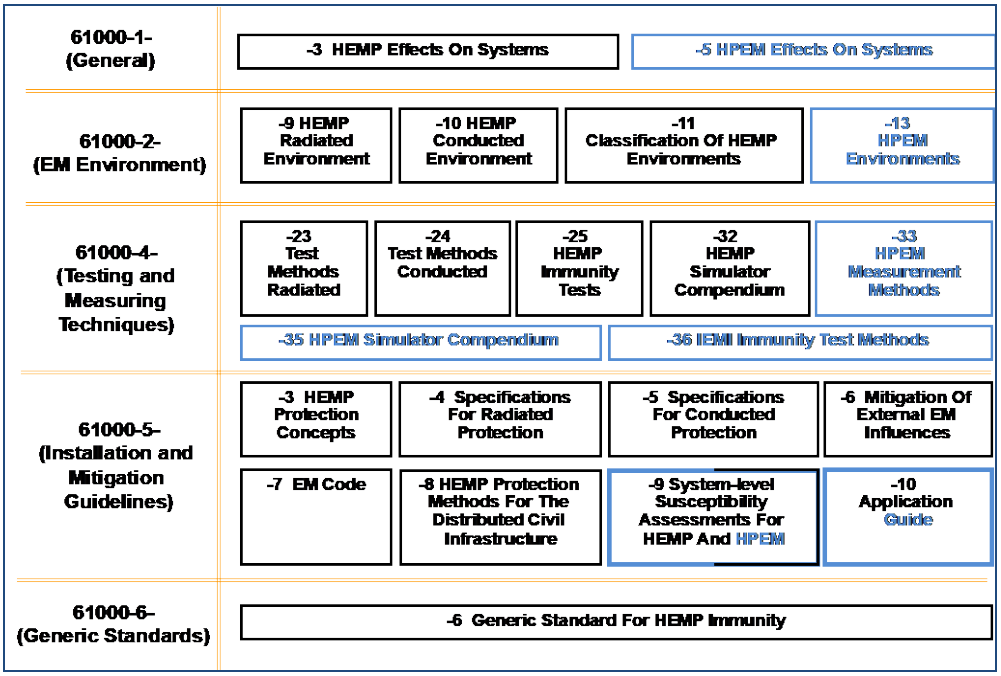
5. LEVEL 3 EMP GUIDELINES

Level 3: Only minutes of mission outages are permitted

In addition to Level 2…

- Use International Electrotechnical Commission (IEC) EMP and IEMI protection standards (IEC SC 77C series, see Appendix F).
- Shielding should be 30+ dB of protection through 10 GHz.
- Use EMP shielded racks, rooms, or facilities to protect critical computers, data centers, phone switches, industrial and substation controls and other electronics.
- Use "Recommended E3 HEMP Heave Electric Field Waveform for the Critical Infrastructures" from EMP Commission for grid and undersea cable protection planning. Use 85 V/km for Continental U.S. (CONUS) E3 threat.
- Use EMP tested SPDs and equipment.
- Institute IEC level hardness maintenance & surveillance (HM/HS).
- Have 30 days of EMP protected power/fuel.
- Store 30 days of food, water, and critical supplies and spares.
- Use time-urgent EMP resilient comms, like X, Ku and Ka satellite, and either HF groundwave or Automatic Link Establishment (ALE) HF.

The following IEC publications apply to Level 3 Protection and are shown in summary in the figure below and in detail in the Bibliography (Appendix F) at the end of this report:



Note: Black text indicates publications dealing with HEMP, while blue/grey text indicates HPEM/IEMI publications.

Figure 22. Organization of the current IEC SC 77C publications

The Level 3 Facility EM barrier should be designed with the same features and provisions as with Level 4 with the exceptions of both Provision 1 noted below and only one entryway door is required instead of a double-door entry as in Level 4. With only a single door, an alarm or automatic closing feature should be installed to prevent the door from inadvertently remaining open for an extended period thus reducing the hardness of the facility.

The evaluation of the shielding effectiveness as identified in Provision 5 for Level 4 ("*EM Barrier Hardness Validation Testing*") is not required for Level 3. Commercial radio signal techniques may be used to evaluate the shielding effectiveness or IEEE 299 can be used [see Reference 13]. This shielding effectiveness testing is only required for the acceptance of the shielded enclosure, as verification testing is not required (as it is in Level 4). Also, non-linear filter PCI testing may be performed in the laboratory and is not required to be performed on site (as it is in Level 4).

1. Six-sided EM shield barrier

The shield barrier can be constructed using 3-6 mm thick steel sheeting (or by using other shielding materials, such as aluminum or nickel composites) which provides the required level of shielding. *Shielding can be accomplished using a combination of bolt-together designs and welded designs.* If a large number of facilities need to be EMP protected, bolt-together designs that are carefully tested in the factory to meet the required protection levels are more economical.

Copper, aluminum, conductive plastics or other materials may be used if they can provide the required shielding effectiveness and are fully compatible with the POE protective treatments and grounding requirements. Steel is typically preferred because of its superior shielding effectiveness at lower HEMP/SREMP frequencies and its mechanical strength. Using metal screen or wire mesh for the barrier presents problems related to inadequate inherent shielding properties and problems posed in circumferentially bonding cable conduit, vent, and piping penetrations to mesh/screen materials.

2. Uninterruptible power supply (UPS) considerations

When selecting a UPS for protecting equipment from EMP, it is recommended that a true on-line, double-conversion type of UPS always be used as recommended in the Level 2 EMP Protection Guidelines. As this UPS will be installed inside the shielded volume in protection level 4, there is no concern over high frequency transient performance as they must be dealt with before entering the building shield. However, the UPS selected shall be tested against high harmonic currents and voltages (especially the 2nd harmonic), which is generated during E3 HEMP and/or GMD events.

Calculated Level 3 Mitigation Effects

Level 3 EMP Protection recommends a minimum of 30 dB of attenuation from a protective shield through 10 GHz. How much additional shielding may be required beyond 30 dB is best determined through an EM Threat Site Assessment Survey. Additional shielding may be required based on the facility's specific operational requirements including factors such as building construction, physical site layout, the types and amount equipment to be protected, and how distributed or contained the power systems and wired infrastructure are extended beyond the building or campus.

The figures that follow illustrate that just applying the minimum recommended level of 30 dB of attenuation can mitigate the EMP threat to typical cables and devices found inside almost every building. The upper models in each example show the unshielded directionally oriented effects from a 1000 kT burst at 250 miles (400 km) above the center of the continental United States. The bottom model in each example shows the survivable effect provided by 30 dB of shielding attenuation. In addition all external currents coupled to cables outside the building must be reduced before entering a building in order to prevent damage to equipment inside the building connected to those cables (e.g. power).

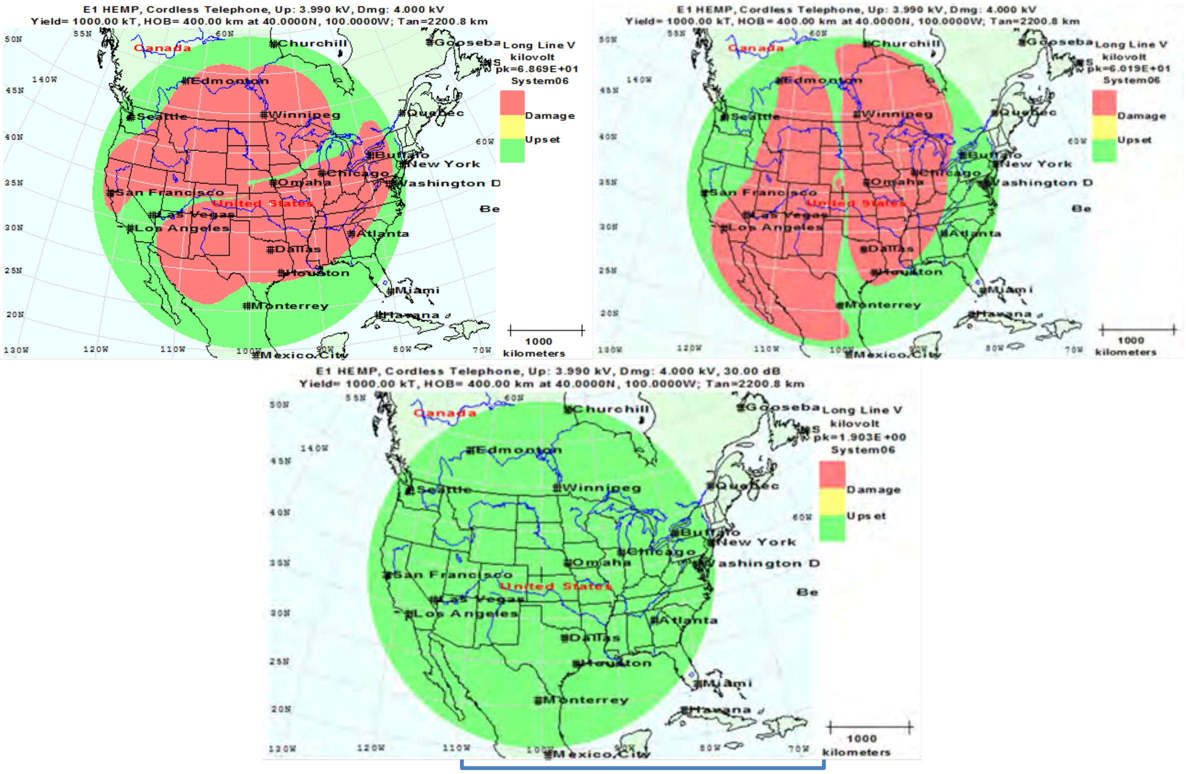


Figure 23. Protective effects on cordless telephones with recommended 30 dB shielding

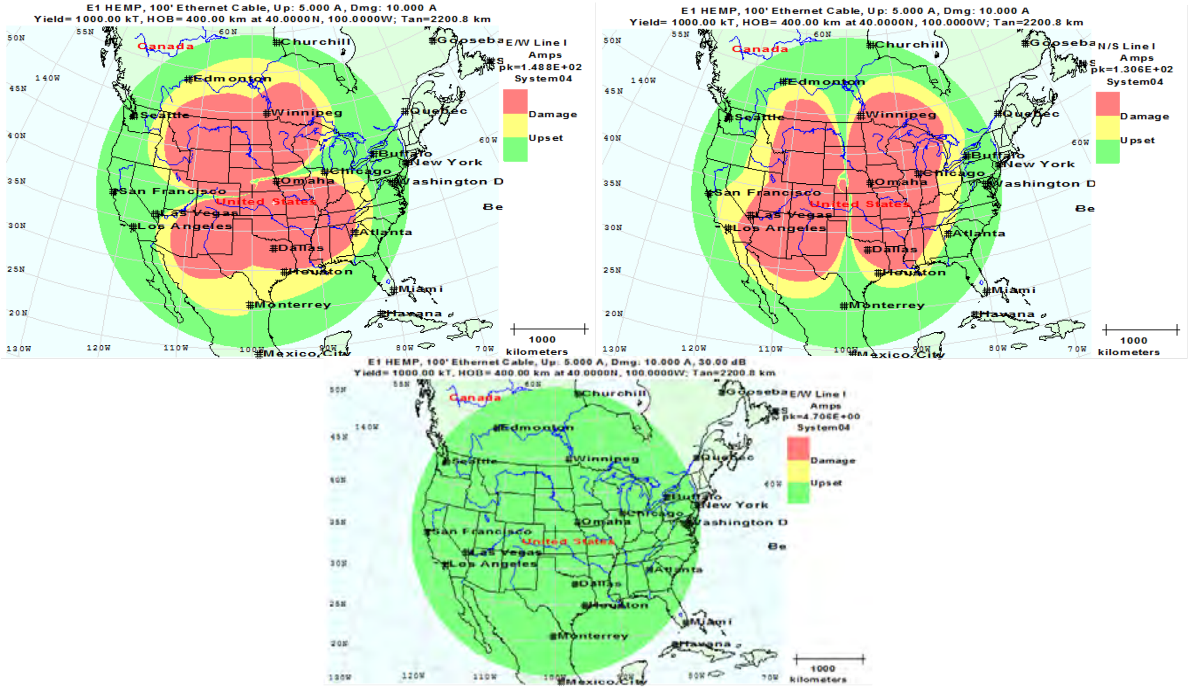


Figure 24. Protective effects on a 100' Ethernet cable with recommended 30 dB shielding

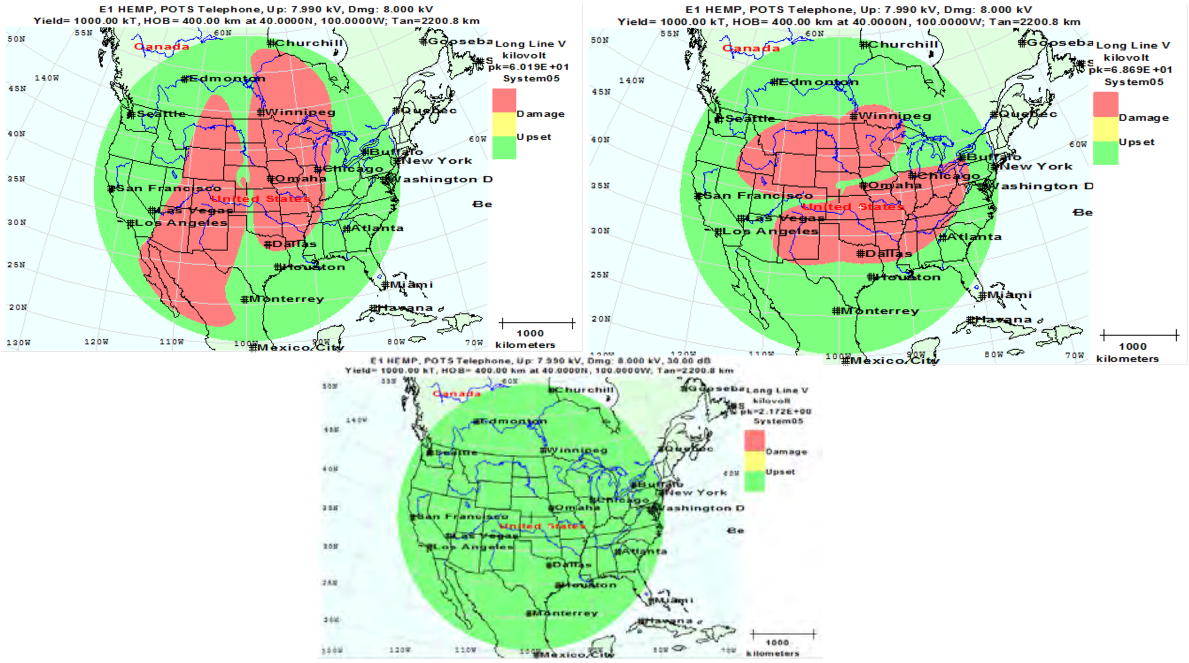


Figure 25. Protective effects on a Plain Old Telephone Service Line with 30 dB shielding

6. LEVEL 4 EMP GUIDELINES

Level 4: Only seconds of mission outages permitted

In addition to Level 3…

- Use Military HEMP Standards (MIL-STD-188-125-1 and MIL-HDBK-423), and 80+ dB hardening through 10 GHz.
- Use EMP shielding in rooms, racks, and buildings as needed to protect critical equipment.
- Use EMP protected double-door entryways.
- Validate per Military guidelines, like Test Operations Procedure (TOP) 01-2-620 HEMP.
- Have 30+ days of Military Standard protected power and fuel plus alternate generation source (renewables preferred).
- Consider double surge protection on critical external lines entering EMP protected areas.
- Consider using communications systems/networks that are designed to meet Military EMP standards, like: Advanced EHF (AEHF) satellite, EMP protected fiber optic networks, and EMP protected radios.
- Institute ongoing Military Standard HM/HS programs.

The military standard for the EM barrier design is MIL-STD-188-125-1 [see Reference 1], which specifies the following hardening program elements for the protection of HEMP:

1. The facility shield.

The facility EM shield is a continuous conductive enclosure that meets or exceeds specified shielding effectiveness requirements. In MIL-STD-188-125-1 this requirement is generally 80 dB up to 1 GHz. For this document we recommend that this requirement of 80 dB be extended to 10 GHz, which will also protect against the IEMI threat. In addition, this level and frequency range is achievable for shielded rooms constructed by industry today.

2. Shield points of entry (POEs) including wire penetrations, conduit/pipe penetrations, doors, and apertures.

The number of shield POEs shall be limited to the minimum required for operational, life-safety, and habitability purposes. Each metallic cable POE is protected with a current limiting device that satisfies the standard's performance requirements.

3. Double surge protect critical external lines entering EMP protected areas.

Redundant RF surge protection is required on critical external lines entering EMP protected areas in case either (1) the first SPD fails and continues to pass voltage or (2) the SPD is faulty and cannot stop the EMP pulse. In the first case with a double EMP event, the first burst could take out the primary SPD (or something like lightning could take it out), and without a secondary SPD the second EMP burst could take out critical equipment. In the case where the SPD is faulty, the SPD might simply pass an EMP pulse through the line into the equipment if there isn't a secondary SPD to protect the equipment. Lastly, two SPDs will block EMP better than one.

In the above cases, if the cable enters the building via a non-EMP protected area, then the primary SPD should be placed at the building egress with a secondary SPD connected to the cable either within the EMP area or immediately prior to it entering the EMP area. These guidelines are applicable to RF, data, and power cables.

4. **HEMP Shield and POE testing.**

The standard requires protection performance certification by testing. The protection program includes quality assurance during facility construction and equipment installation, acceptance testing for the EM barriers, and verification testing of the completed and operational facility.

5. **Life Cycle Hardness Maintenance and Hardness Surveillance (HM/HS).**

HM/HS is included in the facility planning, design, and construction phases to assure that hardness features stay intact over the life cycle of the protected facility and systems. The guidance provided for Level 4 Protection draws heavily on MIL-STD-188-125-1 and the accompanying implementation guidance provided in MIL-HDBK-423 [see References 1 and 2 in Appendix G].

Although the primary method used over the years for protecting equipment from the effects of a HEMP event is to enclose all critical equipment within a steel-shielded electromagnetic (EM) barrier, alternative methods exist including the use of shielded boxes interconnected by non-metallic lines including optical fiber or fluidic control lines.

