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Evolution and Rationale for United States Department of Defense Electromagnetic Pulse Protection Standard

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ABSTRACT
The United States (US) Department of Defense (DoD) Electromagnetic Pulse (EMP) protection standard offers a solid basis for protecting commercial communication, data, and control facilities. Because of the standard's shielded barrier and test requirements, it is not surprising that there is a strong temptation within industry and government to dismiss the MIL-STD 188-125 approach in favor of less rigorous protection methods. It is important to understand that US DoD EMP protection standard for fixed facilities, MIL-STD-188-125, reflects an evolution by trial and error that spanned a period of decades beginning with the acquisition of the Minuteman Missile System in the 1960s. In fact, one of the main motivating factors for developing the standard was that system developers in the Air Force, Army, Navy, and Defense Communications Agency (now Defense Information Systems Agency) and the Federal Emergency Management Agency tried less technically-sound approaches that failed in their effectiveness, testability, and maintainability. This paper revisits the development of the US DoD standard and explains its provisions and underlying technical rationale. The paper's objective is to enable the public officials and engineers involved in planning and implementing EMP protection for critical infrastructure facilities to avoid the pitfalls encountered in the past and use the best practices available to achieve low risk protection designs that can be maintained over the entire lifecycle of critical infrastructure systems.

The United States (US) Department of Defense (DoD) has a long and strong experience base in protecting systems against the nuclear electromagnetic pulse (EMP). The US DoD's EMP protection experience dates back to the 1960s with the development of the Minuteman Missile system. In the late 1970s, recognizing the non-uniformity of EMP protection engineering practices across the services and problems with initial certification testing and lifecycle monitoring and maintenance of EMP protection, efforts were begun at the Defense Nuclear Agency (DNA) to standardize EMP environment criteria and protection engineering requirements. DNA issued the initial contract to develop a standard EMP environment waveform in 1980 to Vector Research (now Metatech, Inc.). This effort was brought to fruition by the issuance of DoD-STD-2169. In 1986 DNA, in a competitive procurement, selected SRI International to draft a protection engineering standard for fixed ground-based facilities, culminating in MIL-STD-188-125-1. In 1987, DNA assembled a technical working group to vet the standard draft material. The working group included expert government and contractor representatives from the Army, Navy, Air Force, and the Defense Communications Agency. The working group met at regular intervals from 1987 to 1991 to edit and approve the final military standard.

A major issue motivating the development of MIL-STD-188 was that, with few exceptions, the exact nature and seriousness of systems malfunctions observed during EMP tests were not predicted by pre-test analysis. Analysts found that EMP effects depend on fine, often trivial, details of system construction which are difficult to model. Some details such as parasitic capacitance and inductance effects and high voltage breakdown locations are unknown, even when with detailed engineering drawings available, since these details do not influence normal system operation. They found assessments based on paper studies, visual inspection, exact replication of circuit schematics, and even low-level testing unreliable (US Defense Nuclear Agency 1995).

The assessment of system EMP vulnerability involves detailed analytical comparison of the EMP stress levels (fields, current, and/or voltage levels) on the system at a selected location on the system, with the strength (current and/or voltage failure thresholds) at the same location. Figure 1 illustrates the system structural layers involved in EMP system response modeling and testing. Note that uncertainties in stress levels are lowest at the system exterior (corresponding to overall system vulnerability) and uncertainties in system strength levels lowest at the system component level. Any one of these layers can serve as the location for stress/strength comparisons. Because our interest is in overall system vulnerability, the ideal location for comparing stress with strength would be at the system exterior since we can precisely specify and impose EMP fields and penetration currents here. However, for unprotected systems, since large EMP fields and cur-

