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Proposal for a DoD Combined Battlefield Electromagnetic Environmental Effects (E3) Initiative

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Proposal for a DoD Combined Battlefield Electromagnetic Environmental Effects (E³) Initiative



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OBJECTIVES

The brief begins by emphasizing the growing importance of electromagnetic survivability and compatibility. Next, the brief considers factors which pose implementation challenges/problems. While many technical questions will need to be resolved, the major challenges are associated with organization and process given the large number of technical disciplines and organizations involved. The last part of the brief proposes a top-level solution path.



OBJECTIVES

- **Review importance of electromagnetic survivability / compatibility**
- **Identify current implementation challenges**
- **Propose OSD-level solution path**

BACKGROUND

Operation Desert Storm demonstrated the clear military advantage provided by sophisticated electronic weapon and C4I systems. In addition, the offensive tactic of taking out the enemy's eyes and ears during the air war paid off, giving us decisive air superiority. The lessons for the future are clear. High-tech electronics now so dominates the battlefield that the outcome of future conflicts could well be decided by electronics attrition rather than human casualties. Our Desert Storm experience thus accentuates the importance of guaranteeing that our electronic systems will not be disabled either deliberately or accidentally by electromagnetic environmental effects.

The increasing use of commercial equipment in military applications will require that commercial and military standards be integrated to some degree.

Recognizing the growing importance of electronics survivability, the Joint Chiefs of Staff (J6) has requested and the Under Secretary of Defense for Acquisition has tasked the development of Combined Battlefield Environmental Effects (CBEE).



BACKGROUND

- **DESERT STORM proved criticality of sophisticated electronics to U.S. military operations**
- **Rapid deployment strategy places even higher premium on electronic control**
- **Outcome of future conflicts could be determined by electronics attrition**
- **Must take steps to ensure that our electronics will not be disabled by intentional or inadvertent means**
- **Integration of commercial and military standards could result in markedly improved**
 - **Cost effectiveness**
 - **Uniformity and consistency of E³ protection**
 - **Control and audit of E³ activities**
- **JCS has requested combined battlefield effects standard (including E³, NBC)**

ELECTROMAGNETIC ENVIRONMENTAL EFFECTS (E3)

The simple definition of E3 is “the sum total of electromagnetic environments in which a system must live and operate.” A multitude of individual effects contribute to this environment. Sources of these environments are both man-made and natural. Man-made environments can be friendly or hostile. The large number of potential sources complicates the environments definition problem. The formidable list of more traditional environments (EMI, lightning, ESD, EMP, HERF, TEMPEST, EW) is lengthened by emerging threats from high power microwave and ultra-wide band electromagnetic technologies. Many of the operative environments overlap in the frequency and amplitude of the electrical stresses they create.

At present, the system acquisition process does not treat electromagnetic environmental effects in an integrated manner. This results in duplication of effort, inconsistencies, and increased cost to protect and validate systems.



ELECTROMAGNETIC ENVIRONMENTAL EFFECTS (E³)



PC 01606 WD 24

E3 INTERRELATIONSHIP

The list of operative effects is long and are shown separated according to nuclear and non-nuclear.

Nuclear weapons create a variety of very intense transient electromagnetic effects on systems on the ground (HEMP from high altitude bursts and SREMP from surface bursts) and space (SGEMP from directly impinging ionizing radiation and DEMP from dispersed electromagnetic fields). Electromagnetic fields induced by nuclear weapons can range up to 100's of kilovolts per meter. Nuclear survivability requirements exist for high-value military systems. The protection measures are conservative and stringent. Evidence exists that measures employed to achieve nuclear electromagnetic survivability may suffice for protecting systems against many non-nuclear effects.

Check-marks denote those environments that could be treated by a combined effect protection design. We must limit our attention to disciplines amenable to readily defined protection engineering techniques, thus Spectrum Management and Electronic Warfare (in band ECM/ECCM) are considered beyond the scope of the proposed effort.