Generally, an EM barrier for Level 4 Protection is constructed using metal plate (copper, aluminum, and/or steel walls, ceiling, and floor) with all seams continuously brazed or welded. To be complete, the barrier must include treatments on all penetrations to limit currents on the penetrating cables and the EM fields incident on doors, windows, vents, and pipes. Figure 26 provides a conceptual representation of a complete EM barrier. For the shield portion of the barrier, steel plate is preferred over copper for the bulk of the construction because of its superior shielding effectiveness at lower frequencies and its mechanical strength. MIL-STD-188-125-1 provides more detailed requirements for EM barrier construction. Additional information on construction of EM protected facilities is also provided in the following military standards, as referenced in Appendix G:

- MIL-STD-785 addresses reliability
- MIL-STD-470 addresses maintainability
- MIL-STD-2165 addresses testability
- MIL-STD-729 addresses corrosion control

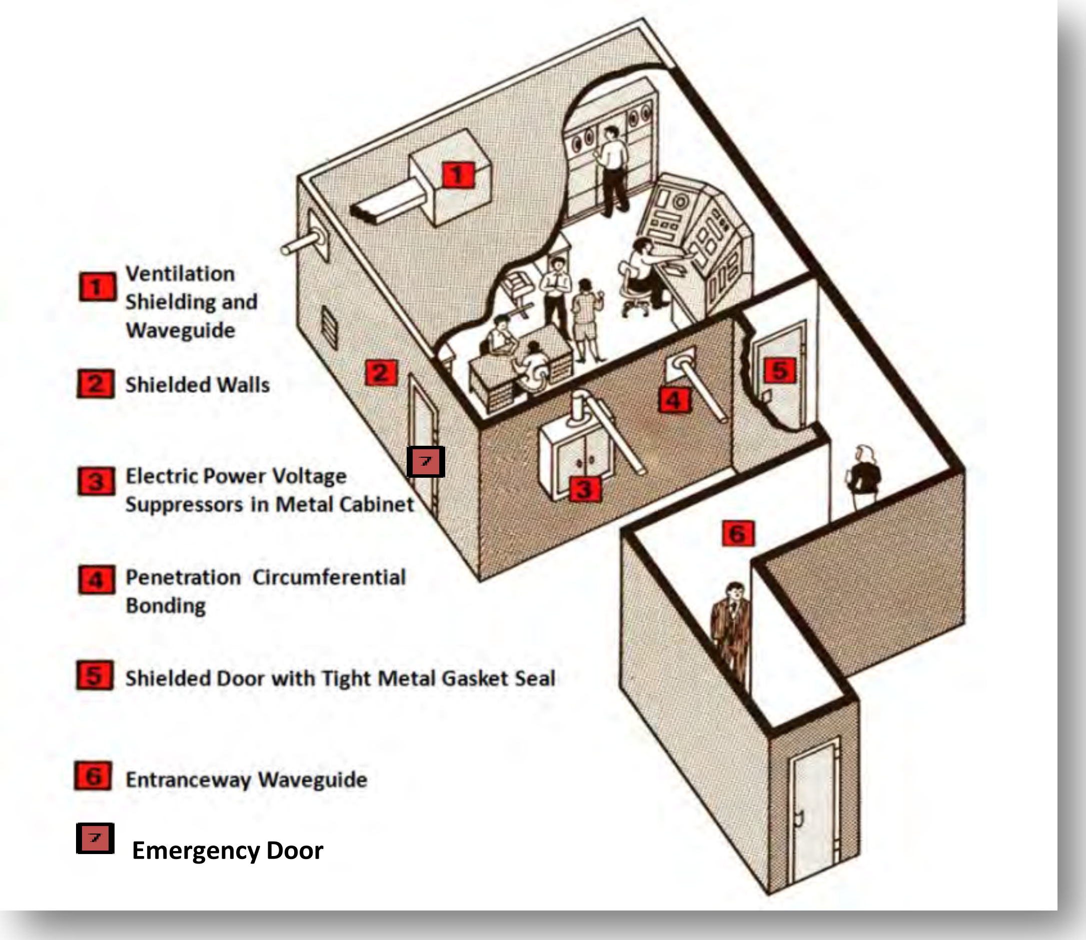


Figure 26. Low-risk EMP barrier protection for facilities (per MIL-STD-188-125-1)

The installation of an EM protection barrier provides a level of immunity to multiple EM environments for electronic equipment. Specifically, the EM barrier provides a shield against EMP and helps accomplish the following:

- Protects MC systems from harmful EM fields.
- Diverts HEMP, SREMP radiating fields and lightning currents to ground.
- Provides immunity to external EMI and IEMI environments,
- Contains classified emissions, which provides Transient EMP Emanation Standard (TEMPEST) protection.
- Provides a sharing path for GMD long-line currents.
- Acts as an excellent ground for internal systems, and, if good contact is made with earth ground, an excellent grounding surface for nearby external systems.

Note that the building surface that in contact with the earth or concrete provides a very low inductance to ground. This is desirable for HEMP and IEMI. Ground rods have high inductance, and while necessary for lightning, are of limited help against high frequency transient phenomena.

The EM barrier provides an EM isolated environment that enables commercial-off-the-shelf (COTS) equipment and systems with no special EM protection to be incorporated within the shielded facility. If the shield is maintained over time, the EM barrier greatly simplifies interior system upgrades and configuration management as systems are moved or replaced. This shifts the focus of system configuration control to maintaining the integrity of the EM barrier.

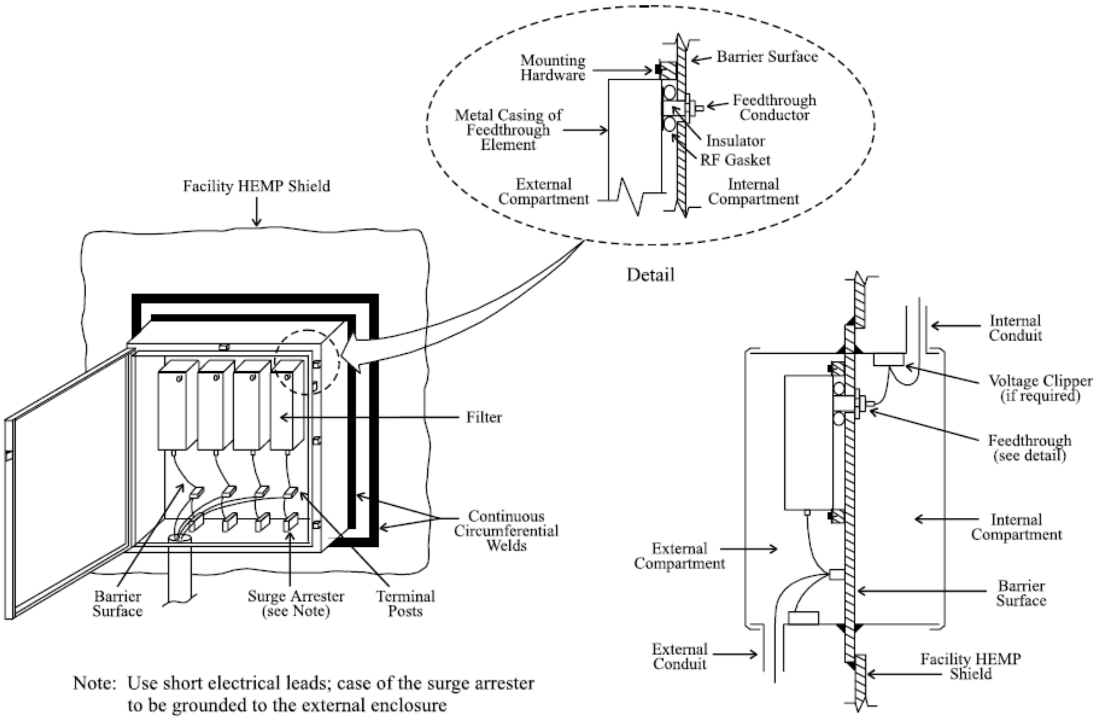
6. Six-sided EM shield barrier

Shielding will be in accordance with MIL-STD-188-125-1 [see Reference 1], and related military standards. The shield barrier should be constructed using 3-6 mm thick welded steel sheeting, which provides at least 80 dB of shielding. Copper or other materials may be used if they can provide the required shielding effectiveness and are fully compatible with the POE protective treatments and grounding requirements. Steel is preferred because of its superior shielding effectiveness at low frequencies and its mechanical strength. Using metal screen or wire mesh for the barrier presents problems related to inadequate inherent shielding properties at lower and higher frequencies and presents problems relating to circumferentially bonding cable conduits, vents, and piping penetrations to mesh/screen materials.

7. Protection of barrier breaches and cable/piping points of entry (POEs)

Treatment of Protection Barrier Breaches and POEs will be in accordance with MIL-STD-188-125-1 [1], and related military standards. The number of shield breaches and cable/piping POEs should be limited to the minimum required for mission operation, life-safety, and habitability purposes. As a design objective, there should be a single penetration entry area on the EM barrier for all piping and electrical POEs except those connected to external conductors less than 10 m (32.8 ft.) in length. To eliminate cross coupling, the penetration entry area should be located as far from normal and emergency personnel and equipment accesses and ventilation breaches in the shield, as is permitted by the facility floor plan. Each POE should be "treated" with a POE protective device. Guidance for specific types of penetrations follows.

Electrical POEs. EM protection for electrical POEs, including all power, communications, and control penetrating conductors whether shielded or unshielded, should be provided with main barrier transient suppression/attenuation devices. The main barrier transient suppression devices should consist of filters (linear elements) and surge arresters (nonlinear elements), as required to satisfy the shielding effectiveness requirements and residual transient limiting requirements. Figure 27 illustrates a typical cable POE protection design including filters and surge arresters. POE protection should be installed in a manner that does not degrade the shielding effectiveness of the facility EM shield.



Note: Use short electrical leads; case of the surge arrester to be grounded to the external enclosure

Figure 27. Typical cable POE protection design

In the case of audio and data line penetrations through the shield, it is highly recommended that fiber-optic signal lines be used exclusively. Likewise, if possible, bring radio antenna signals into the barrier-protected space using fiber optic cables by employing copper-to-fiber converters outside of the barrier, preferably as close to the antenna as possible to minimize loss and reduce EMI. In all cases, fiber optic cables that penetrate the shield must use a metallic waveguide-below-cutoff (WBC) entry. In the case of copper-to-fiber converters outside the barrier, these converters must either be hardened to EMP or the communication system must not be a critical one, as the converter is likely to be damaged.

With regard to electrical power service and associated barrier penetrations, the facility should be provided with a backup EM-hardened electrical power generation and distribution capability sufficient to perform missions, without reliance upon commercial electrical power sources. In cases where external power sources are necessary or if internal power sources are used to power external equipment, individual power feeder lines must be protected by installing an electrical surge arrester (ESA) and MIL-STD-188-125 tested low pass filter within a shielded compartment or "ESA vault" (see Figure 28) at both ends of these power cables. To prevent the enterprise-side MOVs from shorting or blowing up, fuses or circuit breakers should be placed in series with each phase line between the Distribution Transformer and the Filter/ESA Enclosure (these are not shown). The facility should be designed to operate for more than 30 days for this protection level using backup power in case the external transformers are damaged.

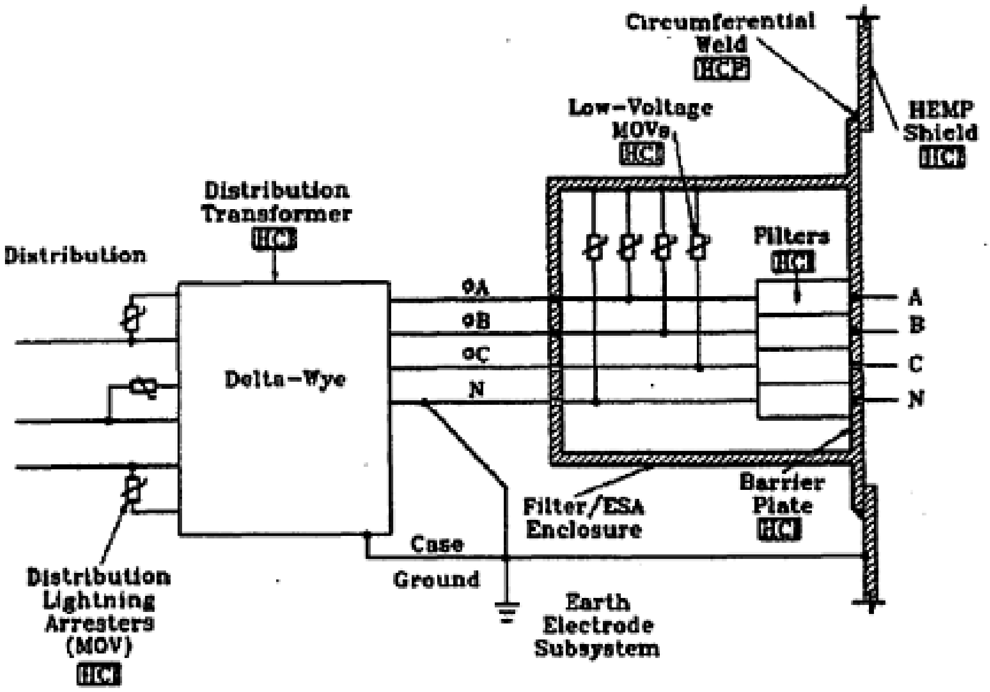


Figure 28. Commercial electric power POE protection

Metallic commercial power entering a critical facility or room that is closer than 50 miles from an urban center with 50,000 or more people (and hence, more likely to be subject to SREMP long line current threats) should be electrically isolated from the power grid. This can be accomplished through either physical separation (disconnection while operating on backup power during periods of heightened threats) or through the use of both an isolation transformer and the use of motor generators outside of the shielded facility or room, etc. As an alternative, fuel cell power technology has been considered in the past for this problem with the fuel passed through the shield.

See Figure 29 to see an example of a power line POE protection approach using a motor-generator set. The input power connection drives a motor external to the EM barrier shield connected to a generator by a dielectric shaft penetrating the shield wall within a WBC. A typical installation would use a flywheel on the motor to electromechanically filter power line disturbances and provide a short, few second UPS function. The primary advantage of a motor-generator set is that there are no metallic power penetrations through the shield. As a result, the motor-generator set provides protection against SREMP, injection-type EM weapons, as well as HEMP (although the essential need for this type of protection is for SREMP). If properly maintained, a motor-generator set can last for more than two decades. The only requirement is to protect the motor against naturally occurring power line transients, such as lightning. This can be accomplished with a Transient Voltage Suppression System (TVSS) usually consisting of MOVs installed at the power input to the motor. In addition, the power line entry to the external motor and any external controls for its operation must be protected against the full set of EMP transients. This is also true if a fuel cell system were used.

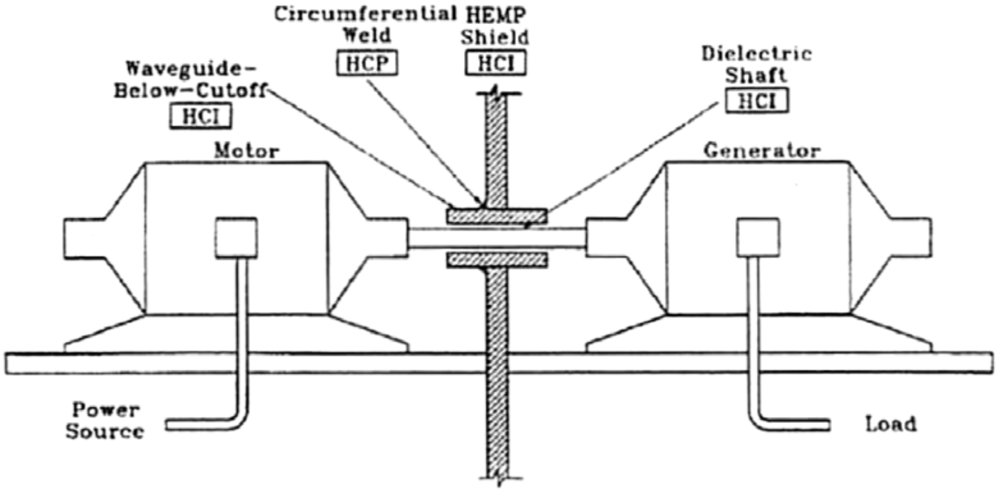


Figure 29. Power line POE protection using a motor-generator set

Personnel and utility breach-type POEs. For personnel entryways, two designs are permissible. The first uses double doors separated by a shielded waveguide-below-cutoff (WBC) vestibule as illustrated in Figure 30. This design provides additional protection for frequencies below ~50 MHz, although for higher frequencies the waveguide alone is not sufficient.

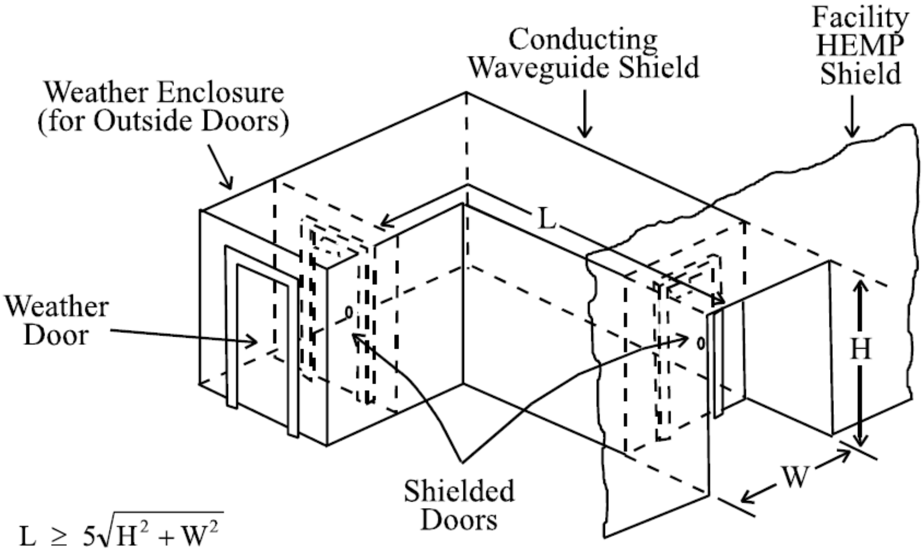


Figure 30. Entryway using two doors separated by a WBC [14]

Figure 31. Sample door with gaskets protecting against EMP threats

The second option uses two doors separated by a metal-enclosed vestibule preferably with an interlock to ensure that only one door is open at a time (including a door interlock). The interlock is needed to ensure that E1 HEMP fields above 50 MHz do not scatter through the waveguide and that the IEMI fields that extend up to 10 GHz do not enter the Facility HEMP Shield when both doors are open (a sample outer door is shown in Figure 31 on the left). This approach is the best in order to deal with all of the EMP threats. In either case, inflatable gaskets or metal fingerstock should be used to ensure electromagnetically tight door.

