & Mgr Prgms Div  
ATTN: A. Strain

Hazeltine Corp  
ATTN: J. Okrent

Honeywell, Inc  
ATTN: R. Johnson  
ATTN: S&RC, Library

Honeywell, Inc  
ATTN: W. Steward  
ATTN: S. Graff

Hughes Aircraft Co  
ATTN: CTDC 6/E110  
ATTN: J. Singletary  
ATTN: K. Walker

Hughes Aircraft Co  
ATTN: A. Narevsky

IIT Research Institute  
ATTN: J. Bridges  
ATTN: I. Mindel

Institute for Defense Analyses  
ATTN: Tech Info Services

International Tel & Telegraph Corp  
ATTN: A. Richardson  
ATTN: Technical Library

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Ion Physics Corp  
ATTN: R. Evans

IRT Corp  
ATTN: N. Rudie  
ATTN: B. Williams

JAYCOR  
ATTN: W. Radasky

JAYCOR  
ATTN: E. Wenaas  
ATTN: R. Stahl  
ATTN: R. Schaefer

JAYCOR  
ATTN: Library

Johns Hopkins University  
ATTN: P. Partridge

Kamar Sciences Corp  
ATTN: A. Bridges  
ATTN: N. Beauchamp  
ATTN: F. Shelton  
ATTN: W. Rich

Kaman Tempo  
ATTN: DASIAC  
ATTN: R. Rutherford  
ATTN: W. McNamara

Litton Systems, Inc  
ATTN: MS 64-61, E. Eustis

Litton Systems, Inc  
ATTN: J. Moyer

Litton Systems, Inc  
ATTN: J. Skaggs

Lockheed Missiles & Space Co, Inc  
ATTN: Technical Information Center

Lockheed Missiles & Space Co, Inc  
ATTN: L. Rossi  
ATTN: G. Heath  
ATTN: E. Smith  
ATTN: B. Kimura  
ATTN: H. Thayn  
ATTN: S. Taimuty

Lutech, Inc  
ATTN: F. Tesche

Martin Marietta Corp  
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McDonnell Douglas Corp  
ATTN: T. Ender

McDonnell Douglas Corp  
ATTN: S. Schneider  
ATTN: Technical Library Services

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

McDonnell Douglas Corp  
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Mission Research Corp  
ATTN: EMP Group  
ATTN: C. Longmire

Mission Research Corp  
ATTN: L. McCormick  
ATTN: A. Chodorow

Mission Research Corporation  
ATTN: W. Ware  
ATTN: W. Stark

Mitre Corp  
ATTN: M. Fitzgerald

Norden Systems, Inc  
ATTN: Technical Library  
ATTN: D. Longo

Northrop Corp  
ATTN: Lew Smith  
ATTN: Rad Effects Grp

Pacific-Sierra Research Corp  
ATTN: H. Brode

Palisades Inst for Rsch Services, Inc  
ATTN: Records Supervisor

Physics International Co  
ATTN: Document Control

R & D Associates  
ATTN: Document Control  
ATTN: C. Mo  
ATTN: P. Haas

R & D Associates  
ATTN: J. Bombardt

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ATTN: LIB-D

Raytheon Co  
ATTN: G. Joshi

Raytheon Co  
ATTN: H. Flescher

RCA Corp  
ATTN: G. Brucker

RCA Corp  
ATTN: L. Minich  
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Rockwell International Corp  
ATTN: B. White

Rockwell International Corp  
ATTN: B-1 Div T1c (BA08)

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Rockwell International Corp  
ATTN: G. Morgan  
ATTN: D/243-068, Q31-CA31  
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ATTN: J. Monroe  
ATTN: V. Michel  
ATTN: G. Morgan

Rockwell International Corp  
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Sanders Associates, Inc  
ATTN: R. Despathy

Science Applications, Inc  
ATTN: R. Parkinson

Science Applications, Inc  
ATTN: N. Byrn

Science Applications, Inc  
ATTN: W. Chadsey

Science Applicatins, Inc  
ATTN: E. O'Donnell

Sidney Frankel & Associates  
ATTN: S. Frankel

Singer Co  
ATTN: Technical Information Center

Sperry Rand Corp  
ATTN: M. Cort

Sperry Rand Corp  
ATTN: Technical Library

Sperry Rand Corp  
ATTN: D. Schow

Spire Corp  
ATTN: R. Little

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

SRI International  
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Sylvania Systems Group  
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ATTN: C. Thornhill

Sylvania Systems Group  
ATTN: J. Waldron  
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ATTN: E. Motchok  
ATTN: H. Ullman  
ATTN: M. Nurefora  
ATTN: C. Ramsbottom

Teledyne Brown Engineering  
ATTN: F. Leopard

Texas Instruments, Inc  
ATTN: Technical Library  
ATTN: D. Manus

Texas Tech University  
ATTN: T. Simpson

TRW Defense & Space Sys Group  
ATTN: R. Kitter  
ATTN: R. Mortensen

TRW Electronics & Defense Sector  
ATTN: H. Holloway  
ATTN: O. Adams  
ATTN: R. Plebuch  
ATTN: W. Gargaro

TRW Systems and Energy  
ATTN: D. Pugsley

United Technologies Corp  
ATTN: Chief Elec Design

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