Electromagnetic Pulse Shielding Mitigations

Best Practices for Protection of Mission Critical Equipment

August 2022

Science &
Technology

ACKNOWLEDGEMENTS

This document was developed with significant input and collaboration from industry and government stakeholders. The Department of Homeland Security (DHS) Science and Technology Directorate (S&T) and the Cybersecurity & Infrastructure Security Agency (CISA) acknowledges and thanks all those who have contributed to this framework.

This document was developed with contributions from the following people:

Name	Organization/Affiliation
Dr. Pauline Paki	U.S. DHS Science and Technology Directorate
Sarah Mahmood	U.S. DHS Science and Technology Directorate
Brent Talbot	U.S. DHS Science and Technology Directorate
Jim Platt	U.S. DHS Cybersecurity & Infrastructure Security Agency
Manny Centeno	Federal Emergency Management Agency (FEMA)
Rebecca Schoonover	Homeland Security Systems Engineering Development Institute (HSSEDI)
Dr. Michael Cohen	HSSEDI
Dr. Gregory Robertshaw	HSSEDI
John Trovato	HSSEDI

Resource

The U.S. Department of Homeland Security, Science and Technology Directorate

Website:https://www.dhs.gov/science-and-technology/electromagnetic-pulse-empgeomagnetic-disturbance

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

The civilian Critical Infrastructure (CI) within the United States (U.S.) faces threats from manmade Electromagnetic Pulse (EMP) attacks, and from natural EMPs caused by major solar storms. As described in Executive Order (EO) 13865, Coordinating National Resilience to Electromagnetic Pulses (March 26, 2019),[1] "An EMP event has the potential to disrupt, degrade, and damage technology and critical infrastructure systems."

Public awareness of manmade EMPs began on July 9, 1962 following the Starfish Prime test, during which the U.S. detonated a 1.4-megaton thermonuclear weapon 250 miles above Johnston Island in the mid-Pacific. On the Hawaiian Islands, 900 miles away, burglar alarms were triggered, circuit breakers opened, and over 300 streetlights in Honolulu failed nearly simultaneously.[2] A few months later, to better understand EMP effects, the Soviet Union conducted a series of high-altitude nuclear tests over Southwestern Siberia, inadvertently demonstrating the weaponization potential of high-altitude EMP (HEMP), as revealed to U.S. scientists in 1995.[3]

Presidential Policy Directive 21 (PPD 21), Critical Infrastructure Security and Resilience (February 12, 2013),[4] cites the responsibility of attaining resilience as one that is "shared among the Federal, state, local, tribal, and territorial (SLTT) entities, and public and private owners and operators of critical infrastructure." Many U.S. civilian and military organizations have incorporated EMP protections into their most critical assets, equipment, and operating concepts to protect against electromagnetic (EM) effects that could threaten CI survival and operability. Still, in 2017 the EMP Commission[5] recommended that the U.S. could further protect and defend the national electric grid and other CI against EMP events "at reasonable cost and minimal disruption."

The Department of Homeland Security (DHS) is responsible for recommending measures to protect the CI of the U.S. In response to E.O. 13865, the DHS Science and Technology Directorate (S&T) is developing guidance on EMP mitigation investments for public and private sector use. There are a variety of EMP mitigation options that can be utilized to protect civilian CI equipment against large-scale EMP events.

This document focuses on a best practice for EMP protection that applies to critical assets across all CI sectors: the placement of co-located groups of time-urgent, mission-critical equipment (MCE) in cabinets or racks, shelters, shielded rooms, or buildings that are protected by an electromagnetic barrier.[6] The objective of this document is to provide information about

---

1 The White House, "Executive Order (13865) on Coordinating National Resilience to Electromagnetic Pulses," Infrastructure & Technology, 26 March 2019. https://trumpwhitehouse.archives.gov/presidential-actions/executive-order-coordinating-national-resilience-electromagnetic-pulses/

2 Longmire, C. L., "EMP on Honolulu from the Starfish Event," Mission Research Corporation, Theoretical Note 353, March 1985, p. 6. http://ece-research.unm.edu/summa/notes/TheoreticalPDFs/TN353.pdf

3 Sequine, H., "Memorandum for Record," 17 February 1995. http://nuclearweaponarchive.org/News/Loborev.txt

4 The White House, Office of the Press Secretary, "Presidential Policy Directive–Critical Infrastructure Security and Resilience," 12 February 2013. https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil

5 EMP Commission, "Assessing the Threat from Electromagnetic Pulse (EMP) Volume I: Executive Report," July 2017, p. 1. http://www.empcommission.org/docs/empc_exec_rpt.pdf

6 EIS Council, "Electric Infrastructure Protection Handbook IV: Electromagnetic Pulse (EMP) Protection Best Practices Handbook," 2021, pp. 144-160.