In the case of barrier penetrations to accommodate utility pipes and conduits, one should circumferentially weld any metal pipe or conduit penetrations at the exterior surface of the metal shield. Waveguide-Below-Cutoff (WBC) designs for air vents and pipes are illustrated in Figure 32 and Figure 33. The cutoff frequency for air filled waveguides can be estimated as f_c (Hz) = $1.5 \times 10^8 / d$, where d in meters is the largest dimension of a rectangular waveguide or the diameter of a circular waveguide. Given the cutoff frequency, the length of the waveguide needs to be greater than 5 times the largest transverse dimension of the waveguide.

It should be noted that for ventilation pipes, while a 10 cm diameter is adequate for HEMP purposes, waveguide dimensions of 1 cm are needed to protect against IEMI threats. Industry typically makes ventilation waveguides that are effective up to 18 GHz, satisfying IEMI and TEMPEST requirements in addition to E1 HEMP. In most cases, even if TEMPEST is not a requirement, the use of 1 cm diameter waveguide meshes create less of a mechanical stress on the shield walls, but if hot exhaust is an issue, then the typical 18 GHz meshes cannot be used if they are made from Aluminum, which cannot withstand high temperatures. In addition, small diameter waveguide meshes will likely require some oversizing of the entire mesh to overcome the air resistance factor.

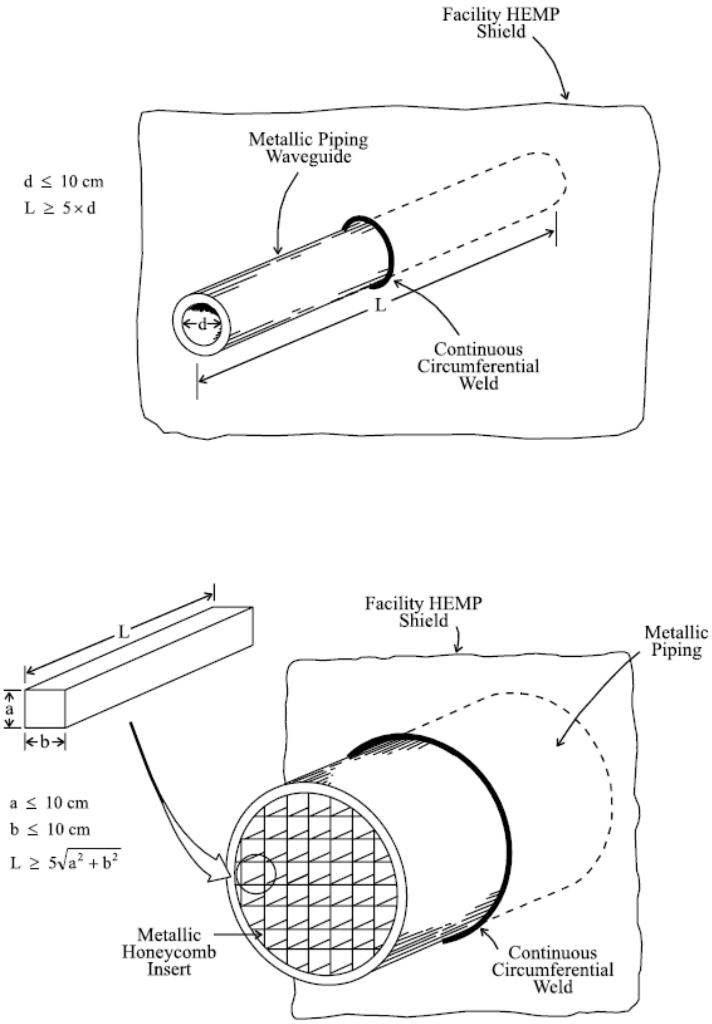
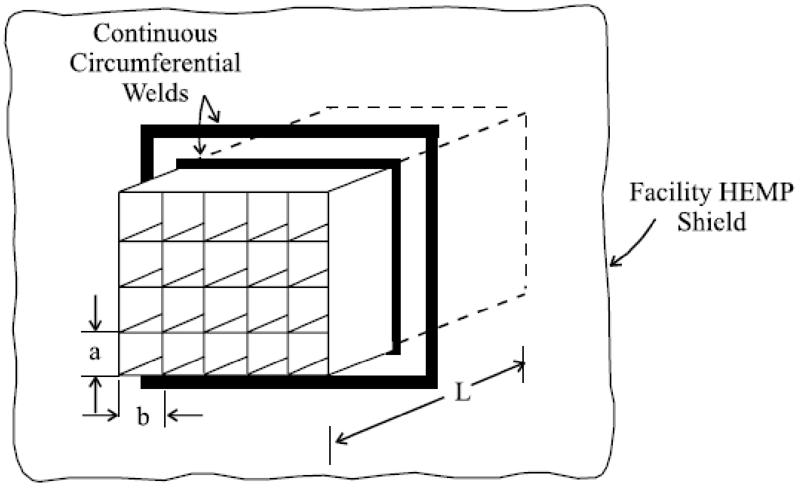


Figure 32. Typical waveguide-below-cutoff (WBC) piping POE protective design for E1 HEMP



$a \leq 10$ cm

$b \leq 10$ cm

$L \geq 5\sqrt{a^2 + b^2}$

Figure 33. Typical waveguide-below-cutoff ventilation POE protective design for E1 HEMP [15]

8. Designation of Mission Critical (MC) Systems

MC Systems include such items as communications electronics equipment, data processing equipment, supervisory control and data acquisition (SCADA) systems, local portions of hardened network interconnects, and critical support subsystems such as power generation, power distribution, transformers, and environmental control systems. All MC Systems, with the exception of equipment that must access the external environment (e.g. antennas, heat exchangers), should be installed within the EM barrier.

EM special protective measures include additional shielding, additional transient suppression/attenuation devices, fiber optic cables, and equipment-level protection required to achieve EM hardness. To facilitate life cycle system hardness, maintenance, surveillance, and configuration management, it is important to minimize the number of subsystems requiring special protective measures. The three categories requiring special protective measures are as follows:

- MC Systems that must be located outside the EM barrier and, therefore, are not protected by the barrier (e.g., cables, radio antennas, evaporative heat exchangers).
- MC Systems that are enclosed within the EM barrier and experience mission aborting damage or upset during verification testing, even though the barrier elements satisfy all performance requirements. (It is noted that this is an exceptional situation that normally indicates that there is in fact a failure of a barrier element.)
- Special protective volumes and barriers to provide supplementary isolation when POE protective devices cannot satisfy the barrier requirements without interfering with facility operation. (This often occurs when it is not possible to prevent in-band HEMP, SREMP or IEMI penetration on antenna lines leading to a transmitter inside the barrier; in this case it is recommended to build a special shielded area for the transmitter equipment inside of the barrier.)

9. EM shield barrier grounding

The barrier grounding practices described here apply to HEMP, SREMP, EM weapons, and lightning. The grounding required for these effects are part of the total facility-grounding network with the ultimate path to ground being the earth electrode subsystem. The lightning subsystem and its earth grounding electrode subsystem are the main interfaces with the EM protection system. It is important that the grounding system be properly designed and constructed to provide the most direct and lowest possible impedance to the earth ground at all frequencies of interest.

The barrier shield exterior should be multi-point grounded to a buried earth electrode system at the corners of the barrier and at 20 foot intervals around the perimeter of the barrier [7-8] (see Figure 34). This approach is particularly important if the shield barrier is not in direct contact with the soil under the facility (when there is soil contact, the shield is grounded in a low inductance fashion providing an excellent path for high-frequency currents on the shield to flow to ground). This buried earth electrode system should also be used as the common ground counterpoise for the EM protection systems of external equipment. Ground straps or cables used to connect the barrier shield to the earth electrode subsystem should be electrically bonded to the external surface of the barrier shield. At least one such low-inductance ground strap, cable or plate should be located at each penetration entry area. Grounds for equipment and structures outside the barrier shield should be electrically bonded to the outside surface of the barrier shield or to the buried earth electrode subsystem.

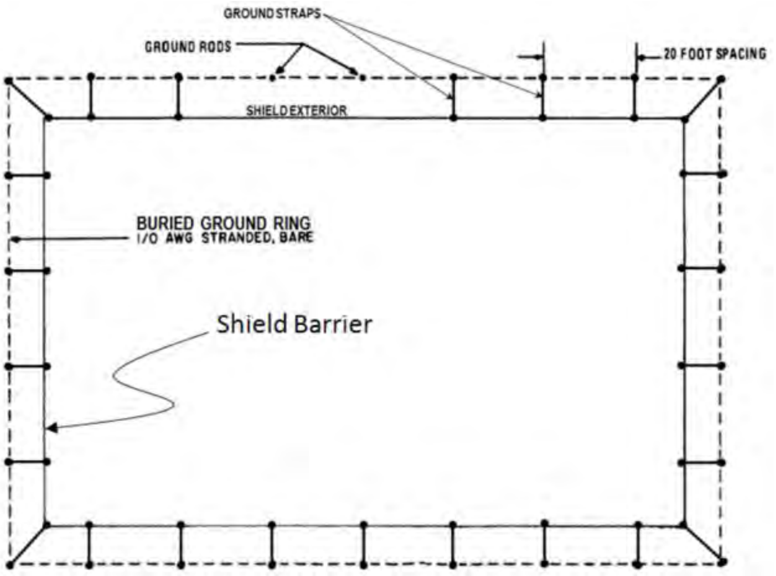


Figure 34. Shield barrier earth electrode system

Grounds for equipment and structures enclosed within the protected volume should be electrically bonded to the inside surface of the shield. Internal equipment should be single-point grounded to the inside of the barrier shield to avoid inductive ground loops, although this aspect is not critical if the shield reduces the external fields correctly. It is a concern for equipment not inside of a shielded volume. All grounding connections to the facility EM shield should be made in a manner that does not create POEs by breaching the shield.

10. EM Barrier Hardness Validation Testing

EM barrier testing is important to ensure the integrity of the shield and the POE protection. The testing should include quality assurance testing during facility construction and equipment installation, acceptance testing for the EM barrier and special protective measures, and verification testing of the completed and operational facility.

Initial EM protection acceptance testing. Initial certification of the EM barrier protection effectiveness should be based upon successful demonstrations of compliance with shielding effectiveness (SE) tests for the barrier and pulsed current injection (PCI) tests of all conducting penetrations. Initial acceptance tests of the EM barrier and special protective measures should be conducted after all related EM barrier shield and PoE construction work has been completed. Initial acceptance test procedures and results should be documented and retained for use as hardness maintenance and hardness surveillance (HM/HS) baseline configuration and performance data.

Operational verification testing. After completion of the EM protection subsystem and installation, operational checks, and installation/acceptance of all system equipment, the EM hardness of the facility should be verified through a program of tests and supporting analysis. The verification program should result in a definitive statement that the critical time-urgent mission functions of the barrier and its contents are certified to withstand exposure to the EM environments of concern. Verification test procedures and results should also be documented and retained for use as hardness maintenance and surveillance (HM/HS) baseline configuration and performance data.

Validation testing types. Both initial acceptance testing and operational verification testing include (1) shielding effectiveness tests, (2) pulsed current injection testing of all electrical POEs and (3) grounding system tests.

(1) **Shielding effectiveness testing is** used to certify that the facility EM shield, with all POE protective devices installed, provides at least the minimum shielding effectiveness shown in Appendix A, Figure A1 for HEMP (80 dB up to 1 GHz). This protection level is sufficient for the radiated fields associated with HEMP and SREMP. To extend the protection to encompass the threat of EM weapons producing IEMI, it is recommended that the shielding effectiveness requirement be extended at the 80 dB level up to 10 GHz. Shielding effectiveness testing should be conducted with barrier POEs and their protective devices in a normal operating configuration, using shielding effectiveness test procedures described in Appendix A of MIL-STD-188-125-1 [1].

(2) **HEMP pulsed current injection (PCI) testing** is well prescribed and involves injecting the pulses prescribed in Appendix A, Table A1 of this document for each electrical POE. This baseline testing for HEMP gives confidence that POE protection will withstand HEMP, radiated SREMP and EM weapon threats up to 1 GHz. To extend the PCI testing to higher frequencies, the IEC has developed test waveforms for EM threats above 1 GHz [9]. The EM barrier passes the test if the POE protective devices attenuate voltages and currents measured inside the shield to the upper bound levels prescribed for each class of electrical POE (as provided in Appendix A, Table A2). Additionally, the main barrier protective device should be rated to withstand a sufficient number of test pulses at the prescribed peak injection current without damage or unacceptable performance degradation to accommodate life cycle testing.

(3) **Ground system testing.** The resistance to earth of the earth electrode subsystem should be tested using the fall-of-potential method. The completed grounding system should be "Megger tested" at the service disconnect enclosure grounding terminal, and at earth electrode system ground test wells. Measure ground resistance not less than 2 full days after the last trace of precipitation, and without the soil being moistened by any means other than natural drainage or seepage and without chemical treatment or other artificial means of reducing natural ground resistance. It is recommended that the tests be performed using the two-point method according to IEEE 81, "Guide for Measuring Earth Resistivity Grounding Impedance and Earth Surface Potentials of Ground Systems." Unless otherwise specified by facility drawings, the earth ground resistance should be 10 ohms or less.

11. Hardness Maintenance and Hardness Surveillance (HM/HS)

A built-in test capability should be installed to at least qualitatively monitor for EM shield leakage. The built-in shield monitoring system should include:

- Radiating antenna(s) external to the barrier shield
- Receiving antenna(s) internal to the shield
- Test control, antenna source, and data analysis electronics inside the shield

To facilitate HM/HS, the barrier shield design should include a crawl space underneath the shield floor to enable inspection for floor plate defects due to maintenance or corrosion and shielding effectiveness testing. On the other hand, if the barrier shield floor can be constructed in direct contact with the soil, high frequency currents induced on the other 5 sides of the shield will be severely attenuated at the soil/barrier interface.

12. Treatment of Mission Critical (MC) Systems outside the EM barrier

For MC Systems that must be located outside of the barrier shield, special protective measures should be implemented to ensure effective EM protection. Special protective measures for MC Systems outside the main barrier may include:

- Cable, conduit, and local volume shielding
- Use of fiber optic cables for signaling
- Linear and nonlinear transient suppression/attenuation devices
- Equipment-level hardening (reduced coupling cross-section, dielectric means of power transport, use of inherently robust components)
- Moving sensitive circuits associated with external MC Systems to locations within the protected volume
- Automatic recycling features or operator intervention schemes, when the mission timeline permits
- Other hardening measures appropriate for the particular equipment to be protected

Performance requirements for the special protective measures should ensure that the highest EMP-induced, peak time domain current stresses reaching the equipment are less than the vulnerability thresholds of the equipment.

RF communications antennas outside the main EM barrier and any associated antenna-mounted electronics, tuning circuits, and antenna cables located outside the main electromagnetic barrier should be treated as MC Systems that are placed outside the EM barrier. Performance requirements for the EM protection should ensure that the highest EM threat-induced peak time domain current stresses at the antenna feed are less than the vulnerability thresholds of the MC Systems located outside the barrier.

Front door in-band protection is one of the more challenging (but not insurmountable) EM protection problems. The high gains associated with most "front door" coupling paths make these potentially the most susceptible portion of radio communication systems. However, these well-characterized front door receive paths have been the subjects of much attention in terms of protection engineering. Radar systems are often protected from their own or neighboring transmitters by a receiver protector or RP. Similar protection can be applied to communication receivers against in-band EM weapon environments. A typical RP uses plasma and diode limiter stages. At a given threshold the most sensitive diode turns on, forming a shunt across the waveguide. At higher energies, the other stages activate in parallel. The plasma "vial" stages turn on at the highest powers through a process similar to air breakdown and are capable of diverting large amounts of energy to ground without damage. Most vial limiters use halogen gas as the breakdown medium. If the system is transmitting, it will be necessary to unkey the transmitter to extinguish the ignited plasma devices. As an example, the schematic of a Westinghouse RP design is provided in Figure 35.

Effective and robust waveguide filters are available for out-of-band front door EM weapon environments. The challenge is to provide protection at the same time minimizing insertion loss effects on normal operation.

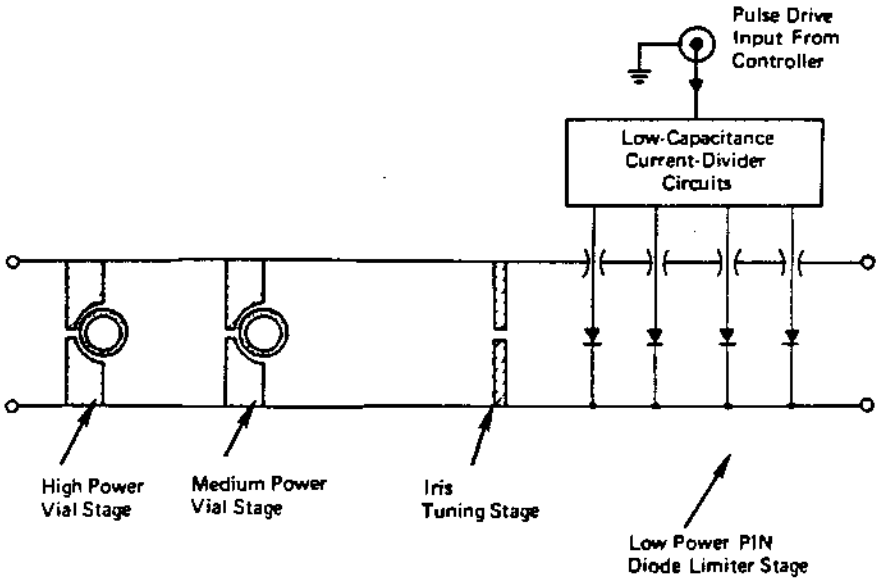


Figure 35. Example receiver protector unit diagram.