E³ INTERRELATIONSHIP

Nuclear Requirements

- ✓ HEMP (E1, E2, E3)
- ✓ SREMP
- ✓ SGEMP/IEEMP
- ✓ DEMP

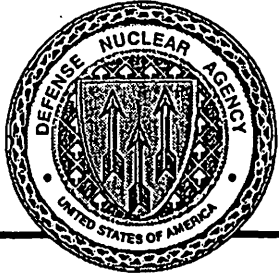
Nonnuclear Requirements

- ✓ EMI / EMC
- ✓ Lightning
- ✓ ESD
- ✓ TEMPEST
- ✓ EMR
- ✓ RF Hazards
- ✓ HPM / UWB
- ✓ ECM / ECCM (out-of-band)
- ECM / ECCM (in-band)
- Spectrum Management

✓ Candidates for inclusion in an integrated protection approach

WAR FIGHTING TREND TOWARD EXPLOITING ELECTRONICS VULNERABILITIES

A major objective of command and control warfare (C2W) is to separate the enemy leadership from his forces. In future conflicts, offensive measures would be employed to destroy, deny, degrade, confuse, or deceive a combatant's capabilities to communicate, sense, reconnoiter, classify, target, and direct an attack. Disruption of electronics is an effective means of accomplishing these objectives. Systems particularly susceptible to E3 problems include command centers, communications systems, surveillance and targeting systems, information processing, decision and display systems, electronic warfare systems, and weapons guidance systems. The proliferation of advanced digital and analog electronic information systems makes electronic systems more and more vulnerable to disruption by extraneous electromagnetic sources. The problem is made worse by new defense guidance requiring that off-the-shelf commercial-spec electronics be used whenever possible. Given the continuing increase in the sophistication and capability of electronics on the battlefield and commensurate increase in military reliance on such electronics, the effects of E³ disruption of electronic means can have a larger and larger effect on the outcome of future conflicts. Thus, a strong need exists to protect our electronics. Requirements need to be made uniform and enforceable through stricter controls on design, manufacturing and test requirements.



WARFIGHTING TREND TOWARD EXPLOITING ELECTRONICS VULNERABILITIES

- **Separate leadership from forces**
- **Targets are electronic technologies embedded in**
 - **Precision guided munitions**
 - **Space-based systems**
 - **High-speed decision aids**
 - **C²**
- **Control enemy use of the electromagnetic spectra**
- **E³ protection becomes critical**

E³: CONSEQUENCES CAN BE SERIOUS

The are several documented incidents where E³ resulted in serious accidents, some of which involved injuries and/or fatalities. The Blackhawk and Apache helicopters have experienced operational problems around high intensity RF sources. An Atlas Centaur FLTSATCOM launch was aborted just prior to launch initiation due to lightning strikes in and around the launch complex. A Pershing II missile detonated in Aldheide Germany in an accident attributed to charge build-up in the motor case. A Tornado aircraft crash was attributed to interference from a nearby radio tower. During the Vietnam era, a very serious accident occurred on board the Forrestal aircraft carrier in which RF fields caused an accidental missile launch. The accident caused extensive destruction and loss of life. Other classified incidents have been documented.



E³: CONSEQUENCES CAN BE SERIOUS

- Helicopter operation irregularities in high-radio-frequency (RF) environments (BLACK HAWK, APACHE)
- ATLAS CENTAUR abort during FLTSATCOM launch
- PERSHING 2 detonation in Waldheide
- TORNADO crash near Munich
- Boeing 747 thrust reverser deployment
- Forrestal incident
- Other classified incidents

SYSTEM E³ CONCERNS

Within systems, E³ can have many different effects on operation from safety to data loss to false/misleading system status information. As more and more of system functionality has been turned over to electronics, the effects of electronics deliberation on mission execution have become more serious. As one example, newer aircraft are using electronic controls in place of traditional mechanical subsystems (including “fly-by-wire” subsystems) making them more vulnerable to E³. Indicative of the sensitivity of these systems to E³, starting in 1993 commercial airliners have banned the operation of certain electronics on board aircraft due to incidents of severe interference with avionics operation.

Other notable examples of increased military dependence on electronics and a corresponding increase in E³ susceptibility include remote sensing and smart munitions. Remote sensing is highly dependent on electronics of increasing sophistication. The sensors may include focal plane arrays, RF transmitter-receivers, and lasers. These sensors need to fit into small volumes and rely on microminiature electronics that have been shown to be extremely sensitive to the electromagnetic environment. Electronics provide the “smart” in smart munitions. If appropriate protection is not afforded, these systems are known to be susceptible to E³ especially during the latter part of their mission since it is during this time that there is little or no possibility of manual recovery.

E³ is an important consideration for military electronics across the board. The chart shows a sample of functional categories, the effects that upset or damage to the associated electronics can have, and an example of an affected system class. Of critical concern are functions/systems where safety is affected. On the battlefield, all listed concerns may lead to actual casualties.