EMP enclosures that will assist critical infrastructure owners and operators in protecting critical assets from the effects of an EMP attack.

2.0 EMP MITIGATION BEST PRACTICES

2.1 Assess System Vulnerability

To determine the need for EMP infrastructure protection, CI owners and operators should consider the following key factors:

- The criticality of the assets that require protection
- The vulnerability of the assets' individual components to EMP
- The current or planned configuration of the system, including location and geography

The Federal Government provides guidelines that private sector CI owners and operators can leverage to assess current equipment protections. These guidelines can be used to evaluate approaches for incorporating protections into existing equipment configurations or as an input to decisions when purchasing new equipment, retrofitting existing equipment or facilities, or building new facilities. These guidelines include a two-part Department of Defense (DoD) military standard (MIL-STD-188-125-1[7] and -2[8]) that describes the protection of critical, time-urgent, ground-based systems and facilities to minimize the possibility of damage from an EMP event. Additional research references are provided in Appendix A.

2.2 Determine EMP Protection Approach

EM signals such as those generated by EMP can couple to equipment circuits through chassis apertures (e.g., slots, holes, windows), communications networks, and power conductors. Electric fields levels can be reduced through EM reduction techniques such as housing MCE in shielded cabinets and enclosures, and the use of filters, fiber optic cables (as opposed to coaxial cables), and non-linear protection devices that provide surge protection. Points of entry (POE), or penetrations that could allow EM energy into the shielded enclosure, should be protected by a POE protective device.

The use of a barrier protection ensures that the equipment housed within the enclosure is subjected to minimal EM levels that do not hamper its survival or operation. Similar techniques are used to meet commercial and military electromagnetic compatibility (EMC) and lightning protection standards. Comprehensive EMP protection in alignment with MIL-STD-188-125-1 and -2 can be achieved by enclosing MCE in a shielded volume that is at least 1m x 1m x 0.7m in size and that provides an 80 decibel (dB) barrier. However, the determination of the number of decibels of attenuation that the barrier needs to provide is dependent on the unique protection requirements of the system. MCE that must be placed outside the shielded barrier to function properly (e.g., antennas, sensors, and environmental control systems) will be exposed to the full EMP threat and thus must be accompanied by spare parts.

When deciding on the best approach to protect important assets from EMP, CI owners and operators should consider the system's architecture and design, location, geography, materials,

7 High Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C4I Facilities Performing Critical, Time-Urgent Missions, Part 1a: Fixed Facilities, MIL-STD-188-125-1a, Department of Defense Interface Standard, 17 July 1998, validated 07 April 2005.

8 High Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C4I Facilities Performing Critical, Time-Urgent Missions, Part 2: Transportable Systems, MIL-STD-188-125-2, Department of Defense Interface Standard, 3 March 1999, validated 07 April 2005.

POEs that allow external EM energy penetrations, and ancillary equipment. Furthermore, the assessment should consider the system from end to end, as disruption to a single, critical, component can result in a system-wide failure. Firms that specialize in the EMP protection approaches described in this document can assist with this assessment.

The EMP protection approach assessment should also consider the complexity of the system configuration and its time urgency (e.g., whether the system tolerates an outage of seconds, minutes, hours, or longer). If temporary outages are not acceptable, then the most stringent protection approach should be followed, as outlined in MIL-STD-188-125-1 and 2. If system outages or time urgency are not critical, then CI owners and operators can take less onerous protection approaches that are accompanied by operator interference such as powering down and restarting the system or repairing the equipment using readily available spare parts.

The following subsections describe three low-risk EMP hardening approaches in order of complexity: Equipment Enclosures, Shelters, and Rooms or Buildings.

2.2.1 Option 1: EMP-Protected Equipment Enclosures

Portions of MCE can be protected through placement inside a small, shielded cabinet or enclosure called a Faraday cage. The rendering in Figure 1 shows an EMP-protected server rack with the door open.