13. Special protective volumes

Special protective volumes for piping POEs. As discussed earlier in this section, when a pipe POE diameter must be larger than 1/5 of the pipe's length and a WBC array insert cannot be used, a special protective volume should be established inside the EM barrier. The protective volume should include a special protective barrier that should completely enclose the non-compliant piping. The protective volume should be protected at the barrier shield outer wall using the WBC technique having a cutoff frequency of at least 1.0 GHz for HEMP and SREMP, but should extend to 10 GHz for IEMI and 18 GHz for TEMPEST. The special protective barrier may be a separate shield with protected penetrations, or it may be implemented by extending the metal walls of the piping system itself as shown in the figure below. Performance requirements for the special protective barrier should ensure that the total shielding effectiveness, measured through the main EM barrier and special protective barrier, satisfies at least the minimum requirements shown in Appendix A, Figure A1.

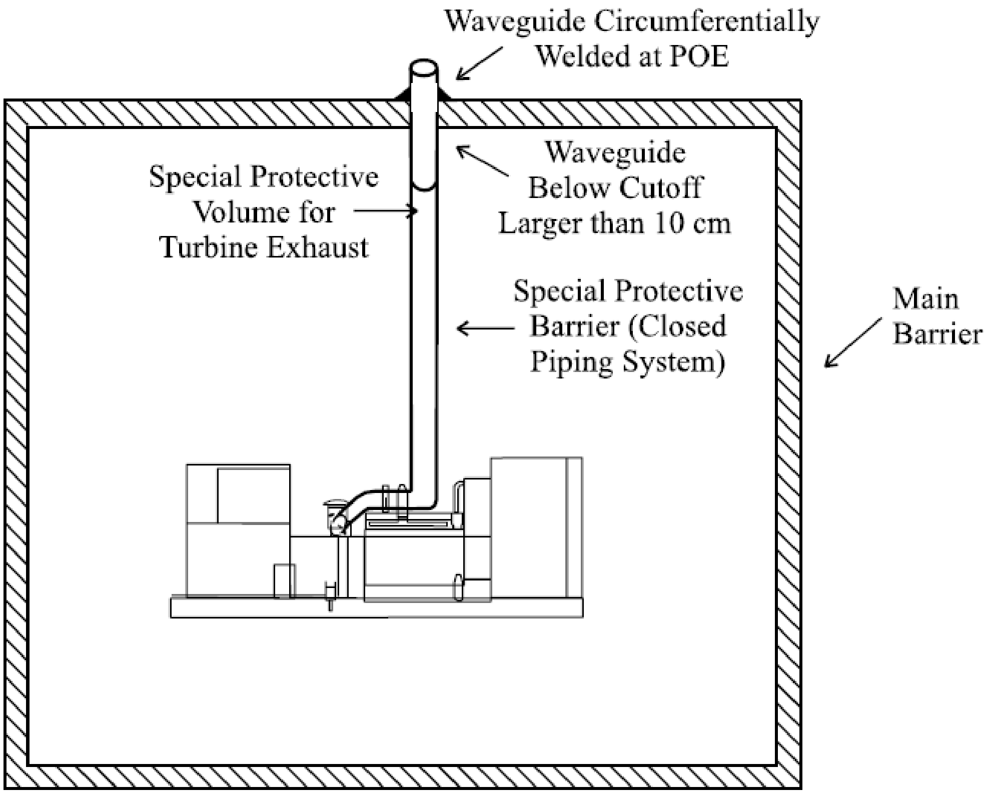


Figure 36. Special protective volume for piping POE for E1 HEMP

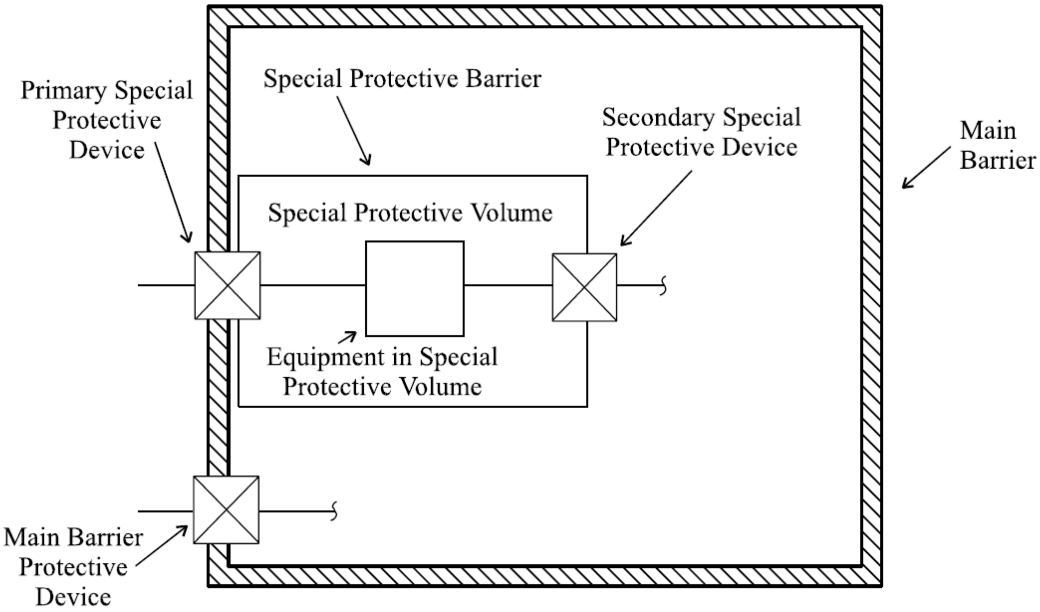


Figure 37. Special protective volume for electrical equipment

Special protective volumes for **electrical** POEs. When a main barrier protective device cannot be designed to achieve the transient suppression/attenuation performance prescribed for the particular class of electrical POE without interfering with operational signals it is required to pass, a special protective volume should be established inside the main EM barrier as shown in Figure 37 above. A special protective volume should be enclosed by a special protective barrier with primary and secondary special electrical POE protective devices, as required to meet the performance requirements prescribed. The special protective barrier should completely enclose wiring and equipment directly connected to a primary special electrical POE protective device. The special protective barrier may be a separate shield, or it may be implemented using cable and conduit shields and equipment cabinets. Performance requirements for the special protective barrier should ensure that the total shielding effectiveness, measured through the main EM barrier and special protective barrier, satisfies at least the minimum requirements shown on Appendix A, Figure A1 (*HEMP Shielding Effectiveness Requirement*).

Secondary special electrical POE protective device requirements. When the combination of the primary special electrical POE protective device and the directly connected equipment cannot be designed to achieve the transient suppression/attenuation performance prescribed for the class of electrical POE (per Appendix A, Table A2), a secondary special electrical POE protective device should be used. The secondary special electrical POE protective device should be designed so that the total transient suppression/attenuation, measured through the primary special protective device, the connected equipment, and the secondary special protective device, satisfies at least the minimum requirements prescribed for the class of POE without device damage or performance degradation.

MC Systems in a special protective volume. Special protective measures should be implemented as necessary to harden MC Systems in a special protective volume to the EM-induced stresses that will occur in that volume. Special protective measures for MC Systems in a special protective volume may include the use of the following:

- Cable, conduit, and volume shielding
- Fiber-optic cables
- Transient suppression/attenuation devices
- Equipment-level hardening
- Remote locating of sensitive circuits
- Automatic recycling or failover
- Operator intervention features
- Other hardening measures appropriate for the particular equipment to be protected.

Performance requirements for the special protective measures should ensure that the highest EM-induced peak time-domain current stresses reaching the equipment are less than the vulnerability thresholds for the equipment. Adequate WBC EM attenuation occurs if the length (L) is greater than $5\sqrt{H^2+W^2}$ where H is the height and W is the width of the conduit or passageway.

14. Special Protection at the box level

While a facility-level barrier ("global" shielding and POE protection) is preferred, there are situations where box-level protection can be used. A conceptual diagram of global vs. box-level protection appears below in Figure 38.

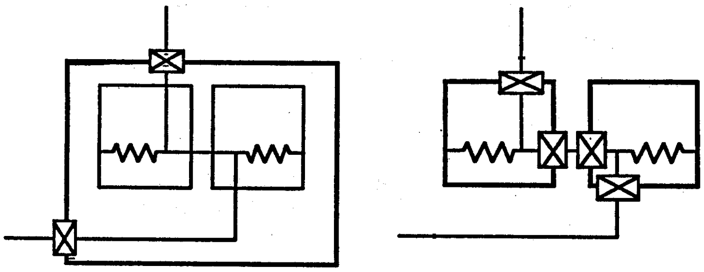


Figure 38. Global barrier vs. box-level protection

A complete facility EM barrier provides the best protection. Its effectiveness is easy to verify using CW field illumination, which facilitates initial protection certification and HM/HS activities. It is the preferred method for critical systems where internal electronic boxes are being changed or upgraded often. It has been successfully implemented for the HEMP protection of the U.S. backbone communication and strategic missile systems. However, for many systems global shielding may impose unacceptable cost and weight increases.

Alternatively, a combination could also be implemented where a 30 dB or more shielded facility is used for equipment and cables that are less important or less sensitive. An additional EM barrier of 50 dB or more in this example could then also be used for more important or more sensitive equipment.

Box level protection can be very effective, especially in the case where only a few pieces of equipment are critical. Well-designed electronic boxes using RF gaskets and cable treatment have been demonstrated to be very effective to the point that internally coupled RF levels are indistinguishable from noise levels. Non-fiber optic cables must be well shielded with high quality connectors circumferentially bonded to the cable shield. Box level hardening techniques are depicted below in Figure 39.

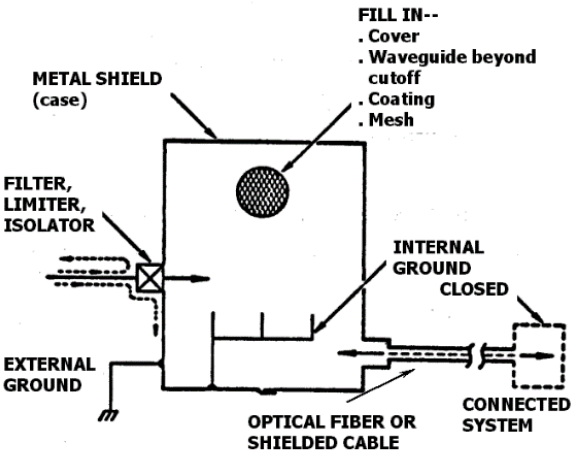


Figure 39. Box-level hardening techniques

15. Multiple shielded buildings or shielded volumes connected by conduits

EMP protection for cables running between two shielded facilities or rooms may be provided by using continuous conduit shielding or highly shielded and tested cables, when the lengths of the runs do not exceed the applicable maximums provided in Table 10 that follows.

Table 10. HEMP Specifications for Cable Runs Between Two Protected Areas

Type of Cable Run and Conduit	Maximum Conduit Length (m)		
	5 cm ≤ OD < 10 cm	10 cm ≤ OD < 15 cm	15 cm ≤ OD
Signal and Low Current Power Lines			
Buried Conduit	37	75	112
Nonburied Conduit	6	12	18
Medium Current Power Lines			
Buried Conduit	200	600	1120
Nonburied Conduit	60	120	180
High Current Power Lines			
Buried Conduit	200	600	1,200
Nonburied Conduit	200	600	1,200

Table Definitions:

(1) **Signal Line**: Contains one or more control or signal conductors.
(2) **Low Current Power Line**: Contains one or more conductors with maximum operating currents less than 1.0 A.
(3) **Medium Current Power Line**: The maximum operating current on the lowest rated conductor is between 1.0 A and 10 A.
(4) **High Current Power Line**: Contains only power lines with operating currents greater than 10 A.
(5) **Buried Conduit:** No more than 1 m (3.3 ft.) of its total length is not covered by earth or concrete fill.
(6) **Nonburied Conduit**: More than 1 m (3.3 ft.) of its total length is not covered by earth or concrete fill.

Main barrier ESAs and filters are not required on the penetrating conductors under conditions where cable runs are shorter than shown in the previous Table and the conduit or cable is bonded to the shields at both ends.

Some design and certification test requirements are shown below. Additionally, "*Figure 40. EMP protected conduit*" on the right shows as a sample conduit running from an EMP filtered area to a 120 dB EMP protected container.

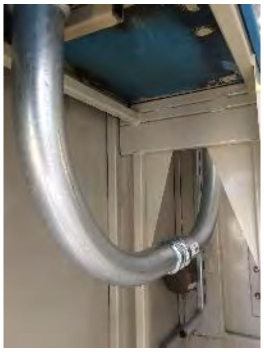


Figure 40. EMP protected conduit

- Conduit design requirements. EMP protection conduits should be rigid metal conduits, with circumferentially welded, brazed, or threaded closures at all joints and couplings, pull boxes, and at both ends of penetrations through the facility EMP shields.
- Conduit certification test requirements. A pulsed current injection (PCI) source, producing an 800-A short-circuit current on a buried signal or low current power line conduit and a 5000-A short-circuit current on a non-buried signal or low current power line conduit, 20 ns risetime and 500-ns pulse width (full width at half maximum), and source impedance ≥ 60 Ω, should produce a residual internal transient stress no greater than 0.1 A on the wire bundle inside the conduit.

The same PCI source connected on the outer surface of a medium or high current power line conduit should produce a residual internal transient stress no greater than 10 A, when the operating current on the lowest rated conductor in the wire bundle inside the conduit is greater than 10 A, and no greater than 1.0 A when the operating current is between 1.0 A and 10 A.

If a multi-conductor shielded cable can be tested in the laboratory to the pulses described in the second bullet above, and it can achieve the required peak residuals, then a shielded cable can be used instead of a conduit.

7. HEMP MODEL MITIGATION RESULTS

This section uses a HEMP protection effectiveness model based upon: IEC recommendations, known nuclear yields by nuclear-capable countries, and real-world testing of commonly used cables and equipment. This model was developed to better understand the ramifications of a HEMP attack and how much protection is needed to prevent damage or upsets (resetting the device). This protection would also be critical for SREMP and IEMI attacks. The model showed that even though minimal protection of 10 dB helps significantly, 20 dB is much more helpful, and 30 dB eliminates almost all damage.

The above is excellent news since 10 dB can often be met simply by following good lightning protection practices, including ensuring low inductance ground connections. 20 dB can generally be met and sometimes 30 dB can also be met by making small, inexpensive modifications. These EMP improvements include using EMP rated SPDs, adding ferrites, burying external cables, and moving operations toward the middle of a building perhaps in the basement with more walls between the cable runs and the potential HEMP burst.

These simple EMP related changes or additions could substantially reduce the risks associated with an EMP attack and prevent it from devastating the country.

7.1. Model Assumptions

This section discusses the results of an EMP model that was created to better understand the relationship between improved EMP protection and decreased equipment damage and upsets. The key parameters in the model are shown in Table 11 below.

Table 11. Modeling Parameters Used to Calculate HEMP Damage

Parameter	Assumption
Nuclear Yield	100 kiloton (kT) or a peak field of 50 kV/m (peak field is per IEC recommendation)
Height of Burst	400 km (about 250 miles) (per IEC recommendation)
Latitude and longitude of burst	40.0 North, 100.0 West
100 ft. Ethernet	• 0.1m height over ground; aligned radially • Current into 100 ohms • Maximum of calculations for 0.01 S/m or 0.001 S/m ground conductivity • Damage at 10 A; Upset at 5 A (per actual testing)
POTS Telephone	• Voltage calculation for 1 km radial line • Damage at 8 kV; no upsets (per actual testing)
Cordless Telephone	• Voltage calculation for 1 km radial line • Damage at 4 kV (AC/DC Power Adapter failed) (per actual testing)

The baseline of 0 dB shown in the results assumes that the item in question has a clear line of sight to the HEMP burst and that the cables are not shielded.

7.2. Model Results

Below are the modeling results using the assumptions discussed under *Model Assumptions* above. The first subsection below reviews the *High Level HEMP Model Results*. The next three subsections show the damage and upset areas for the following: (i) *100' Ethernet Model Results*, (ii) *POTS Telephone Model Results*, (iii) *Cordless Telephone Model Results*. These results include protections of 0 dB, 10 dB, 20 dB, and 30 dB.

High Level HEMP Model Results

The high level HEMP modeling results shown in Table 12 demonstrate the potential devastating national impact of a 100 kT HEMP burst. Fortunately, the results also demonstrate the potential to substantially reduce the impact with 20 dB of protection and essentially eliminate it with 30 dB of protection. These results drive the government's desire to ensure that at least the critical infrastructure has adequate EMP resiliency, particularly given the minimal cost that is often involved in obtaining improved resilience.

Table 12. Example HEMP Model Damage and Upset Mitigation Results

Scenario – with amount of Protection in dB	Damage Area US (sq mi)	Damage % US	Upset Area US (sq mi)	Upset % US	Total Damage + Upset Area US (sq mi)	Total Damage + Upset % US
100 ft Ethernet – 0 dB	1,600,214	54.2%	458,229	15.5%	2,058,443	69.7%
100 ft Ethernet – 10 dB	617,929	20.9%	588,277	19.9%	1,206,206	40.8%
100 ft Ethernet – 20 dB	49,642	1.7%	193,159	6.5%	242,801	8.2%
100 ft Ethernet – 30 dB	0	0.0%	0	0.0%	0	0.0%
POTS Telephone – 0 dB	1,522,461	51.5%	0	0.0%	1,522,461	51.5%
POTS Telephone – 10 dB	380,791	12.9%	0	0.0%	380,791	12.9%
POTS Telephone – 20 dB	0	0.0%	0	0.0%	0	0.0%
POTS Telephone – 30 dB	0	0.0%	0	0.0%	0	0.0%
Cordless Telephone – 0 dB	2,305,017	78.0%	0	0.0%	2,305,017	78.0%
Cordless Telephone - 10dB	970,088	32.8%	0	0.0%	970,088	32.8%
Cordless Telephone - 20dB	129,791	4.39%	0	0.00%	129,791	4.4%
Cordless Telephone - 30dB	0	0.00%	0	0.00%	0	0.0%

100’ Ethernet Model Results

As shown in the figures below, the amount of EMP upset/damage to equipment connected to 100’ Ethernet cables could be substantially reduced or eliminated with 20 dB or 30 dB of protection.