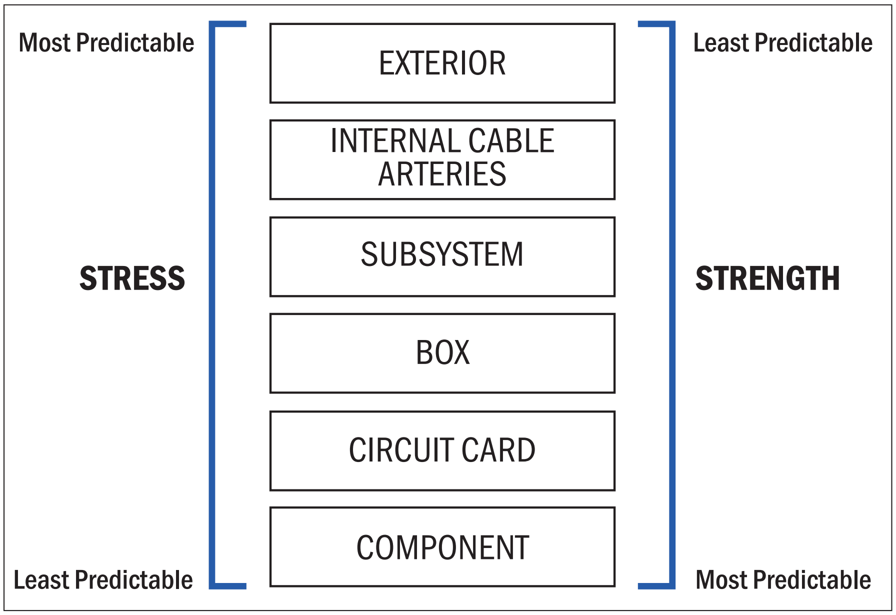

Figure 1. System EMP Coupling Layers

rents are allowed to flow through up to 6 coupling layers from the system exterior to internal components of the system (where actual failure occurs), it is very difficult to predict system strength to a given exterior stress. The uncertainty in system exterior strength levels magnifies over the system lifecycle since internal system components are modified or replaced over time.

The difficulty in predicting systems' EMP vulnerability had a major effect on the evolution of the DoD EMP protection approach. An intense debate occurred with the EMP community from the early 1960s through the 1980s. There were two schools of thought:

1. The "tailored hardening" advocates maintained that protection should occur at the box level based on box failures observed during system testing. This approach placed a heavy emphasis on the use of terminal protection devices. The major attraction of the tailored approach was its lower up-front costs – systems required no initial EMP hardening and only those boxes that failed under test required protection. The tailored hardening approach was also known as the "test-fix-test" approach.
2. The "global hardening" advocates maintained that protection should occur at the system exterior level by including an electromagnetic barrier as part of the initial system design. This approach placed a heavy emphasis on external shielding. The major attraction of the global approach was that the external barrier created an electromagnetically "quiet" interior such that unhardened commercial off-the-shelf boxes could be installed inside the system. The downside was higher initial costs associated with shielding materials. The global hardening approach was also known as the "fix-test-fix" approach.

The impasse precipitated two high-level reviews. The first review, conducted by a special convocation of the Defense Science Board (DSB), during 1979-80 focused on aircraft protection – "Report of the DSB Task Force on EMP Hardening of Aircraft (http://www.dod.mil/pubs/foi/Reading_Room/Special_Collections/11-M-1293.pdf)" The second, conducted by the National Research Council of the National Academies of Science, during 1982-84 looked at EMP protection of systems in general – "Evaluation of Methodologies for Estimating Vulnerability to Electromagnetic Pulse Effects (http://www.dtic.mil/dtic/tr/fulltext/u2/a144408.pdf)."

The DSB Task Force Report addressed three protection approaches: (1) global system shielding, (2) adaptations involving protecting only mission-essential equipment, and (3) component hardening. They identified two major sources of uncertainty underlying their recommendations –uncertainties in EMP coupling level (stress) analysis, and uncertainties in overall system failure prediction (strength) analysis. The DSB concluded that the tailored protection approach had an excessive reliance on analysis, and the associated uncertainties in stress and strength levels did not provide high confidence in system survivability. The Board recommended that the best approach to EMP protection is to use a minimum number of contiguous shields with the smallest possible number of EMP penetrations (penetrating wires, doors, pipes, and apertures). They acknowledged that adaptations involving isolating mission critical equipment would permit cost-savings by reducing necessary shielded volumes.