SYSTEM E³ CONCERNS

FUNCTIONAL CATEGORY	CONCERNS	RELEVANT SYSTEM CLASSES
Fly-by-wire	Safety	Modern aircraft systems
Remote sensing	Data loss	Target acquisition
Fire and forget; fuzing	Performance degradation	Advanced munitions
Remote control	Mission abort	RPV/robotics
Jam-resistant C³I	Timing; sync	C³I
Position location, tracking	Data loss	C³I/RSTA
Ordnance	Safety/mission abort	Electrically initiated ordnance
Guidance and control	Performance degradation	All guided weapons
Information processing	Data loss	C³I systems
Weapon simulation	False response	Training devices

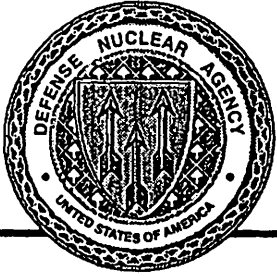
UNIFIED ELECTROMAGNETIC EFFECTS WORKSHOP EXECUTIVE PANEL FINDINGS

DNA and the Army organized this workshop at the Naval Postgraduate School in October 1991. The workshop brought together experts from the major EM disciplines to consider a unified approach to protecting U.S. military systems. The sequencing of session presentations and discussions was designed to (1) identify protection requirements for emerging EM effects; (2) review how requirements have been met for existing EM effects; (3) identify protection and test technology capabilities and limitations; and (4) consider how best to combine system EM protection requirements. An Executive Panel comprised of representatives from the Army, Navy, Air Force, Defense Nuclear Agency, Strategic Defense Initiative Office, and industry convened on the last day of the workshop.

The panel concluded that unification of electromagnetic effects protection is not only feasible, but necessary. The panel felt that the technology required to provide the required protection is well in hand, that the major challenge will be to improve the process and organization. Panel members were convinced that there is much room for improvement in the present DoD E³ policy and process.

The panel made a number of specific recommendations on future steps to achieve a combined, coherent DoD approach:

1. Define a common set of terminology.
2. Review existing hardening specifications, standards, and guidelines to identify overlaps and incompatibilities.
3. Whenever possible, integrate hardening design guidelines/procedures/processes to handle multiple environments.
4. Establish minimum requirements for reporting during the system acquisition process regarding how E³ protection will be achieved and verified.
5. Develop a top-level road map document as a guide to all existing E³ documentation.
6. Establish a DoD/industry working group to provide E³ input to the revision of DoD-I-5000.2.
7. Assure that future EM simulation facilities address E³ issues and consolidate test facilities and capabilities.
8. Define "low-risk" protection in a more general context.
9. Establish procedures to define and incorporate "new" E³ threats.
10. Establish an E³ hardening data base.



UNIFIED ELECTROMAGNETIC EFFECTS WORKSHOP EXECUTIVE PANEL FINDINGS (OCTOBER 1991)

- **Much commonality among EM effects**
- **E³ protection integration (programmatic and technical) is not only doable but highly desirable**
 - **Necessary technology is in hand**
 - **Challenge is to define process**
- **Need for focus within DoD**
 - **Designated OPR**
 - **Top-down OSD guidance**
 - **Flow-down to services, PMs in consistent manner**
 - **Uniform terminology / standards / direction ...**
- **Need to address emerging threats (HPM, UWB)**
 - **Hostile**
 - **Friendly**

CHALLENGE: MULTIPLICITY OF ENVIRONMENTS

A major challenge is to interrelate all applicable EM environments with the goal of combining any overlap while eliminating any significant over- or under-specification. As shown by the examples in this table there are a multiplicity of specifications for EM environment. To a certain degree it may be possible to combine a few of these specifications where the important defining parameters tend to overlap without over or under specifying any one environment. This is indeed a difficult challenge, but one that is worthy of consideration.

The environment sources are divided into hostile and non-hostile classes and are further subdivided into nuclear and non-nuclear and into natural and manmade environments, respectively. The hostile non-nuclear environments include UWB, HPM and out-of-band ECM. As pointed out earlier, inband ECM will be excluded from this integration program. On the non-hostile side, the natural environments include lightning and ESD. EMI including effects on ordinance and hazards constitute the man-made environments. Although some waveform characteristics vary significantly, there is much overlap in amplitude and frequency. Thus it should be possible to combine some specifications where certain environments dominate.