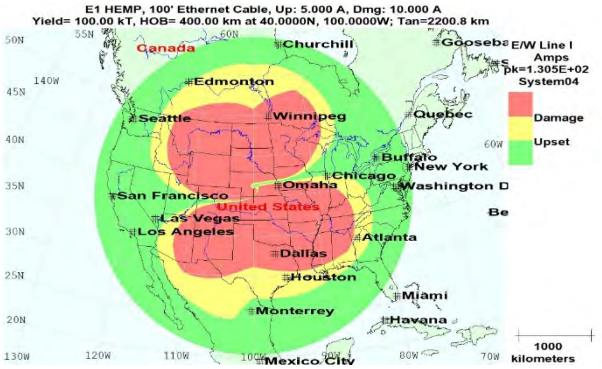


Figure 41. Potential upset/damage of equipment connected to 100’ Ethernet cable with 0 dB protection

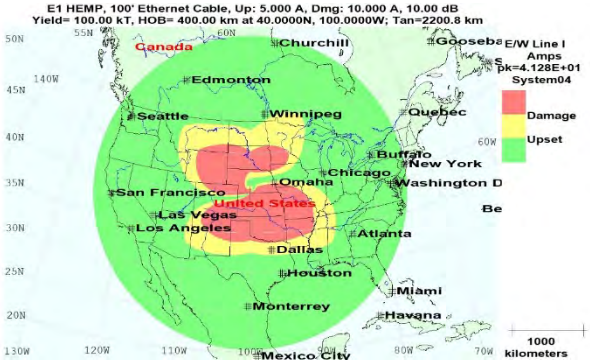


Figure 42. Reduced damage with 10 dB protection to 100’ Ethernet cable connected equipment

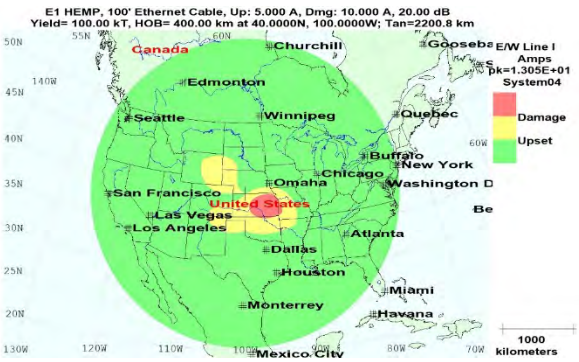


Figure 43. Localized damage only with 20 dB protection with 100’ Ethernet cable

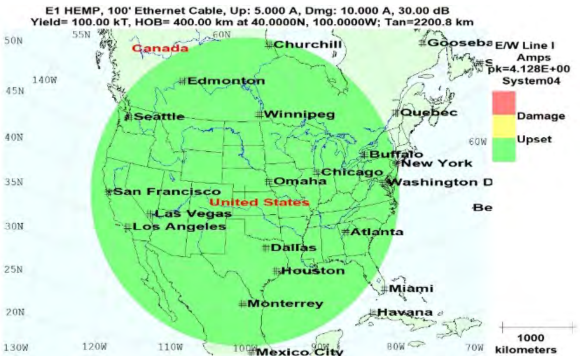


Figure 44. No damage with 100’ Ethernet cable and 30 dB protection

POTS Telephone Model Results

As shown in Figure 45 through Figure 48 below, the amount of damage to a POTS telephone could be substantially reduced or even eliminated with 20 dB or 30 dB protection.

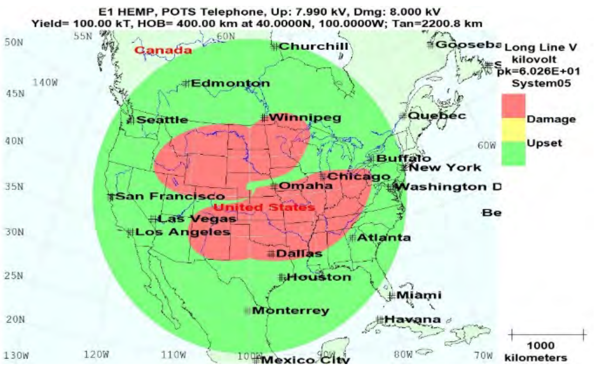


Figure 45. Devastating POTS telephone damage with 0 dB protection

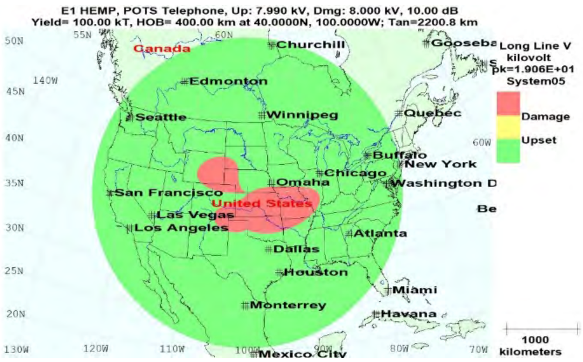


Figure 46. Significantly reduced damage with 10 dB protection

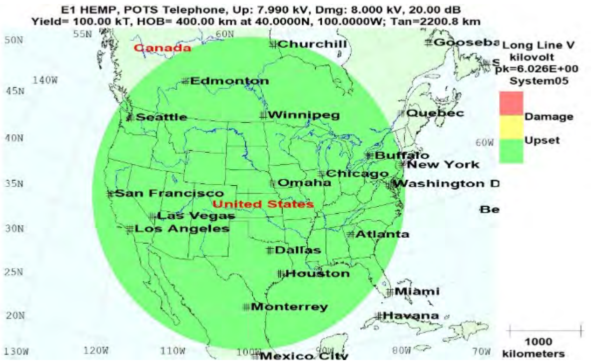


Figure 47. No POTS telephone damage with 20 dB protection

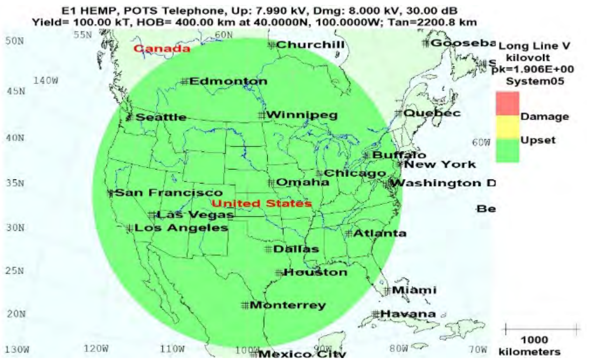


Figure 48. No POTS telephone damage with 30 dB protection

Cordless Telephone Model Results

As shown in Figure 49 through Figure 52 below, the amount of damage to a cordless phone base could be substantially reduced or even eliminated with 20 dB or 30 dB protection. In all cases, the damage was due to the AC/DC power adapter failing (not the handset).

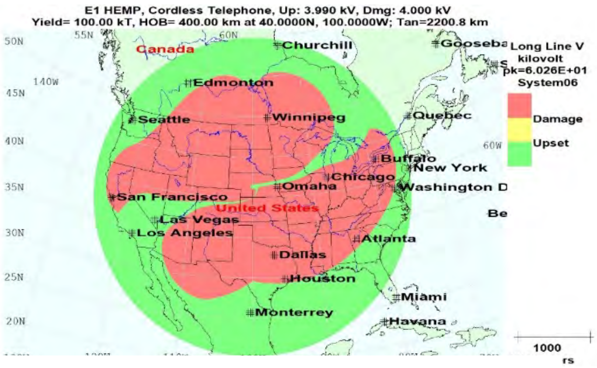


Figure 49. Devastating cordless telephone AC/DC adapter damage with 0 dB protection

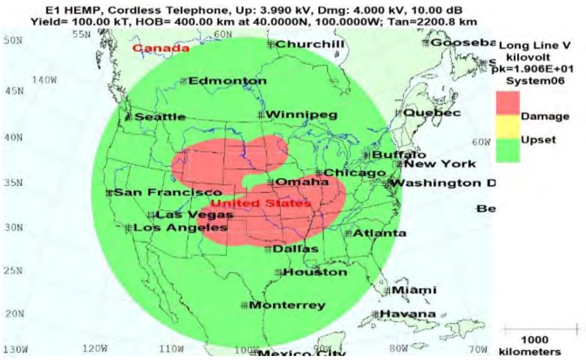


Figure 50. Significantly reduced damage, but still huge with 10 dB protection

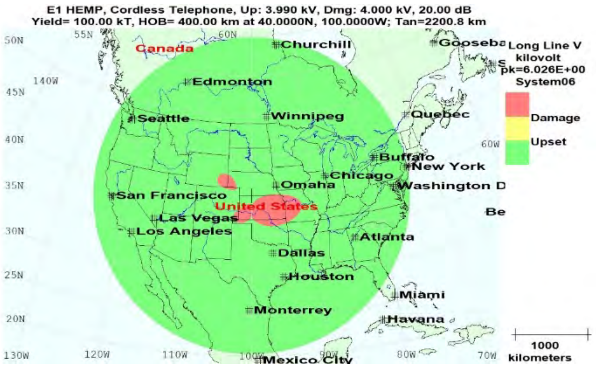


Figure 51. Only localized damage to cordless telephones with 20 dB protection

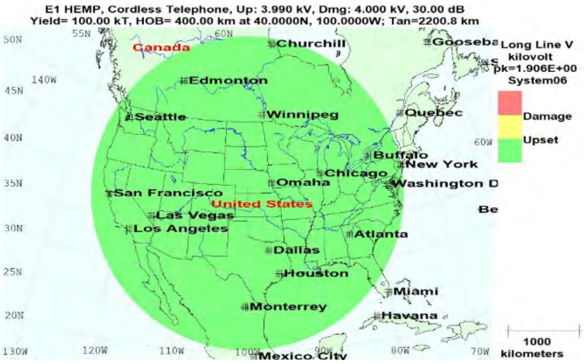


Figure 52. No cordless telephone damage with 30 dB protection

8. NEXT STEPS

There are several next steps planned for this document to better support the DHS released "*Strategy for Protecting and Preparing the Homeland against Threats of Electromagnetic Pulse and Geomagnetic Disturbances*" document released on October 9, 2018. In particular, these next steps include the following with references to the DHS EMP Strategy in parentheses:

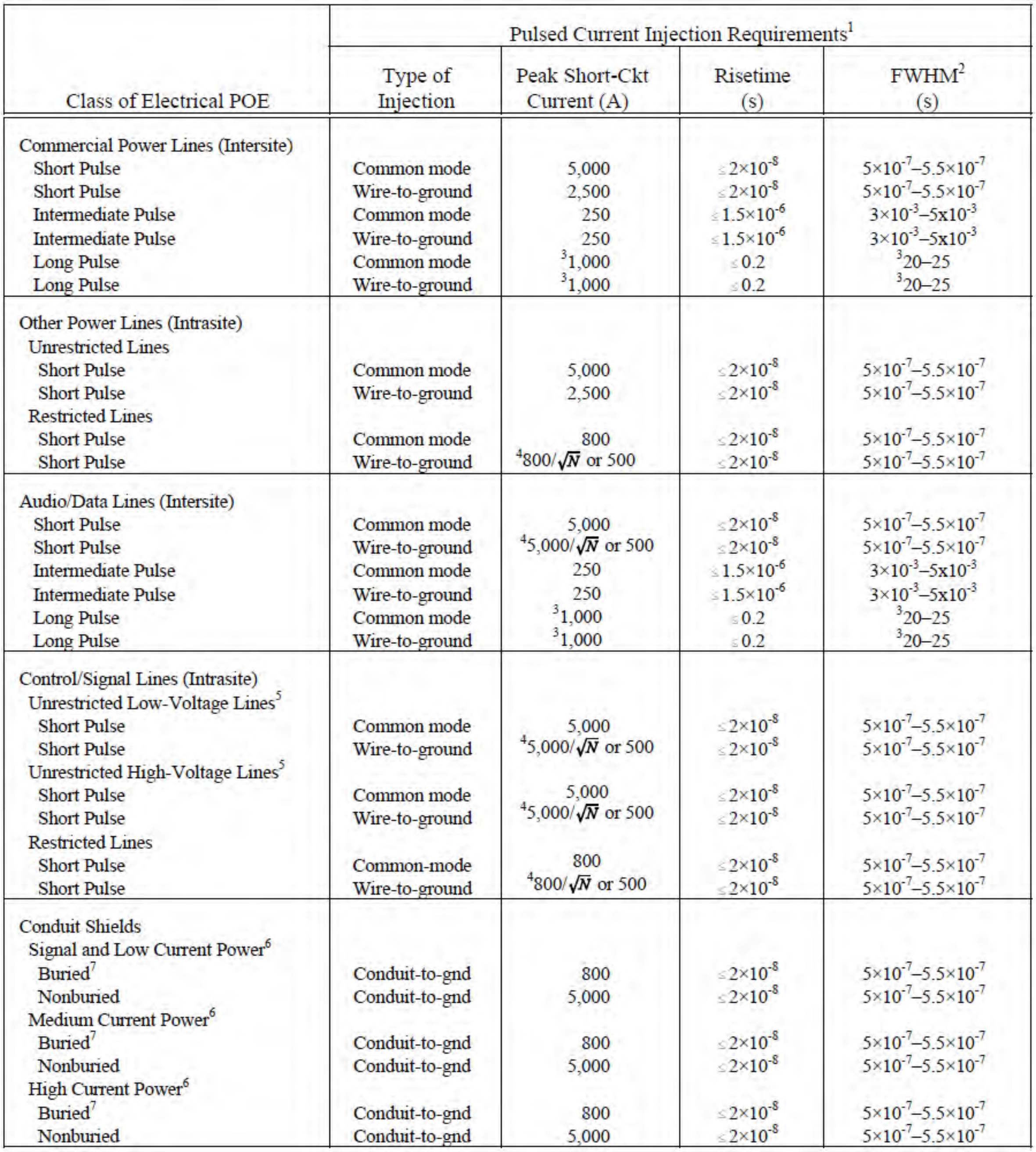
- Review additional "intra-Departmental, Federal interagency, and civilian scientific research on EMP and GMD and their effects on critical infrastructure." (1.2)
- Include both more real world test data and additional prior research on the effects of EMP on critical infrastructure systems. (1.2.1)
- List EMP knowledge gaps and prioritize potential research opportunities that could reduce vulnerabilities in a cost-effective manner. (1.2.1, 1.2.2, 1.2.3, and 2.2.3)
- Discuss additional EMP-GMD response and recovery mechanisms, particularly guidelines that can help make the critical infrastructure operational again or help technically mitigate the damage. (2.2.2)
- Further prioritize the critical infrastructure operational resilience activities based on risk management principles. (2.3.1, 2.3.3 , 3.1.1, and p. 6 of 3rd Core Principle)
- "Identify the technological advances likely to significantly enhance resilience or reduce vulnerability of critical infrastructure to electromagnetic incidents." (2.3)

Some of the above next steps are iterative by nature and the timeframe to complete each of the above next steps will vary, which will likely lead to one or more incremental releases of this document.

Appendix A. EMP PROTECTION TEST AND ACCEPTANCE CRITERIA

From Reference 1. See notes at end of Table A-3.