- This approach can be designed for portability.
- This solution is practical when there are only a few pieces of equipment that require protection (e.g., a server or a single distribution transformer).
- The use of multiple cabinets or racks will result in numerous verification and maintenance activities that can create complex asset management challenges.
- As the entire system may not be shielded, the solution may rely on the availability of working spare parts and the execution of operational procedures to bring the system back online after an EMP event.

Figure 1. Interior of an EMP-Protected Equipment Enclosure

2.2.2 Option 2: EMP-Protected Shelters

An effective form of low-risk hardening consists of placing clusters of MCE into one or more EMP-protected shelters. These shelters are typically larger than the cabinet or rack enclosures described in Option 1, but smaller than the room or building-size enclosures described in Option 3. Shelters are ideal for remote locations to reduce maintenance requirements.

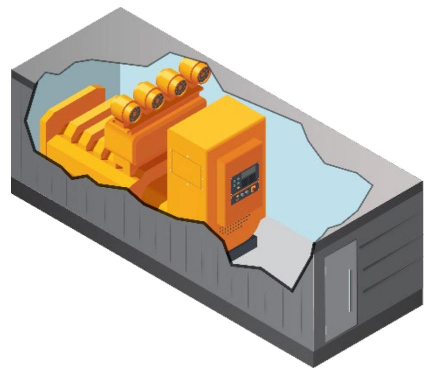

Figure 2. EMP-Protected Shelter

- Shelters can be fixed or transportable.
- Multiple shelters can be connected if the POEs between the shelters are sufficiently protected.
- In addition to the MCE, the shelters should enclose support equipment such as associated control and communications equipment, vulnerable spare parts, and heating, ventilation, and air conditioning (HVAC) equipment. If the MCE is accompanied by an emergency diesel generator with a fuel tank, the electrical fuel pump controls also require sheltering. A rendering of a mission critical generator housed in an EMP-protected shelter is provided in Figure 2.
- The use of shelters to group equipment reduces the number of components and devices that must be verified and maintained throughout the life of the system. Therefore, the shielding inspection requirements, maintenance time, and labor costs for shelters can be lower than for the enclosures described in Option 1.
- Shelters can be attended or unattended depending on the system operating concept. The best practice described in Section 2.4 provides additional information.
- The shelter design should ensure that the POEs leading into the shelters are protected, for instance by EMP filters on lines going through the shelter POEs or by uninterruptible power supply (UPS) and EMP-rated surge protectors on power lines leading to critical equipment. External communications and power lines should be placed underground to reduce coupling to external cables. The best practice described in Section 2.5 provides additional information on protecting POEs.

2.2.2.1 DHS Implementation of EMP-Protected Shelters

The use of multiple, connected EMP-protected shelters is the approach adopted by the DHS Federal Emergency Management Agency (FEMA) Integrated Public Alert & Warning System (IPAWS). IPAWS partners with commercial and public radio broadcast stations nationwide to ensure the continuity of terrestrial broadcast services through the National Public Warning System (NPWS).

Currently, there are 77 IPAWS shelter installations nationwide. A sample IPAWS installation is shown in Figure 3. The system infrastructure consists of two freestanding EMP shelters that are each the size of a shipping container and that connect via a shielded umbilical unit. The interior of these shelters, which are operated by local station personnel, are equipped with backup communications equipment and a power generator so they can continue broadcasting information to the public after an emergency.

Although the IPAWS solution is intended for fixed use, the shelters are transportable and can be moved between locations or installed in unique configurations as dictated by the location and mission need.

Figure 3. FEMA IPAWS EMP-Protected Shelters in Massachusetts (Source: FEMA)

2.2.3 Option 3: EMP-Protected Rooms or Buildings

The placement of MCE in protected rooms or buildings is a low-risk but complex approach. EMP-protected rooms or buildings may be constructed of metallic shielding, conductive concrete shielding, or hybrid concrete/steel shielding. The architecture and engineering literature for firms that specialize in EMP protection can provide additional information.