CHALLENGE: MULTIPLICITY OF ENVIRONMENTS

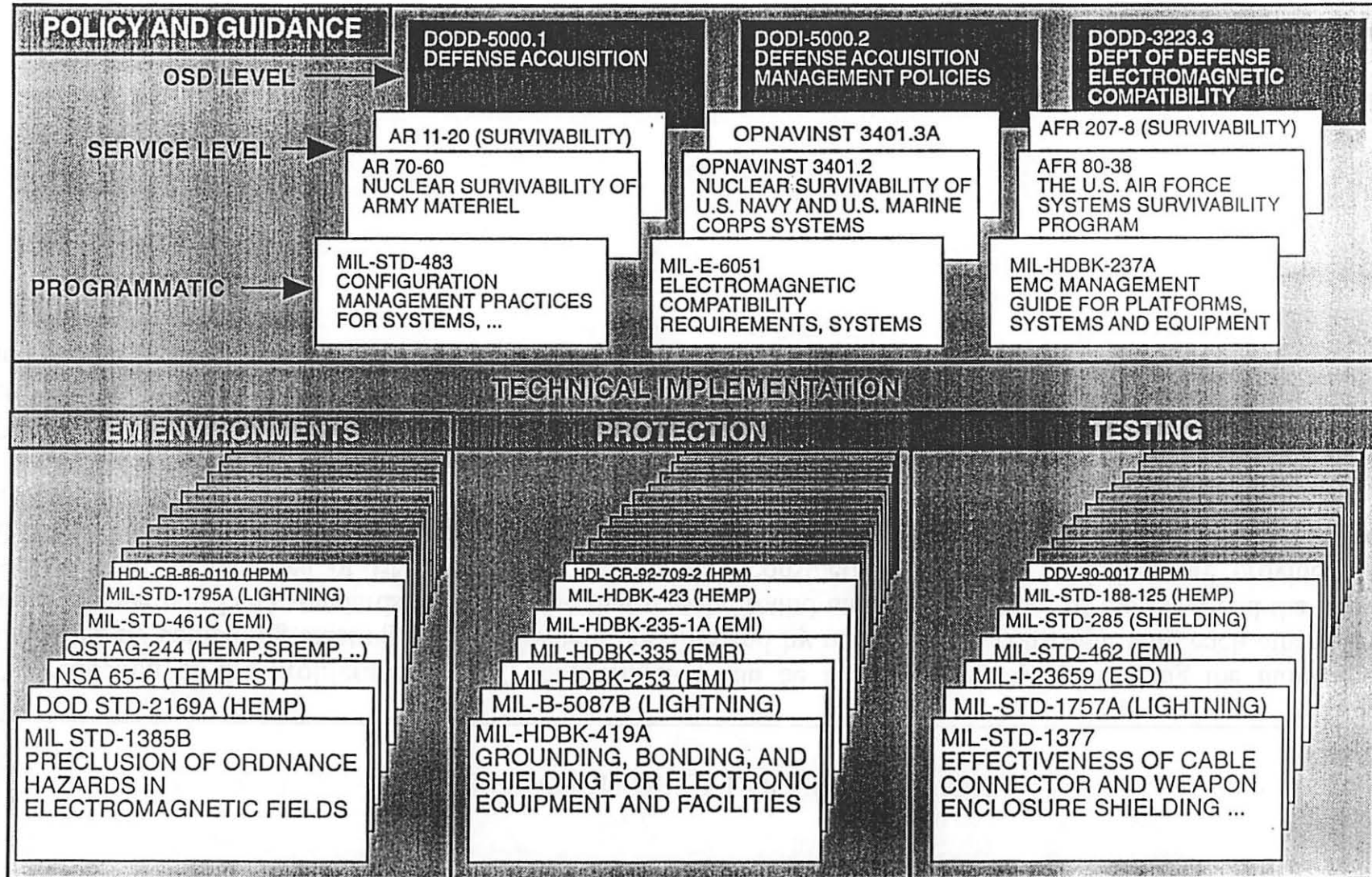
Source		EMI Environment	Time Waveform	Peak Amplitude	Rise Time/ Frequency	Coupled Stress
Hostile	Nuclear	HEMP SREMP SGEMP - Vacuum - Thin air DEMP	Pulse Pulse Pulse Pulse Pulse	~50,000 V/m ≥100,000 V/m ≥1,000,000 V/m ~500,000 V/m 100 V/m	Nanoseconds Nanoseconds Nanoseconds Nanoseconds Nanoseconds	~2,000 A ≥25,000 A ~3,000 A ~80,000 A 20 A
	Non-nuclear	RF weapons - UWB - HPM ECM (out-of-band)	Pulse Pulsed CW Modulated CW	≤10,000 V/m ≤10,000 V/m ≤200 V/m	≤Nanosecond 1 - 100 GHz 0.1 - 6 GHz	≤10 A ≤1 A ≤1 A
Nonhostile	Natural	Lightning - Attached - Radiated ESD	Pulse Pulse Pulse	200,000 A ≤3,000,000 V/m 25,000 V	Microseconds Microseconds Nanoseconds	200,000 A ~3,000 A 50 A
	Man-made	EMI - EMRO - EMRH	Modulated CW	≤200 V/m	All frequencies	≤1 A