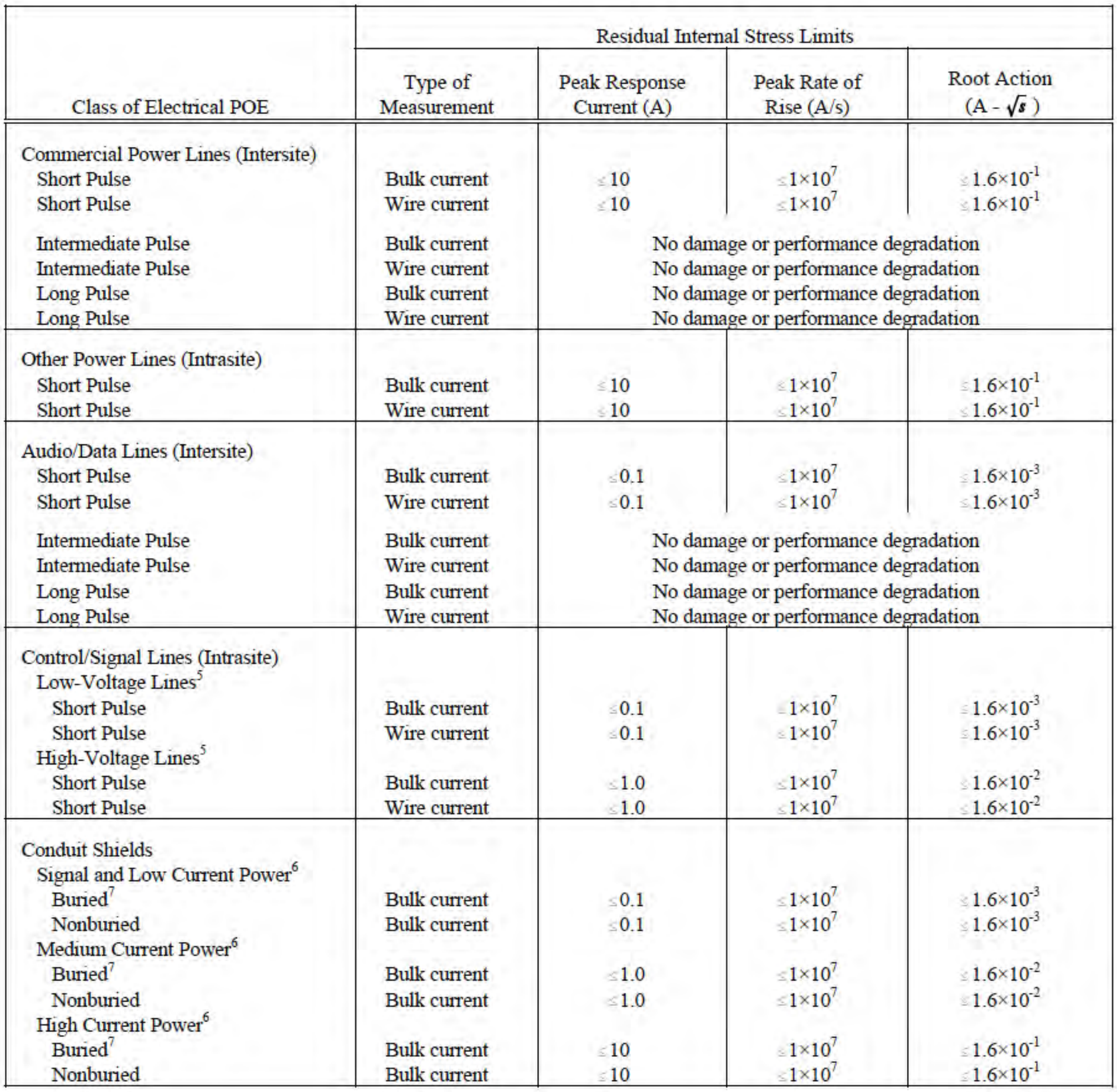
Table A-1. Injected Pulse Characteristics



Class of Electrical POE	Pulsed Current Injection Requirements[1]			
	Type of Injection	Peak Short-Ckt Current (A)	Risetime (s)	FWHM[2] (s)
Commercial Power Lines (Intersite)				
Short Pulse	Common mode	5,000	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Short Pulse	Wire-to-ground	2,500	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Intermediate Pulse	Common mode	250	$\leq 1.5\times10^{-6}$	3×10^{-3}–$5x10^{-3}$
Intermediate Pulse	Wire-to-ground	250	$\leq 1.5\times10^{-6}$	3×10^{-3}–$5x10^{-3}$
Long Pulse	Common mode	[3]1,000	≤0.2	[3]20–25
Long Pulse	Wire-to-ground	[3]1,000	≤0.2	[3]20–25
Other Power Lines (Intrasite)				
Unrestricted Lines				
Short Pulse	Common mode	5,000	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Short Pulse	Wire-to-ground	2,500	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Restricted Lines				
Short Pulse	Common mode	800	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Short Pulse	Wire-to-ground	[4]800/$\sqrt{N}$ or 500	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Audio/Data Lines (Intersite)				
Short Pulse	Common mode	5,000	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Short Pulse	Wire-to-ground	[4]5,000/$\sqrt{N}$ or 500	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Intermediate Pulse	Common mode	250	$\leq 1.5\times10^{-6}$	3×10^{-3}–$5x10^{-3}$
Intermediate Pulse	Wire-to-ground	250	$\leq 1.5\times10^{-6}$	3×10^{-3}–$5x10^{-3}$
Long Pulse	Common mode	[3]1,000	≤0.2	[3]20–25
Long Pulse	Wire-to-ground	[3]1,000	≤0.2	[3]20–25
Control/Signal Lines (Intrasite)				
Unrestricted Low-Voltage Lines[5]				
Short Pulse	Common mode	5,000	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Short Pulse	Wire-to-ground	[4]5,000/$\sqrt{N}$ or 500	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Unrestricted High-Voltage Lines[5]				
Short Pulse	Common mode	5,000	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Short Pulse	Wire-to-ground	[4]5,000/$\sqrt{N}$ or 500	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Restricted Lines				
Short Pulse	Common-mode	800	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Short Pulse	Wire-to-ground	[4]800/$\sqrt{N}$ or 500	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Conduit Shields				
Signal and Low Current Power[6]				
Buried[7]	Conduit-to-gnd	800	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Nonburied	Conduit-to-gnd	5,000	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Medium Current Power[6]				
Buried[7]	Conduit-to-gnd	800	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Nonburied	Conduit-to-gnd	5,000	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
High Current Power[6]				
Buried[7]	Conduit-to-gnd	800	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Nonburied	Conduit-to-gnd	5,000	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}

From Reference 1. See notes at end of Table A-3.

Table A-2. Residual internal stress limits for classes of electrical POEs



	Residual Internal Stress Limits			
Class of Electrical POE	Type of Measurement	Peak Response Current (A)	Peak Rate of Rise (A/s)	Root Action (A - $\sqrt{s}$)
Commercial Power Lines (Intersite)				
Short Pulse	Bulk current	≤10	≤1×10^{7}	≤1.6×10^{-1}
Short Pulse	Wire current	≤10	≤1×10^{7}	≤1.6×10^{-1}
Intermediate Pulse	Bulk current	No damage or performance degradation		
Intermediate Pulse	Wire current	No damage or performance degradation		
Long Pulse	Bulk current	No damage or performance degradation		
Long Pulse	Wire current	No damage or performance degradation		
Other Power Lines (Intrasite)				
Short Pulse	Bulk current	≤10	≤1×10^{7}	≤1.6×10^{-1}
Short Pulse	Wire current	≤10	≤1×10^{7}	≤1.6×10^{-1}
Audio/Data Lines (Intersite)				
Short Pulse	Bulk current	≤0.1	≤1×10^{7}	≤1.6×10^{-3}
Short Pulse	Wire current	≤0.1	≤1×10^{7}	≤1.6×10^{-3}
Intermediate Pulse	Bulk current	No damage or performance degradation		
Intermediate Pulse	Wire current	No damage or performance degradation		
Long Pulse	Bulk current	No damage or performance degradation		
Long Pulse	Wire current	No damage or performance degradation		
Control/Signal Lines (Intrasite)				
Low-Voltage Lines[5]				
Short Pulse	Bulk current	≤0.1	≤1×10^{7}	≤1.6×10^{-3}
Short Pulse	Wire current	≤0.1	≤1×10^{7}	≤1.6×10^{-3}
High-Voltage Lines[5]				
Short Pulse	Bulk current	≤1.0	≤1×10^{7}	≤1.6×10^{-2}
Short Pulse	Wire current	≤1.0	≤1×10^{7}	≤1.6×10^{-2}
Conduit Shields				
Signal and Low Current Power[6]				
Buried[7]	Bulk current	≤0.1	≤1×10^{7}	≤1.6×10^{-3}
Nonburied	Bulk current	≤0.1	≤1×10^{7}	≤1.6×10^{-3}
Medium Current Power[6]				
Buried[7]	Bulk current	≤1.0	≤1×10^{7}	≤1.6×10^{-2}
Nonburied	Bulk current	≤1.0	≤1×10^{7}	≤1.6×10^{-2}
High Current Power[6]				
Buried[7]	Bulk current	≤10	≤1×10^{7}	≤1.6×10^{-1}
Nonburied	Bulk current	≤10	≤1×10^{7}	≤1.6×10^{-1}

Table A-3. Injected pulse characteristics and residual internal stress limits for antenna POE

Class of Electrical POE	Pulsed Current Injection Requirements[8]				
	Type of Injection	Dominant Response Frequency[9] (MHz)	Peak Short-Circuit Current (A)	Risetime (s)	FWHM[2] (s)
RF antenna line shield					
Buried[7]	Shield-to-gnd	Not applicable	800	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Nonburied	Shield-to-gnd	Not applicable	5,000	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
RF antenna line signal conductor	Wire-to-shield	≤ 30	Threat-level[9]	$\leq 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
	Wire-to-shield	>30	Threat-level[9]	$\leq 5\times10^{-9}$	Variable[9]

Class of Electrical POE	Residual Internal Stress Limits			
	Type of Measurement	Peak Response Current (A)	Peak Rate of Rise (A/s)	Root Action $(A - \sqrt{s})$
Receive only antenna line	Shield Current	≤ 0.1	$\leq 1\times10^{7}$	$\leq 1.6\times10^{-3}$
	Wire Current	≤ 0.1	No damage or performance degradation	
Transmit and receive antenna line	Shield Current	≤ 0.1	$\leq 1\times10^{7}$	$\leq 1.6\times10^{-3}$
	Wire Current	≤ 1.0	No damage or performance degradation	

Notes for Tables A-1, A-2 and A-3.

[1] Pulse current injection requirements are in terms of Norton equivalent sources. Short-circuit currents are double exponential waveshapes. Source impedances are $\geq 60\ \Omega$ for the short pulse, $\geq 10\ \Omega$ for the intermediate pulse, and $\geq 5\ \Omega$ for the long pulse.

[2] FWHM is pulse full-width at half-maximum amplitude.

[3] The long pulse peak short-circuit current (1,000 A) and FWHM (20-25 s) are design objectives. Any double exponential waveform with peak short-circuit current ≥ 200 A, risetime ≤ 0.2 s, and peak current x FWHM product $\geq 2 \text{ x } 10^{4}$ A-s satisfies the minimum requirement.

[4] Whichever is larger. N is the number of penetrating conductors in the cable.

[5] Low-voltage control/signal lines are those with maximum operating voltage < 90 V. High-voltage control/signal lines are those with maximum operating voltage ≥ 90 V.

[6] High-current power lines have maximum operating current > 10 A. Medium-current power lines have maximum operating current between 1 A and 10 A. Low-current power lines have maximum operating current < 1 A.

[7] An antenna shield is considered buried when it terminates at a buried antenna and less than 1 m (3.3 ft.) of its total length is not covered by earth or concrete fill. A conduit is considered buried when it connects two protected volumes and less than 1 m (3.3 ft.) of its total length is not covered by earth or concrete fill.

[8] Pulse current injection requirements are in terms of Norton equivalent sources. The short pulse generator, with a source impedance $\geq 60\ \Omega$, is used for shield-to-ground injections and for wire-to-shield injections at dominant response frequencies ≤ 30 MHz. A charge line pulser, with a source impedance $\geq 50\ \Omega$, is used for wire-to-shield injections at dominant response frequencies > 30 MHz.

[9] The dominant response frequency (or frequencies) and threat-level peak short-circuit current are determined from extrapolated coupling measurements. The length l of the charge line of the charge line pulser is the quarter-wavelength of the dominant response frequency: $l = 0.25\, c/f$, where $c = 3 \text{ x } 10^{8}$ m/s and f is frequency in Hz.

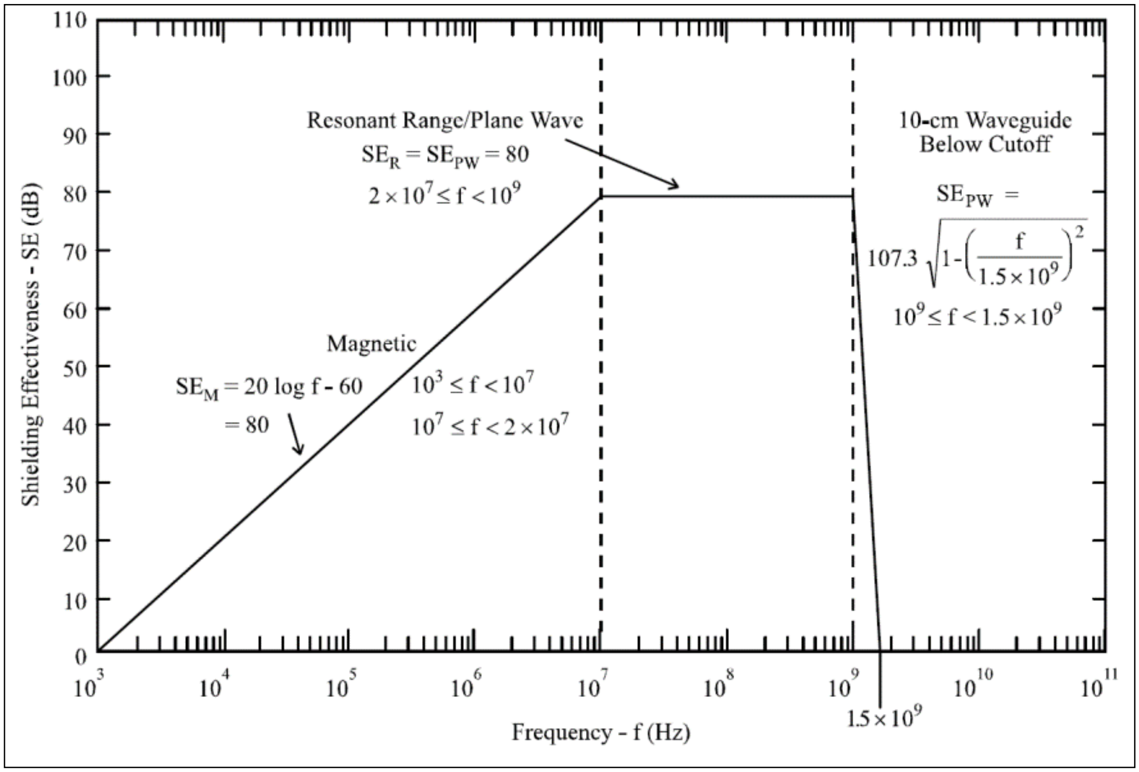


Figure A-1. HEMP Shielding Effectiveness Requirement

Appendix B. EMP PROTECTION VENDORS AND SERVICES

This appendix is intended to familiarize those considering EMP protection options with the types of solutions currently available in the U.S. marketplace. The companies listed offer specialized products or services that address the threats from HEMP, radiated SREMP, and IEMI. This list is not a comprehensive source listing of companies who offer EMP related products and services. If you are a business who offers related products or services and would like to be included in future releases of this document, please contact Kevin.Briggs@hq.dhs.gov and include, where possible, any independent testing data that verifies product claims and customer references from previous work, if applicable.

Disclaimer: Reference to any specific company's product or service herein does not represent an endorsement by the Department of Homeland Security (DHS) or the NCC as to the effectiveness or adequacy of any product or service, nor should this Appendix be considered an approved or recommended vendor list. Use of any vendor product or service listed in this Appendix should be based entirely on the buyer's own analysis of alternatives and research of vendor capabilities.

EMP Protection Levels

Achieving cost effective protection from EM threats requires a "defense-in-depth" approach to progressively increase equipment immunity and resiliency and ultimately harden critical systems and infrastructures. It is not necessary or financially feasible to harden all systems and infrastructure to survive and operate through an EMP event. System prioritization and planning for an EMP event should be an integral part of each organization's continuity and contingency planning efforts.

DHS EMP Protection Level 1 generally uses manual procedures to isolate off-line equipment from EM threats and adding ferrite devices to cables to attenuate unwanted HF cable signals. These are intended to be added by existing site personnel for minimal cost. Level 2 measures focus on increasing resiliency by installing active and passive components to mitigate the conductive effects that threaten on-line systems. Level 2 measures can be performed by skilled in-house personnel or obtained through contracted services.

Levels 3 and 4 measures address the radiated effects of EM threats by installing layers of EM shielding around prioritized systems to harden operations. Shielding a new or existing facility is typically performed by an experienced contractor who will design, engineer, install and test the solution to meet the unique site requirements and performance specifications.

EMP Protection Level 1

Level 1 protection measures are the first line of defense in protecting essential equipment from the conductive and radiated effects of EM threats. These manual isolation procedures can protect off-line and spare equipment from the initial EM effects for little to no cost. Simply unplugging the cables from equipment that is only required for continuity or backup purposes will create physical and electrical separation and provide protection from EMP induced currents.

Add ferrite clip-on beads to equipment cables that must remain connected and on-line. To best shield against the radiated effects of EMP, off-line equipment must be stored behind protective metal barriers. Placing larger equipment in a Faraday case and storing it in a steel constructed warehouse is preferable to on-the-shelf in an office or operations building.

Faraday Bags

Faraday bags are the most basic type of shielding available and are widely available online. They are primarily designed to protect small electronics such as cell phones, key fobs, tablets, laptops, and handheld radios from EMI. The frequency range covered is dependent upon the Faraday bag, but some work as low as 10 MHz and others shield as high as 18 GHz. Most Faraday bags at least cover the pre-5G cellular range as well as the frequency ranges for RFID (315 MHz in North America), the GPS bands, and many cover Wi-Fi bands (the higher Wi-Fi frequency is at 5.9 GHz).

Bag size, construction and the level of protection can vary greatly although one bag should be sufficient for most Level 1 and Level 2 protection situations. Nesting within multiple bags or storing the bags in a metal container to create more layers will increase the level of protection. Be aware that many bags marketed as Faraday bags are designed for evidence collection and may only provide electrostatic protection. Prices range from a few dollars for small disposable bags to a couple or few hundred dollars for backpacks or heavy-duty duffel bags. Also, while the material in some bags can provide high levels of EM attenuation, often the closing method for the bags are the main leakage point. Look for bags, which indicate that the entire bag has been tested.

Vendors selling Faraday bags can easily be found using a search engine or popular general online shopping sites (e.g., Amazon, Walmart). Specific vendors include (see Disclaimer on page B-1):

Defender Shield: www.defendershield.com

Faraday Defense: https://faradaydefense.com/

Mission Darkness: (MOS Equipment) https://mosequipment.com/

Faraday Containers

If portability is required, a Faraday **container** offers a more durable solution than a Faraday **bag**. These rigid containers are suitable for transport and can be stacked to store equipment off-line until needed. Containers range in size from briefcase-sized for phones and laptops to suitcase size containers and transit cases for large components or multiple devices. Prices typically range from a few dollars to several hundred dollars although less expensive and more expensive containers are available. Custom engineered cases can cost between $10K-$40K with deployable system solutions offering onboard power, interfaces and thermal management ranging from $40K to over $100K.

Vendors selling Faraday containers include (see Disclaimer at the beginning of this Appendix):

> **Conductive Composites** (www.conductivecomposites.com/SystemSolutions) offers a line of injection molded and laminated electronics enclosures that provides shielding performance across a broad range of frequencies that meets MIL STD 461, 464 and 188-125 requirements.

EMP Engineering (http://empengineering.com/storage-faraday-boxes) makes a line of welded aluminum Faraday cases ranging from several hundred dollars to over a thousand ($787 - $1171 dollars in July 2018).

Ferrite Cores/Beads

Ferrite beads are widely available online and cost just a few dollars each. Normally more than one bead is required to achieve significant attenuation (~10 dB). They can be clamped on, snapped on or slipped over cables near the equipment end to attenuate unwanted high-frequency cable signals. Type 61 (HF) ferrites made of Nickel Zinc are recommended. These are designed for inductive applications to attenuate interfering pulses from 200 MHz to 2 GHz. They can be added to existing cables or purchased with ferrites pre-built in common cable types. A wholesale distributor such as **Digi-Key Electronics (**http://www.digikey.com/product-search/en/filters/ferrite-cores-cables-and-wiring/3408554?WT.srch=1) allows for filtering any combination of sizes and specifications to fit requirements (see Disclaimer at the beginning of this Appendix).