- EMP-protected rooms or buildings can be planned into the construction of new facilities or incorporated by retrofitting existing structures.
- This approach can be used to completely cover and house an entire system. Example facilities to which this approach applies include electric power control centers, national or regional network operations centers, and national cloud service provider centers.
- This is the most complicated of the three options to implement due to the amount of shielding material used and the maintenance required. As stated by the Electric Power Research Institute (EPRI) in 2019, "Cost is always a consideration. Several utilities have hardened their control centers to MIL-STD-188-125-1 specifications. Some have chosen to harden the entire facility, while others have hardened only the portions deemed critical to maintaining bulk power operations."[9]
- Maintainability and asset management should be considered when selecting a building shielding technology and designing the internal layout of the building.

2.3 Identify External Dependencies

A site may fail to maintain post-EMP operational readiness due to structural dependencies on unhardened external systems.

9 Electric Power Research Institute, "2019 Technical Report: High-Altitude Electromagnetic Pulse and the Bulk Power System Potential Impacts and Mitigation Strategies (3002014979)," 2019, Chapter 5, pp. 5-2.

- Assets that are outside the facility's boundary and control should be identified, including wireline communications (e.g., Public Switched Telephone Network or the internet), the electric power grid, fuel sources, transportation, and other critical services.
- Mitigation strategies for external assets should be developed. Facilities should consider installing collocated, EMP-protected backup power sources and fuel stores, and for systems that rely on wireline communications, alternative radio frequency communications such as commercial satellite communications.

2.4 Determine Requirements for Unattended and Attended Solutions

The determination of whether the protected equipment will be unattended or attended is driven by the system operating concept.

Unattended systems are those that run continuously (e.g., before, during, and after an EMP event) or that are used solely for automatic failover backup purposes. These may include the following:

- A single backup switch at a telecommunications switching office serving a national security or emergency preparedness customer
- A single or small group of power transformers at a substation
- Toxic chemical processing equipment that must operate continuously to avoid a hazardous chemical incident

Systems are attended primarily when active human operation of the equipment is required, and when the equipment is critical for public health, public safety, national security, or emergency response purposes. Attended solutions may be designed with workspaces that are collocated with the MCE, as depicted in the rendering in Figure 4.

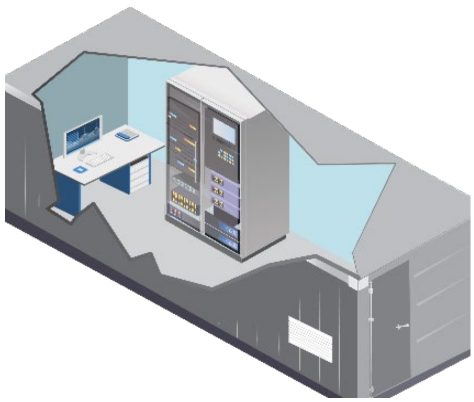

Figure 4. Attended Shelter

Examples of facilities that would use an attended solution include the following:

- Primary and Backup public service answering point (e.g., 911 call/dispatching center)
- Nuclear power plant offsite emergency operating facility (EOF)
- Local government emergency operating center (EOC)
- Emergency radio or television broadcast station

Attended solutions require consideration of livability requirements. The FEMA IPAWS shelters described in Section 2.2.2.1 can be attended during an emergency. They include back-up communications equipment, living quarters with a fold-down bed, supplies, an air filtration system, hygiene facilities, and 30 days of rations. The personnel sustainment supplies provided in the FEMA IPAWS shelters are shown in Figure 5.

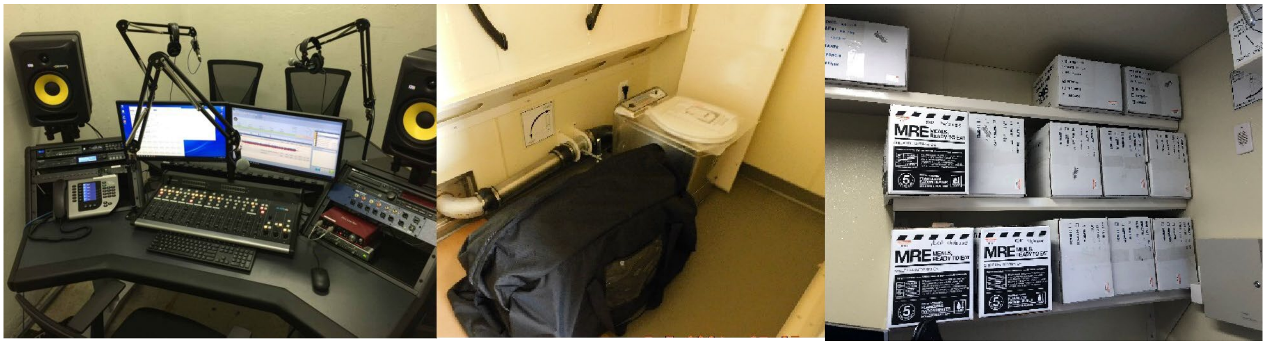

Figure 5. FEMA IPAWS Attended Shelter Solution: Backup Broadcasting Capabilities, Living Quarters, and Rations (Source: FEMA)