CHALLENGE: PROLIFERATION OF E³ DOCUMENTATION

The large number of electromagnetic environments to be reckoned with is more than matched by the proliferation of applicable guidelines, standards, and handbooks, over 100 at last count. These documents exhibit redundancy in requirements and mitigation techniques. In some cases (e.g., ground techniques), guidelines are inconsistent or incompatible with each other. Associated with the guidelines is a multitude of separate test requirements and simulator facilities exhibiting similar redundancies and overlap in environments. These factors provide a strong motivation to unify the guidance and approach for dealing with E³.



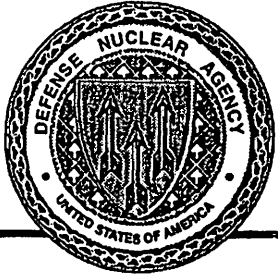
CHALLENGE: PROLIFERATION OF E³ DOCUMENTATION



PROLIFERATION OF E3 DOCUMENTATION

The reduction of the proliferation of E³ documentation can be accomplished by minimizing the number of standards, by combining existing standards where possible and by making them consistent with each other. This could include non-DoD standards such as those that may be found under the auspices of the FAA and the IEEE. For example, in the area of EM grounding and bonding considerably different guidelines are provided for EMI/EMC than would be required for nuclear EMP, that is, single point grounding required for EMI/EMC is not desirable for EMP.

The second goal is to integrate the E³ related requirements under the applicable 5000 series of directives and instructions. At present the 5000 series calls out the EM survivability and compatibility requirements separately and should be combined so that any existing inconsistencies are eliminated.



PROLIFERATION OF E³ DOCUMENTATION

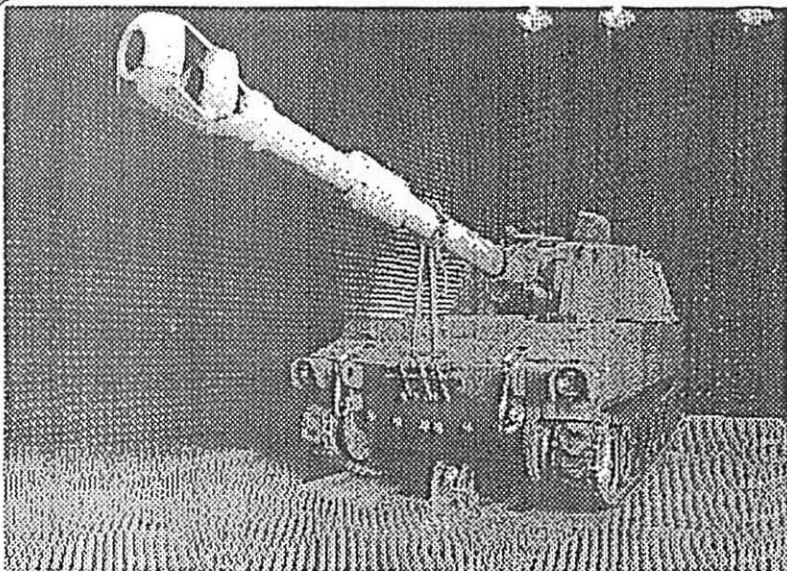
- **Minimize documentation, combine, and make consistent**
- **Integrate E³ under applicable 5000-Series documents**