Other suppliers include:

Amindon Corporation: http://www.amidoncorp.com/61-material-ferrite-toroids/

API Delevan: http://www.delevan.com/

Bourns: https://www.bourns.com/

Fair-Rite Products: https://www.fair-rite.com/

Kemet: http://www.kemet.com/Ferrite_Products

Laird: https://www.lairdtech.com/

Leadertech: https://leadertechinc.com/

muRata: https://www.murata.com/en-us/products/emc/ferrite

Palomar Engineers: http://palomar-engineers.com/ferrite-products

TDK: tdk.com or https://product.tdk.com/info/en/products/ferrite/index.html

Toshiba: Toshiba.com or https://toshiba.semicon-storage.com/us/product/amorphous/high-permeability-cores.html

Wurth: https://www.wuerth.com or https://www.we-online.com/web/en/wuerth_elektronik/start.php

EMP Protection Level 2

Level 2 adds active and passive components designed to limit the conductive effects of EMP while essential systems remain operational and connected to external power and network connections. The cost to add Level 2 measures to an existing facility is relatively low proportional to the quantity of power and communications connections that must be protected.

Surge Suppressors and Filters

Many commercially available power strips have surge protection built in. These should be used to protect all essential equipment and must have response characteristics as discussed in Section 2 "*EMP PROTECTION AND RESILIENCE CONSIDERATIONS"* (see Disclaimer at the beginning of this Appendix):

Alpha Delta https://www.alphadeltacom.com/ Transi-Trap ATT3G50 coaxial surge protectors have replaceable GDT elements for different power levels. A Transi-Trap has an N female connector on both ends (no suffix) or SO-239 UHF female connectors (U suffix). They are available for either stud mounting (no suffix) or bulkhead mounting (B suffix). One of the UHF connectors is 1.5 inches long with a UBXL suffix. The standard version of the ATT3G50 is suitable for protecting a 125-watt transmitter, and the HP version is suitable for protecting a 1 kW transmitter. Transmitters operating at other power levels can be better protected by selecting GDTs with different voltages.

Alpha-Delta uses standard 6x8-mm (height x diameter) GDTs which are available from GDT manufacturers/distributors in voltages of 90, 230, 350, 470, 600, 900, 1000 and higher for less than $3 each. Alpha-Delta uses GDTs from: EPCOS (https://en.tdk.eu/arresters) and Littelfuse (http://www.littelfuse.com/~/media/electronics/product_catalogs/littelfuse_gdt_catalog.pdf.pdf). Littelfuse also has a variety of catalogs featuring their other surge protection devices (e.g., datacenter lines) at http://electronicscatalogs.littelfuse.com/app.php?RelId=6.7.0.18.4

Alpha-Delta stocks only the 350 and 1,000-volt rating GDTs, suitable for 125 and 1,000-watts, respectively, based on a VSWR of 3:1 or better (lower). VSWR is a function of the impedance mismatch between the radio (which is almost always 50-ohms) and the antenna impedance, which can vary widely as a function of frequency. If your worst (highest) VSWR is more or less than 3:1, different voltage GDTs should be used. The GDT voltage is a concern because the voltage across the GDT increases with transmitter power and antenna VSWR, which can cause the GDTs to trigger and wear out prematurely if the GDT voltage-rating is too low. Although lower voltage-rating GDTs provide better protection for the radio equipment, a GDT with a high enough voltage-rating needs to be used so it won't be triggered from normal operating voltages.

APC's ProtectNet (http://www.apc.com/products/family/index.cfm?id=145&ISOCountryCode=us) line of surge protection devices provide protection against power transients traveling over telecommunications lines and meet rating requirements to be effective for EMP types of transients. These types of devices should be used to protect all essential equipment at each power, phone and network connection. Its SurgeArrest protectors will alert the user if they are damaged or compromised. Prices range from $15 to $40 dollars per device.
http://www.apc.com/products/family/index.cfm?id=145&ISOCountryCode=us

Emprimus (www.emprimus.com) is a research and development company partnered with ABB, a global leader in power and automation technologies, working with major utilities to produce effective products to protect the electric power grid (both AC and HVDC) against stray DC currents, Solar Storm/Geomagnetic Induced Currents (GIC), EMP including Nuclear EMP (E3 Pulse), and Intentional Electromagnetic Interference (IEMI) caused by Radio Frequency Weapons. The SolidGround™ neutral blocker is a solution to help protect the electric power grid from stray DC, Solar Storms (GMD) and Nuclear EMP E3.

ETS Lindgren (www.ets-lindgren.com) is an international manufacturer of components and systems that measure, shield and control electromagnetic and acoustic energy. Their Red Edge Technology line of EMP rated power filters is designed to MIL-STD-188-125 for both TEMPEST and non-TEMPEST applications.

Huber+Suhner (http://empselector.hubersuhner.com/) makes a line of EMP coaxial, data and power components. Their EMP Protector Tool Box helps you select the correct EMP devices to meet your requirements.

The H+S series of N-type connector inline GDT protector housings 3401.17.A and 3402.17.A, have replaceable GDT elements for different voltage levels.

Huber+Suhner (H+S) has a very helpful on-line calculator for finding the recommended GDT for various VSWRs and power levels at http://empselector.hubersuhner.com/gdtcalculator/index.php. The H+S on-line calculator determines the voltage for specifying a GDT when the power and VSWR are known. The VSWR should be measured at the point where the RF surge protector will be located. The VSWR should also be measured at whatever operating frequency produces the highest (worst) VSWR. Using the H+S on-line calculator, insert the “RF CW Power in W” (Watts), the “DC Supply Voltage” (normally zero), the maximum antenna “VSWR” (normally at least 3), and the “Impedance Z” (normally 50), and then click on the “Calculate” button.

Using the H+S online calculator for three typical powers of 100, 400, and 1000 watts (with a 3:1 VSWR) results in the following required GDT voltage ratings:

- 100 watts has a peak voltage of 150 volts, which x1.5 = 225 volts – requires a 350-volt GDT.
- 400 watts has a peak voltage of 300 volts, which x1.5 = 450 volts – requires a 600-volt GDT.
- 1,000 watts has a peak voltage of 474 volts, which x1.5 = 712 volts – requires a 900-volt GDT.

There are two reasons why the required GDT voltages in the above three examples are so much higher than the calculated peak voltages: (1) The on-line calculator multiplies the calculated peak voltage by 1.5 to provide a safety factor against false triggering, and (2) GDTs have nominal voltages specified with a 15 or 20% tolerance. Therefore, the calculated tolerance voltage must be subtracted from the nominal voltage to determine the GDT’s minimum striking voltage. That is, the 350-volt GDT may strike at only 298 volts, the 600-volt GDT may strike at only 510 volts, and the 900-volt GDT may strike at only 765 volts.

Going into more detail for the last example above, a 900-volt GDT is used despite a calculated striking voltage of 712 volts (to protect an amplifier with an output power of 1,000 watts) because it might strike at a voltage as low as 765 volts with its 15% tolerance. This means that the voltage induced in the antenna lead from a lightning strike or EMP will reach at least 765 volts before the GDT fires. But the induced voltage could go up into the thousands of volts without the surge protector. Also, a VSWR of 3 may only be nominal: Many VSWRs will be higher, requiring GDTs with even higher voltage ratings. Disregarding the safety factor and the tolerance would result in selecting a GDT with a striking voltage that is too low, compounding false triggering problems.

NexTek (http://nextek.com) was founded in 1986 to supply EMI/EMC solutions to the electronics industry. It designs and manufactures its products in the USA for the communications, aviation, computer, military, and medical electronic industries. The core product portfolio is based upon two basic product types; coaxial RF protector designs using gas discharge, quarter-wave, and filter technology, and the high-current feedthrough C-type EMI/RFI filters. The industry-leading coaxial arrestor product portfolio delivers both superior performance and value for wireless communications, telecom, WiMAX, Wi-Fi, aviation, military, and homeland security applications. The filter solutions provide similarly class-leading performance and compact form factors for mobile power system, industrial laser, medical device, and aerospace applications.

PolyPhaser, an Infinite Company, has several lines of GDT type coaxial line filters that can provide EMP protection. The PolyPhaser IS-50NX-C0 (http://www.polyphaser.com/products/rf-surge-protection/is-50nx-c0) limits at 600 Volts (+/- 20%) to protect transceivers with transmitter output powers of 400 watts (with a 3:1 VSWR as was assumed previously with the H+S GDTs).

The PolyPhaser IS-NEMP-C0 has a lower turn-on voltage limiting at 330 Volts to provide better protection against HEMP damage for a 100-watt transceiver.

Both of the above PolyPhaser protectors have female N connectors on both ends, but they are also available with one female and one male N connector, or with UHF connectors instead (with different part numbers). Both of these protectors contain capacitors in series with their center pins, so they cannot pass a DC voltage (which some installations require for powering a remote antenna tuner or switch). Both protectors contain non-replaceable GDTs.

See www.polyphaser.com for more information.

Transtector, an Infinite Company, (https://www.transtector.com/) product offering includes AC, DC, high speed data and signal protection, EMP/EMI filters, power conditioners, UPS and power distribution units. Their products include a 6 outlet AC Surge Protection device *SL-V Surge Cord P/N 1101-058*, which uses a silicon avalanche suppression diode and has a published surge suppression response time of <5 ns. Some of its products have been tested to MIL-STD-188-125 E1 and E2 environments, such as the AC EMP product *APEC IMAX HT*, which is applicable to 120/208 VAC, 240 VAC, and 120 VAC applications.

Other vendors supplying EMP rated filters and suppressors include:

Captor Corporation – http://www.captorcorp.com/index.html

EMP Shield – www.myempshield.com/compliance-tests/ www.myempshield.com

Fischer Custom Communications – http://www.fischercc.com/transient-protection-devices/

Glenair EMI/EMP Filter Connectors and TVS Devices - www.glenair.com/filter/index.htm

LCR Electronics (under Astrodyne TDI) **–** http://www.lcr-inc.com/emi-rfi-filters/

Technical Sales Solutions, LLC – http://mytechnicalsalessolutions.com

Double Conversion On-line and Line Interactive UPS

A true on-line, double-conversion type UPS or a high quality line interactive UPS is recommended for protecting equipment from EMP. Double Conversion On-Line UPS provide continuous output power from the battery backup through an inverter and not directly from the AC power source. This design provides isolation from transients on the AC power line and continual power without transfer. A high quality line interactive unit is often used for lower power applications (a few pieces of equipment or a rack) and it uses a combination of surge suppression, line noise filtering, and switchover to a battery to prevent damage to sensitive equipment.

Double Conversion On-line UPS are available from (see Disclaimer at the beginning of this Appendix):

APC – http://www.apc.com/products/family/index.cfm?id=163

CyberPower – http://www.cyberpowersystems.com/products/tools/selector/ups

Dell – www.dell.com

Emerson-Liebert (a business of Vertiv) **–** http://www.emersonnetworkpower.com/en-US/Products/ACPower/Pages/default.aspx or https://www.vertivco.com/en-us/products-catalog/critical-power/uninterruptible-power-supplies-ups/

Tripp-Lite – http://www.tripplite.com/products/ups-systems~11

EMP Protection Levels 3 and 4

The next two levels of protective measures involve adding protective metallic shielding to the operating environment. These solutions can range from a single equipment rack, to an operations room, to an entire building or facility. Level 3 is designed and installed to meet commercial IEC standards. Level 3 protection can be achieved with bolt-together shielded panels around all six-sides of a room or an equipment rack or by relocating essential equipment into a pre-built shipping container-size shielded enclosure. Nesting equipment behind multiple barriers has an additive effect. For example, placing essential equipment radios in a moderately shielded container or room in the middle of the basement of a building may be as good as placing the equipment near the window of a building in a shielded container.

Level 4 increases the degree of protection to the higher MIL-STD-188-125-1. Level 4 requires electrically bonded and tested joints. All penetrations into the shielded enclosure must be bonded and grounded. Food, fuel and supplies should be provisioned to operate in an EMP environment for up to 30 days.

Shielded Enclosures, EMP/GIC Testing, Engineering and Consulting Services

Building a shielded enclosure into a new or existing facility is the traditional proven method of EM hardening. Many companies with EMP hardening experience support the Department of Defense

(DoD). They are very experienced in designing, engineering, installing and testing RF shielded enclosures to meet MIL-STD-188-125-1 and -2 applications (note: see Disclaimer at the beginning of this Appendix). As more industries begin to address EMP threats, companies will offer more solutions for commercial and civil applications with different site requirements and performance specifications that the military specifications do not cover.

Advanced Fusion Systems, LLC (AFS), (203-270-9700) is a division of Stratum (http://stratum-technologies.com/). Its products include an EMI coating.

ARMAG Corporation (www.armagcorp.com) Armag Corporation has a rich history of client partnership, particularly in U.S. Defense and Government, in developing and manufacturing secure facilities to provide uncompromised physical security. Armag designs and manufactures prefabricated steel, both large and small, to protect against HEMP, IEMI, GMD, and a broad spectrum of threats. Armag incorporates over forty years of experience in consultation with the client to provide solutions that meet their specific requirements. ARMAG has successfully produced and provided third party testing of facilities in order to certify RF Shielding protection in accordance with MIL-STD-188-125-2 and NSA 94-106.

ATEC Industries (http://www.atecindustries.com/) ATEC Industries is a full-service general contractor headquartered in Elkridge, Maryland specializing in the design/build delivery of RF shielded facilities. ATEC has the expertise to provide a turnkey solution for both new construction and renovations of varying size and scope. Since 1987 ATEC Industries has been continuously involved in the design, fabrication, construction and testing of RF shielded facilities. ATEC specializes in EM/RFI shielding for governmental, military and medical facilities, both as stand-alone projects and as part of larger integrated construction projects. RF attenuation requirements have varied in the magnetic and electric fields from 50 dB at 1 kHz to 100 dB at 100 KHz to 100 dB at 50 MHz and microwave performance of 115 dB at 18 GHz to 80 dB at 50 GHz.

Braden Shielding Systems, LLC (www.bradenshielding.com) designs, manufactures, integrates and tests EM shielding systems for medical, industrial and defense applications. A core competence of the company is hardening of critical infrastructure facilities for protection against the damaging effects of EMP, IEMI and GMD.

For more than 30 years, Braden Shielding has manufactured a comprehensive line of proven RF shielding products at its facility in Tulsa, OK. The company provides a number of high-performance shielding systems and a broad range of RF shielded facility penetrations designed specifically to address every Point of Entry (POE) to the EM shield, such as shielded doors, power/signal/data and fiber optic filters, waveguide penetrations for mechanical, fire protection and HVAC systems, as well as custom POE's for hardness critical items outside the main shielded barrier, e.g., cooling towers, generators and telecommunications.

Braden's staff of experienced design, engineering, fabrication, installation, testing and project management personnel deliver turn-key RF shielding solutions for any shielding project. The Company utilizes the latest 3-D design and Building Information Modeling (BIM) technology and offers comprehensive design support for: Hardened facility planning, architectural/structural/electrical and mechanical design integration, special protective measures and hardness maintenance/hardness surveillance.

CenterPoint Energy (www.centerpointenergy.com) CenterPoint Energy embarked on an initiative to identify an effective, cost efficient solution for High-Power Electromagnetic (EM) mitigation for new and retrofit installations. The focus of mitigation efforts was substation assets used for the protection and control of the power delivery network. The design basis required the identified electromagnetic protection not compromise the reliability of existing substation functions, result in minimal increases to maintenance costs, and avoid significant changes in normal operating procedures. The development of a solution was achieved in 2018 and is rapidly progressing to the field pilot phase. The practical application of EM mitigation design practices in an unobtrusive method will speed the time for implementation, lower initial installation costs, and minimize ongoing maintenance. Each of the aforementioned achievements are realized while meeting the shielding effectiveness requirements of MIL-188-125.

The EM module will be installed as a backup protection and control system as well as online monitoring while the legacy protection and controls are still in service. If an EM event occurs, the mitigation system could be used in response. By having the system as a redundant parallel backup, the field technicians would not have to interface daily with the EM enclosure, which would help maintenance cost and ensure the integrity of the module. The field technicians also would not need to instantly change their skill sets learning the grounding, bonding and digital protection that would be required on a complete EM control house. Lastly, the EM module has enhanced data gathering and reporting capabilities for control center information which exceeds legacy systems.

From a financial perspective, the proposed solution is cost effective when compared to building a new EM control house. Based on initial estimates, a new EM control house will cost over one million dollars. The EM module enclosure would be less than 10% of a new EM control house. In conclusion, utilizing a module based approach would be a cost effective retrofit solution to harden substations for EM events. By being a redundant system, the module also provides a backup for non-EM emergencies such as control house fire or flooding and it does not intrude on present protection and control systems.

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EMP Engineering (http://empengineering.com/) is dedicated to the analysis, design, fabrication and installation of specialized shielding, components and systems to mitigate the harmful effects of EMP and Geomagnetic Storms on buildings, vehicles and structures world-wide. Their team of highly skilled professional engineers, project managers and fabricators have worked on military, government and private projects world-wide. Services include custom evaluations, installation and commissioning services, shielding, verification testing, hardness, hardness assurance, maintenance and surveillance and EMP solutions that integrate with Architectural, Structural, Electrical, and Mechanical Engineering services to create a secured and safe shelter / bunker environment.

They provide full service professional architectural, engineering solutions and products for hardened facilities including CBRE (chemical, biological, radiological, explosive) filters, structural engineering, blast engineering and electrical/mechanical engineering are keep designed environments effective against evolving threats now and in the future. All designs and projects are HEMP hardened per MIL-STD-188-125-2. EMP Engineering also provides portable, custom designed HEMP resistant electrical generators; communications centers and data centers fabricated in ISO shipping containers at 10, 20, 30 and 40 foot lengths. These can be ballistic/blast hardened with CRBN Air-Filtration systems.