It is noteworthy that the National Research Council (NRC) committee came to the same conclusions as the DSB. Like the DSB, the NRC report emphasized the large uncertainties inherent in the entire process of estimation of currents and voltages at the component level and the associated protection requirements. Their solution was to recommend controlling system stress to well-known values by using integral shielding and penetration control at the system exterior. They also recommended great emphasis on developing better and less expensive means for virtually complete and effective shielding of systems. Their idea was to put up a tightly shielded barrier to keep the energy out of the system. This creates an interior "quiet zone" such that there is no need to predict what happens inside thus avoiding the associated prediction uncertainties. With the proper engineering, barrier designs can provide interior field and current levels so low that virtually any type of electronic component will survive. The best way to reduce electronics' strength uncertainties is to provide a system design that limits EMP fields and currents at the system's exterior to levels known to be generally safe – levels comparable to normal signal background noise.

The NRC committee also recommended the development of design strategies that are testable. A major advantage of global shielding is that testing is much easier – one must validate only that the outer shield is effective. The NRC report stated that if the system shield is such that virtually nothing gets through, periodic tests of the integrity of the shield and high-level current injection tests on all cables entering the shielded enclosure constitute an adequate test. This is important not just for initial system acceptance tests, but for lifecycle hardness surveillance testing required for EMP hardness maintenance. If the outer system shield certified effective, interior electronics can undergo replacement over the system lifecycle without fear of compromising system EMP survivability.

The NRC was critical of the tailored hardening approach stating, "The Committee is uncomfortable with the use of tailored hardening to design new systems." They observed that the component-level protection rather than the system-level protection carries much more risk of vulnerability, again pointing to inaccuracy of analytical EMP coupling and system response predictions. It is straightforward

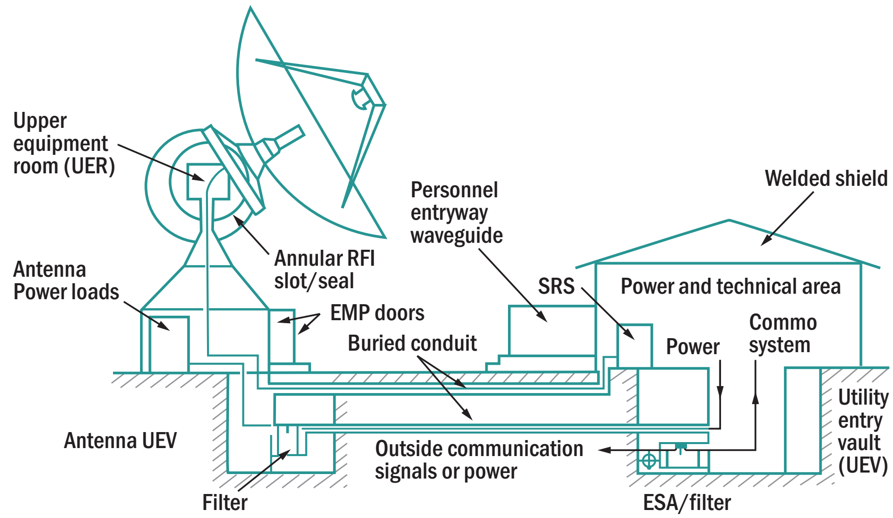

Figure 3. MIL-STD-188-125 Protection Design Example – DSCS Ground Terminal

to specify or predict EMP levels outside a system, but as EMP energy propagates inside the system, internal wiring complexity makes it very difficult to predict the levels of currents and voltages that flow to individual components. The crux of the global versus tailored protection issue was that this is where the tailored hardening proponents were attempting to protect. It should be noted that the NRC did not entirely dismiss box level protection, but observed that protection concepts involving shielding at the box level could be admissible provided that optical fiber was used for all box interconnections.

The global shielding approach used by DoD beginning in the 1980s follows the recommendations of the DSB and NRC committees. MIL-STD-188-125-1 embodies the global shielding approach for fixed ground-based communication and data centers. MIL-STD-188-125-2 embodies the global shielding approach for portable and ground-mobile systems.