CHALLENGE: OPTIMUM USE OF TEST FACILITIES

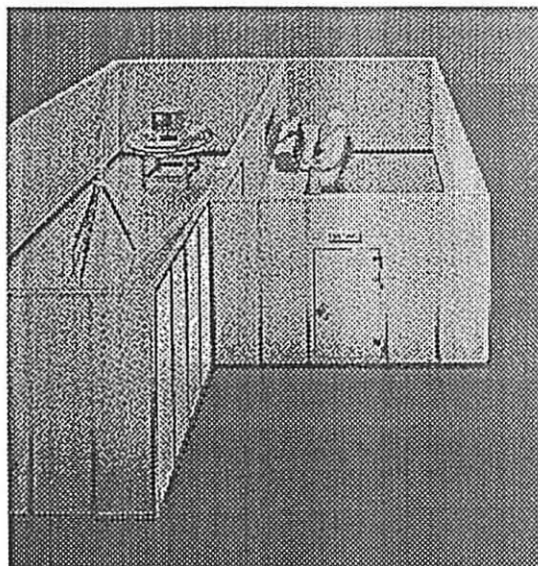
Another challenge will be to optimize the use of existing EM test facilities by eliminating those that are redundant and combining others as necessary. Many of the facilities that exist overlap in capability and should be carefully reviewed technically and programmatically to ascertain their need. However, a variety of test facilities are required due to the differing nature of the various EM environments and the fact that not all systems will have the same EM protection requirements. For example, HPM requires higher power levels than EMI and higher frequencies than EMP. Lightning and EMP are closer matched from a spectral point of view but differ in the mode of system excitation.



CHALLENGE: OPTIMUM USE OF TEST FACILITIES



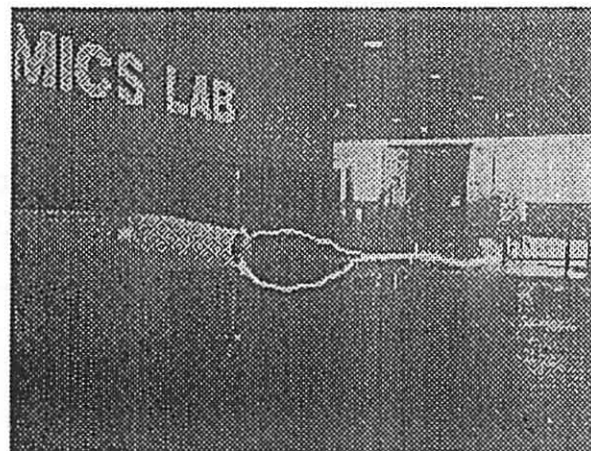
Microwave



EMI



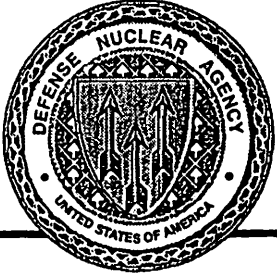
EMP



Lightning

OPTIMUM USE OF TEST FACILITIES

The use of EM test facilities may be optimized by integrating system test requirements and facilities through the elimination of redundancies and by the eventual centralization and co-location as deemed to be practical.

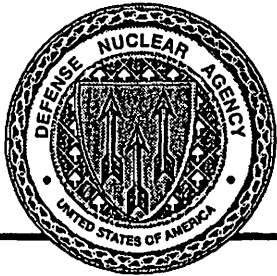


OPTIMUM USE OF TEST FACILITIES

- **Integrate test requirements and test facilities**
- **Eliminate redundancies**
- **Centralize and collocate facilities as deemed practical**

COMMITMENT TO E3

The DoD, DNA, Services and Joint Offices are committed to the development of systems that are survivable to modern day E³. Each service has assigned an OPR and associated principal directives that relate to the system E³ problem. In addition, the Electromagnetic Compatibility Analysis Center (ECAC) has been assigned as the OPR for the Joint Services.