ETS-Lindgren, an Esco Technologies Company**.** (http://www.ets-lindgren.com/). ETS-Lindgren is an innovator of systems and components for the detection, measurement and management of EM, magnetic and acoustic energy. ETS-Lindgren has the experience and expertise gained from over 70 years' experience of designing and installing more than 10,000 shielded systems worldwide. Their *RedEdge Pulse Protection* brand provides certified EMP Shielding to protect equipment and points of entry and a higher level of protection for continuous data operations with independent, uninterrupted power and utilities. Their solutions include welded steel construction, modular panel systems, doors, filters, waveguide vents and penetrations and fiber optic penetrations.

HV TECHNOLOGIES, Inc. (https://hvtechnologies.com/hv-equipment) sells (N)EMP test equipment and hardened video camera products. 8526 Virginia Meadows Drive, Manassas, VA 20109

Instant Access Networks, LLC (www.stop-emp.com) is a veteran-owned Maryland based company whose on-demand services center on the protection of mission critical facilities and infrastructure from EMP primarily through its commercial-off-the-shelf products and services. IAN has produced and tested products that provide shielding from 30 dB to 140 dB and include EMP-safe inserts that fit into standard cargo containers or trailers and can come with biological/chemical/radiological air filter systems making an all-hazards safe system. IAN also developed and tested EMP-protected solar arrays, wind turbines and diesel turbines. IAN is working with over 40 companies in its DTRA SBIR contract to provide EMP protected microgrids and communications systems and welcomes additional collaborators.

Jaxon (https://www.jaxon-em.com/) Jaxon is one of the leading High Altitude Electromagnetic Pulse (HEMP) specialty engineering firms in the country. Jaxon is a woman owned, small business located in Colorado Springs, CO. Jaxon's staff represents one of the largest and most experienced full service EMP service teams in the world. It designs, builds, tests and maintains EMP hardened structures for government and commercial clients around the world.
Jaxon has developed multiple sets of 'Next Generation' HEMP test equipment. This equipment exceeds Mil STD 188-125 requirements with leading performance characteristics. Jaxon's state of the art test equipment and engineering staff accelerate the test process and minimize mission down time requirements. Jaxon management serves on the FBI's InfraGard EMP Special Interest Group as one of their Subject Matter Experts.

Keystone Compliance (https://keystonecompliance.com/emp/) in New Castle, Pennsylvania is a full-service regulatory compliance laboratory offering solutions for nearly all EMC/EMI, environmental, ISTA-certified package and ingress protection testing requirements. Their EMC/EMI lab reportedly features five test chambers, including three anechoic/ferrite lined 3-meter chambers. Keystone Compliance has extensive experience with shielding effectiveness and EMP testing and works with manufacturers and citizens to determine if their equipment and shielding can handle natural or man-made EMPs. MIL-STD 461 contains test methods and levels to determine a device's immunity to EMP from both a radiated and conducted immunity standpoint. Radiated immunity in RS105 assesses the impact of radiated exposure. Conducted immunity in CS116 assesses the impact of damped sinusoidal transients on the cables of equipment.

L-3 Advanced Technology, Inc. (L-3 ATI), is a subsidiary of L-3 Communications. (https://www2.l3t.com/ati/solutions/redesign.htm) L-3 ATI is known worldwide for its contributions in pulsed high-voltage and high-current systems. Engineers and scientists on the EMS team have pioneered the use of most of the high-power techniques taken for granted today: oil and water dielectric pulse forming line and Blumleinpulse generators; Marx generators; intense bremsstrahlung, z-pinch, plasma radiation and X-ray sources; high-resolution x-radiography; low-jitter, multi-site switching systems, and more. The systems that it has delivered include EMP Generators and Large Area EMP Simulators.

Its ancestor **Jaycor** provided the first High-Altitude EMP (HEMP) shielding technologies to mission-critical U.S. assets. It was formed in 1975 to perform nuclear weapon effects survivability hardening and testing. The JAYCOR EME division formed by Mike Bell in Colorado Springs in 1977 became the pre-eminent underground nuclear test organization. JAYCOR - Colorado Springs worked on many major weapon system EMP hardening programs (Minuteman, Peacekeeper, B-52, B-1, B-2, Polaris, Trident, M-1 Abrams, AH-64). JAYCOR EME began hardening and testing to MIL-STD-188-125 requirements in 1999 for Air Force Space Command. They have performed over 500+ Appendix A SE, 150 Appendix B PCI and 100 Appendix C CWI test sequences since 2011. These tests have been performed on over 400 test objects ranging from facilities buried in mountains to small shielded rooms buried in large buildings to small telecommunications cabinets, from small mobile systems to 12 story fixed radar sites. They have MIL-STD-188-125 tested for AFSPC, NORTHCOM, STRATCOM, ACC, GMD, NMCC, DTRA, PM DCATS, DISA, Bechtel, Harris, and Boeing.

Shield Rite was formed in 1987 by Dr. Dave Merewether as a manufacturer of high quality RF doors and RF shielding. The Shield Rite door is a patented design installed in over 360 locations worldwide. Over the past 38 years, the main business has been the fabrication of extremely robust, HEMP Shielded doors, but has expanded to provide custom designed hardened shelters and facilities. Shield Rite was purchased by JAYCOR in mid - 2002 along with all manufacturing rights, patents for various Shield Rite technologies.

LBA Group Inc. (https://www.lbagroup.com/about) is a North Carolina Top 50 Hispanic minority-owned small business and is CVMSDC-certified. It has over 50 years of experience in providing technology and risk management for industrial and telecommunications infrastructure assets in the radio frequency and electromagnetic spaces. The group includes LBA Technology, Inc., a leading source and integrator of radio frequency systems, lightning protection, and EMC equipment for broadcast, industrial, and government users worldwide.

Little Mountain Test Facility (LMTF) is a USAF nuclear hardness simulation facility hosted by the ICBM Systems Directorate (AFNWC/NI). LMTF is a state-of-the art laboratory dedicated to simulation testing of radiation, shock and vibration, and electromagnetic effects for defense and commercial systems. Since 1974 the Boeing Company has operated and maintain LMTF. The Boeing Company operates, maintains, and upgrades all critical test capabilities at LMTF.

LMTF has over 40 years of experience in EMP harness design and testing a complete and comprehensive approach to EMP test programs. LMTF extensive experiences includes site surveys, system architecture and cost/schedule analysis to assist in a successful test program. Developing a comprehensive test plan includes addressing system topology, operational scenarios, test mythologies, test levels and points, and pass/fail criteria provides success for the basis for a successful test execution.

LMTF has a long term working relationship with ICBM and MILSTAR in performing EMP test planning/integration and test execution both per adapted EMP requirements in the systems' specifications and per MIL-STD-188-125. LMTF developed complete MIL-STD-188-125 Hardness Maintenance Hardness Surveillance (HMHS) programs for several programs.

Government customers may fund work efforts by MIPR or AF Form 616. Commercial customers work with LMTF through a Cooperative Research and Development Agreement (CRADA).

Metatech Corporation (http://www.metatechcorp.com/) is a small veteran-owned and operated business of highly-qualified scientists and engineers with broad experience in developing technically sound and innovative EM environmental solutions. Offerings include EM compatibility (EMC), protection designs and testing procedures, geomagnetic storm protection, nuclear EMP prediction for any burst situation, assessments, protection and standardization (e.g. HEMP and SREMP), and IEMI assessments, protection and standardization.

Metatech is a key contributor to EMP research in the areas of HEMP and SREMP environments and coupling and in the development of hardening and testing technologies including military standards, specifications, handbooks, and software. Major programs include SREMP testing and analyses at flash x-ray simulators, SREMP and HEMP standards development, HEMP environment and long-line coupling calculations and direct support for the design of facilities to achieve HEMP hardening. Their IEMI activities have involved performing assessments of critical infrastructure facilities, performing tests to determine the IEMI susceptibility of equipment and designing protection for the high-frequency portions of HEMP and IEMI together.

Metatech has also been a leader in participating in the development of 22 International Electrotechnical Commission (IEC) high power transient (HEMP and IEMI) protection standards for commercial applications through IEC Subcommittee 77C. These standards were developed for commercial usage and fully consider the immunity of commercial electronics to EMI in the protection methods to be used for HEMP, SREMP, IEMI and GMD disturbances.

Michael A. Caruso, (carusomi54@gmail.com, 847-226-8849) is an independent consultant based in Arizona offering consulting services for TEMPEST, SCIF, and EMP protected facility design. Mr. Caruso has been involved in the business working with both Government and private clients for over 30 years and offers an independent perspective of risk evaluations, various mitigation techniques and available vendor materials.

Noovis (www.noovis.com) provides critical communication and IT-based infrastructures which have core advantages from those currently deployed including EMP resilience, reduced energy consumption, higher bandwidth, expedited post-event recovery, and reduced CapEx and OpEx requirements. It designs, installs and integrates core IT infrastructures using passive optical networking that drastically reduces copper connectivity and its associated power requirements within communication and Information systems.

The Noovis passive, fiber-rich designs and infrastructures are intrinsically more resistant to EMP and high power microwave (HPM) attacks, thus complimenting existing risk mitigation strategies and disaster recovery plans. This is accomplished, in part, as the Noovis network topology effectively eliminates the need for access switches, within a Local Area Network (LAN) and provides an entirely passive and encrypted optical pathway for data to support communication networks, typical end user devices as well as critical Industrial Control Systems (ICS), Supervisory Controls and Data Acquisition (SCADA) networks. Noovis designed networks can run miles without the insertion of electronics versus the requirement for electronics approximately every 300 feet for many current networks. In addition, this creates substantially reduced power consumption over traditional network connectivity, decreasing the draw on microgrid generated power, allowing the reallocated energy to be used for additional critical needs.

NVIS Communications (www.nviscom.com) and its systems integration partner Pepro LLC (http://www.peprollc.com/) designs and manufactures shielded enclosures using a patented Faraday Cage technology to protect sensitive communications equipment against lightning strikes, EMP, EMI, Passive Intermodulation (PMI), and Radio Frequency Interference (RFI). Their equipment has endured many thousands of amps/joules in very rigorous industry standard testing criteria and always performed flawlessly.

Each product has the ability to be customized in order to best address a variety of potential applications and needs. These needs range from remote, difficult to reach fixed sites to small/medium and very large deployable mobile platforms all the way to very compact rapid deployable (C130/C17 transportable) kits. It provides ongoing support for all of its products as well as a strong warranty.

Scientific Applications & Research Associates (SARA), Incorporated (https://sara.com) was formed in 1989 to harness the creativity, innovation and entrepreneur spirit of engineers and scientists. SARA, Inc. is employee-owned and is managed by leaders that each has 20+ years of experience in Defense and Aerospace. SARA has nearly 100 innovative scientists and engineers doing research and development for government, military, and industrial clients. It has world-class expertise in understanding, modeling, fabricating, testing and adapting high power EM (EMP and HPM) transmission, propagation, detection, diagnosing and shielding/hardening and low signal level EM and RF sensing and signal processing, including passive EM detecting. Their “Cradle to Grave Hardening” offers architectural and engineering services for EMP subsystem/electrical subsystem integration, hardness maintenance and surveillance, EMI/EMP modeling, testing and analysis and power quality and reliability of EMP related components.

Storm Analysis Consultants (http://solarstormconsultant.com/) provides consulting and information on severe solar storms, space weather, geomagnetic storms and the electrical power grid impacts. Principal Consultant John Kappenman has been a one of the leading advisors for power companies both nationally and globally on the effect of solar storms to utilities. Storm Analysis Consultants analysis services include (1) Assessing the Space Weather Threat Environment, (2) Assessing Impact on Critical Infrastructures & Systems with PowerCast™, (3) Geomagnetic Storm NowCasting and Forecasting Technology…Tailored to the Electrical Power Industry, (4) Simulate Historic and Probable Threat Scenarios, (5) Model Complex Geologies for Accurate GIC Calculation, (6) Scalability of PowerCast to Model Large Geographic Regions and Multiple Interconnected Power Grids, (7) Assessing Space Weather Threat Environment Over Broad Ocean Regions, and (8) Modeling Geo-potentials on cross undersea cables.

TEMPEST Inc. (http://www.tempest-inc.com/ 703-836-7378) provides TEMPEST security engineering services including EMSEC, HEMP, high power microwave (HPM), and EMC testing with cybersecurity, intelligence, surveillance, and reconnaissance (ISR) systems, as well as design services in accordance with current U.S. DoD, FCC, Australian and European community requirements.

Triton Metals Inc. (http://www.tritonmetals.com/) is one of the largest metal manufacturers on the East Coast. Together with Electromagnetic Associates, LLC (www.emag-associates.com) they provide EM threat hardening, design and integration, as well as EM threat project management and construction administration/construction management services of critical infrastructure systems and life-safety systems that must work during and after a HEMP/EMP attack, such as power systems, controls, data centers, CBRN air-filtration systems, water systems, communications systems and sensor systems.

Trusted Systems (http://www.trustedsys.com/) is the pioneer and industry leader in the development and deployment of the Information Processing System Security Container or SCIF in a Box® which combines the physical strength against near blast protection and magnetic shielding of a GSA Class 5 IPS Container with EMP shielding exceeding MIL-STD-188-125. Their product line offers sizes and configurations from COOP sites, to remote critical infrastructure facilities to office and large data centers.

Page Southerland Page, Inc. (Page) (http://pagethink.com/v/iemi-hemp-protection/)
A 400-plus person architecture and engineering firm working in the U.S. and abroad offering specialty design and engineering services for Critical Infrastructure facilities. Services include planning, programming, design, commissioning and construction administration for facilities protected from HEMP, IEMI, GMD and other high- and low-frequency EM radiation. Page offers complete solutions, drawing upon experience protecting buildings and campuses owned by government, public utilities, universities, healthcare, research, petrochemical, and manufacturing companies from many types of threats: explosion, espionage, terrorism, floods and hurricanes. Page has extensive experience with EM shielding for network operations centers, embassies, data centers, and medical and biotechnology research facilities. Page can manage a critical design project from program concept to completion of construction, working with experienced partners to ensure that shielded facilities perform as designed. Page's recent portfolio includes two large (>70,000 SF), privately-owned HEMP and IEMI-shielded SCADA control and data centers, each serving markets of over 2 million customers.

Shielded Data Centers

If a hosted solution is an option for data storage, particularly for a disaster recovery environment, two companies are known to offer data center services within their EM hardened data centers (see Disclaimer at the beginning of this Appendix).

Cyber Innovation Labs (CIL) (http://www.cyberinnovationlabs.com/) is a premier provider of enterprise-class managed Infrastructure-as-a-Service (IaaS) solutions and professional services. CIL's Protected Platform as a Service (PPaaS) can provide EMP, HEMP, and IEMI shielded colocation and 100% private, single-tenant cloud solutions for delivery of mission critical applications and services to customers, at price points on par with less robust traditional offerings. CIL offers custom designed steel wall, slab-to-roof facility shell, installed with 360 degree EMP shielded protective hardened enclosure. Customer facilities include all shielding, housing, filtering and/ or hardening for all electrical, mechanical and related MEP/FP infrastructure and related subsystems. All facilities are designed, installed and tested per MIL-STD-188-125-1/2 standards.

EMP Grid Services LLC, (http://www.empgridservices.com/) is a consortium of industry-leading advanced engineering and data-center centric design/build specialists who have delivered over 10 million square feet of premier global enterprise data center facilities and represent over $1.4 B in annual revenues. Its team embody decades of experience in the data center build, commission and delivery of EMP, HEMP, IEMI and Geomagnetic Storm Protected facilities. The EMP GRID Services Team possesses core enterprise data center competencies that include:

- Master Technology Planning
- Facility Design/Build/Delivery
- Turn-key Program Management
- Infrastructure Commissioning
- Certification/Test-out
- Technical/Operational Service Support

New Approaches to EMP Protection

Hardening a new facility with welded steel can be cost prohibitive. Retrofitting an existing facility adds operational disruption to the complexity and cost of a major renovation project. Depending on your site specific mission and requirements, this may remain the best approach. However, two alternative solutions are now commercial and address EM threats for civil and commercial applications which may be more cost effective and less disruptive to current operations (see Disclaimer at the beginning of this Appendix).

1. Conductive Composites (http://www.conductivecomposites.com/) has developed and commercialized a line of multifunctional electrically conductive and EM shielding materials. In essence, they make plastics and composites conduct and shield like metals, creating a whole new realm of possibilities and opportunities for plastic and composite products. They provide cost effective shielding across a broad spectrum of EM threats for numerous types of applications. They offer multifunctional structural materials that integrate directly into typical manufacturing architectures, in addition to installation, test, and certification services.

Solutions include conductive wallpapers, paints, adhesives, stuccos, concretes, and window screens. Facilities shielded with these materials have been shown to effectively attenuate EMI/RFI as well as shield against EMP threats. A key differentiating feature is that the materials can be easily retrofitted into existing facilities as well as new construction. Conductive Composites is considered critical to the defense industrial base, with rated production contracts and classified programs, and has been awarded numerous funding phases from the Defense Production Act (DPA) Title III program.

2. Omni-Threat Structures, LLC (OTS) (www.omnithreatstructures.com) designs and builds multi-threat structures protecting against HEMP, IEMI, Emanations, Ballistic/Blast, and extreme natural disasters. OTS's proprietary construction methods have been deployed successfully to build steel and concrete structures that are threat configurable, scalable, and cost effective. The company completed the world's first shielded concrete structure that exceeded the shielding requirements of MIL-STD-188-125. OTS has successfully completed multiple specialty and hardened and shielded structures throughout the country for utility, commercial, and government clients. Notable projects include the successfully completed Vertical Electro-Magnetic Pulse Simulator (VEMPS) at Patuxent River Naval Air Station, Patuxent River, Maryland as well as a 65,000 square foot utility control and data center in Texas that incorporates commercial, hurricane-resistant, and HEMP shielded structures all in one building.

Omni-Threat Structures' team has three decades of success as a high integrity industrial GC, over a decade of success with specialized design-build hardened structures and experience in the nuclear power industry, building Fukushima Flex/Beyond Design Basis structures that meet NRC Regulatory Guide 1.76 standards. Building on a history of success, OTS now constructs EMP – IEMI shielded structures that also incorporate protection from ballistic/blast, natural threats, including Cat 5 hurricanes, EF-5 tornados, and seismic events.