Electromagnetically simple systems with a contiguous shield and having a small number of protected penetrations engineered by the US DoD can survive EMP. The engineering principles are straightforward as illustrated in Figure 2:

1. Make the electronics portion of the system as compact as possible.
2. Enclose these electronics in a single continuous shield.
3. Limit the number of electromagnetic penetrations through the shield and protect all remaining penetrations.
4. Certify the hardness of the system via shielding effectiveness tests and current injection tests of cable penetrations.
5. Periodically retest the shielding and penetration protection integrity to maintain hardness over the system lifecycle.

Numerous systems successfully implemented this approach in their engineering design and fabrication. A partial list includes:

Missiles (Minuteman Upgrade, Peacekeeper, Air Launched Cruise Missile); Aircraft (B1-B, TACAMO, E-3A, E-4B); and Ground Systems (Ground Launched Cruise Missile, MILSTAR, Ground Wave Emergency Network, National Military Command Center, Alternate National Military Command Center, Defense Satellite Communication System (DSCS) Ground Terminals, Pershing launch control system).

An illustration of the MIL-STD-188 facility outer boundary shield implemented on the DSCS ground terminals is included in Figure 3.

It is important to note that the US DoD standards are test-performance based. Engineers can use different shield designs and penetration protection devices, as long as the shielding effectiveness and penetration currents meet the specified final acceptance test.

The justification for EMP protection costs for critical infrastructure systems is clear when compared to the cost of lost societal services. For long-term outages of the electric power grid caused by EMP, economic losses would measure in trillions of dollars (Baker 2013). The costs to harden are a small fraction of system cost for new systems. For example, the US DoD has found that EMP protection costs for large buildings amount to 3 to 8 percent of total system cost if included in the initial system design (Gertcher). Costs are manageable for retrofit protection of existing systems by isolating critical electronics within shielded cabinets or rooms.

It is noteworthy that EMP protection has many benefits in addition to EMP immunity. The MIL-STD-188-125 EMP protection design enhances signal emanation security (TEMPEST protection). In addition, DoD standard protection reduces radio frequency (RF) weapon effects, and is effective against solar geomagnetic disturbance effects, electric power outages caused by line transients, lightning effects, and electromagnetic interference. ■

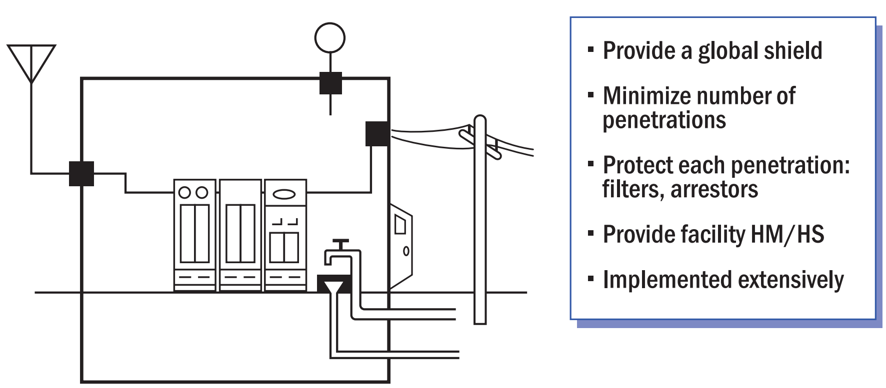

Figure 2. Notional Illustration of the Global Shielding Approach for Fixed Facilities

REFERENCES

- US Defense Nuclear Agency. 1995. ELECTRA Program Technical Review Group Report.
- Baker, G. H. 2013. "Cost-Effective EMP Protection for Communications Networks and Power Sources." In *Proceedings of 2013 Dupont Summit on Mitigating High-Impact Threats to Critical Infrastructure*, edited by C.L. Manto and A.A. Kaewert. Washington, US-DC: InfraGard National EMP SIG.
- Gertcher, F. 1999. Benefits and Costs of Protecting Infrastructure Systems Against Terrorist and Related Threats: Cost Analysis, Defense Threat Reduction Agency, Report No: RT-0103-99.

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