COMMITMENT TO E³

- **U.S. Navy / Marines**
 - OPRs: NAVAIR, NAVSEA, SPAWARs, MCRDAC
 - Principal Directives: OPNAVINST 3401.3A, OPNAVINST 3401.2

- **U.S. Army**
 - OPRs: OASA (RDA), USAMC
 - Principal Directives: AAE Memorandum 91-3, ADS-37, TOP-1-1-511

- **U.S. Air Force**
 - OPR: SAF(AQQS), FMA / FE
 - Principal Directives: MIL-STD-1818, AFR 80-23, AFR 80-38

- **Joint**
 - OPR: ECAC
 - Principal Directive: DoDD 3222.3

PROPOSED SOLUTION PATH

The Unified Electromagnetic Effects Workshop has made the case for combined E³. The Under Secretary of Defense for Acquisition has designated the Assistant to the Secretary of Defense for Atomic Energy [ATSD(AE)] as the OPR for Combined Battlefield Environmental Effects. An Executive Steering Committee charter is now being defined to be chaired by ATSD(AE). A first order of business for this group will clarification of acquisition policy as contained in DoD Instruction 5000.2.

A DoD effort is envisioned with top level objectives as follows:

- a. To simplify an streamline the acquisition of systems which must withstand multiple E³.
- b. To realize cost, weight, and size economies inherent in using the same protection design feature/hardware to mitigate multiple effects.

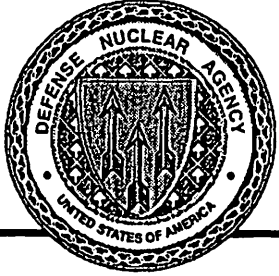
Three implementation phases would proceed as follows:

Phase I: The first phase would matrix effects vs. systems categories. System and effects would be rank-ordered based on amenability to combining and simplifying protection requirements. Those systems/effects where the largest reductions in associated acquisition costs/schedules could be realized would be identified. Phase I would also include a survey and assessment of existing protection guidance.

Phase II: Efforts in the second phase would pursue the top-ranked matrix blocks where combining effects requirements produces the largest benefits. The Phase II effort might first produce combined environments documentation, followed by development of integrated effects protection engineering guidance.

Phase III: The third phase would place the protection engineering guidance into the DSSP pipeline to codify the combined guidance into military standards and handbooks. The culmination of Phase III would be Service-ratified combined protection documentation immediately applicable to system acquisition and maintenance.

DNA has initiated a joint pilot program the Army SSDC to develop combined E³ guidelines for critical ground-based C4I and missile defense systems. This effort has determined the technical feasibility of combined E³ designs and developed an initial draft guidelines document.



CONCLUSIONS

- **E³ protection more and more important**
 - **Electronics attrition could determine outcome of conflicts**
 - **HPRF weapon technology is advancing**
- **Need for uniform and consistent E³ protection of U.S. systems**
- **EMP hardening offers excellent baseline for unified E³ protection**
 - **Have standardized protection / test requirements at system level**
 - **Test results show EMP hardening mitigates other effects**
- **DNA has developed and coordinated program approach and initiated pilot program**
- **Integration of commercial and military standards could provide payoff in cost effectiveness and uniformity of EM protection**
- **Payoffs in cost effectiveness, control / audit, uniform EM protection**

CONCLUSIONS

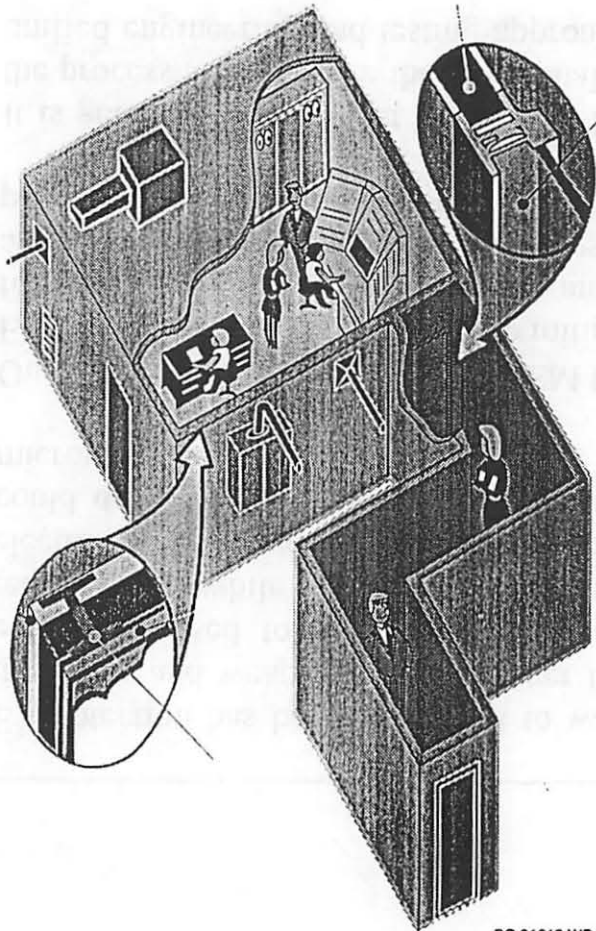
E³ protection has become critical to war fighting. As we turn more of our command, control, communications, targeting, and weapon functions over to electronics we must recognize the risks. The technologically advanced equipment used to provide a decisive advantage is a double-edged sword. Failure to recognize protection requirements while electronics are advancing can have serious consequences, especially if we continue to rely on electronics to increase efficiency of our military with smaller numbers. It is conceivable that electronics attrition could determine the outcome of future conflicts. These problems are exacerbated by the advent of high power microwave weapon technology.

Our national workshop on Unified EM Effects Hardening pointed to the need for uniform and consistent protection. EMP protection has been shown to mitigate other electromagnetic effects including lightning and microwaves. Thus for systems with EMP requirements, an integrated approach should be straightforward, using the conservative EMP approach as the baseline. For other systems, integration of commercial and military standards could also provide payoff in cost effectiveness and uniformity of EM protection.

It is generally agreed that combining E³ requirements is technically feasible. The difficult challenge is to define the process and organize the individual communities and organizations to work together to achieve a coherent and unified engineering and testing approach and standard documentation.



INTEGRATED E³ PROTECTION FOR FIXED FACILITY



PC 01613 WD 24

Feature (Purpose)

Continuous Metal Shield (Ref & Atten Fields)	●	●	Ext	Ext	●	●	●	●	●
Waveguide Below Cutoff (Attenuate Fields)	●	●	Ext	Ext	●	●	●	●	●
Filters (Alternate Conducted I&V); Grounded Utility Penetration (Prevent Current Entry)	●	●	Ext	Ext	●	●	●	●	●
Shielded Entry Door(s) (Prevent Field Penetration)	●	●	Ext	Ext	●	●	●	●	●
Entry WBC/Vestibule (Attenuate Fields Below f_c)	Part	●	Part Ext	Part	Part	Part	●	●	●
Shielded Cable/Connector (Attenuate Wire I&V)	●	●	●	●	●	●	●	●	●
Grounded Conduits (Shielded Electrical Wires)	●	●	Ext	Ext	●	●	●	●	●

ENVIRONMENT
 HEMP Lightning SEMP EMI EMI/RFI EMI/RO RFI/EMI/RFI/OWE EMI (Out-of-Band)

PC 01613 WD 24

INTEGRATED E³ PROTECTION: FIXED FACILITY EXAMPLE

This example depicts common protection engineering features and indicates that each feature mitigates several electromagnetic effects. Combined effects guidance should specify a balanced protection approach that considers the effects in toto rather than as individual requirements. Major cost savings can be realized with such an approach as well as systems with protection that is both complete (no effects overlooked, lost) and balanced (not overhardened to any particular effects).



GENERIC EM PROTECTION ENGINEERING METHOD

- **Reduce EM coupling by**
 - **Shielding**
 - **Grounding and bonding**
 - **Isolation**
- **Reduce transients at equipment using**
 - **Filters**
 - **ESAs**
 - **Clamping diodes**
- **Reduce effect on equipment by**
 - **Robust subsystems and piece parts**
 - **Software checks**
 - **Circumvention / reset techniques**

GENERIC EM PROTECTION ENGINEERING METHOD

There is much commonality among the various electromagnetic disciplines. The same protection engineering tools apply. The first line of defense is at the system level where EM coupling is reduced by shielding, grounding, bonding and dielectric isolation. Inside the system, equipment interference is eliminated by the use of filters, electrical surge arresters (ESAs) and voltage clamps. Effects of spurious electrical effects is further reduced on internal equipment by the choice of robust subsystems and pieceparts, software checks, and circumvention/reset techniques.



PROPOSED SOLUTION PATH (COORDINATED WITH SERVICES)

- **Organize and conduct national workshop**
- **Identify OSD-level E³ OPR to provide defense-wide policy**
- **Clarify OSD policy**
- **Establish interim E³ protection integration coordination panel**
- **Develop integrated E³ protection / testing approach**
 - **DNA pilot program in place for FGBC4I and USASDC systems**
- **Demonstrate approach on these systems**
- **Develop widely applicable technical implementation guidance**