2.5 Protect Points of Entry

All POEs must be protected from the EM fields produced by EMP. This will ensure that the amount of EM energy that enters the enclosure or facility is limited to levels where electrical and electronic equipment is not damaged or upset.

POEs can be protected by shielded cables or conduit, waveguides beyond cutoff, gaskets/ spring fingers, filters, nonlinear protection devices. The choice and level of protection are driven by the system requirement.

- MCE should be kept in EM enclosures that include environmental control systems and auxiliary generators. This may require multiple enclosures or separate shielded zones connected by shielded cables or conduits. Additional filtering at entry points may be needed to reduce coupled currents.
- Plumbing should use metal pipes that are grounded at both ends.
- Air handling ducts should follow the rules for waveguide beyond cutoff.
- Fiber penetrations should also occur via a waveguide and not use armor clad cables.
- EMP-rated surge protectors and an UPS should be placed on power lines leading to critical equipment and external communications.
- Power lines should be placed underground to reduce coupling to external cables. Connection to the utility should be made with a Delta transformer (preferred) or long-line protection module to eliminate the EM effects coupled to long lines. The entry points must also have filters and surge suppressors to reduce the EM effects coupled to the wires.
- Personnel entryways must ensure that shielding integrity is maintained. This is typically achieved with a knife-edge gasket. For the most stringent designs, the shelter should use a double door vestibule to ensure the shielding is maintained during entry.

2.6 Develop Activation and Operational Procedures

The EMP protection options described in this document rely on a concept of operations (CONOPS) for routine and emergency operations. As the operating procedures and configuration of the protected equipment may vary from the equipment that is not EMP-protected (e.g., located within the primary CI facility), a CONOPS should be developed that is tailored to the selected protection approach. At a minimum, the CONOPS should include the following features:

- Roster of authorized personnel
- Personnel roles and responsibilities
- Conditions under which the protected equipment should be activated and deactivated, including a timeline for operating in an EMP-contested environment to reduce the risk of EMP exposure
- Operational checklist to activate, shut down, and reactivate the system
- Physical security access control mechanisms
- Methods and procedures for communicating with personnel before, during, and after an EMP event
- A sustainment plan for maintaining and inspecting the EMP protections
- Cybersecurity access control mechanisms for equipment with a Human Machine Interface (HMI)
- The identification of storage areas for materials and supplies that support human sustainment (e.g., food, water, blankets, sanitary, first aid)
- A schedule and procedure for refreshing materials and supplies
- Procedures for operating backup power sources (e.g., generator, green renewable power) and for maintaining supplies (e.g., generator fuel, generator lubricant, and batteries)
- Instructions for controlling and maintaining the HVAC and temperature and Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) air filters
- Emergency generator startup, refueling, and lubrication instructions
- An inventory and storage process for EMP-protected spare equipment
- Status reporting guidelines for the system operating period (may be 30 days or longer)
- Procedures for securing the system and restoring the EMP-protections following the recovery of the primary operating facility.

2.7 Conduct Regular Inspections, Maintenance, Training, and Exercises

Collocating equipment and systems in a protected shelter or room is generally preferable to the use of multiple individual equipment enclosures as it reduces the number of POEs and streamlines the testing, inspection, and maintenance requirements for the shielded barrier and POEs. To maintain EMP protection, facility sustainment activities must incorporate routine inspections of EMP shielding and POEs to detect leaks. These inspections should take place prior to deployment, annually, and when configuration changes occur, including the addition of new equipment.

A Hardness Maintenance/Surveillance Plan should be developed that includes the identification of Hardness Critical Items (HCI), including the POEs through which lines pass that are connected to the internal equipment. The plan should detail inspection frequency and preventive maintenance requirements. The depth and frequency of inspections should be tailored to the criticality of the equipment housed within the facility.

Configuration management practices should be applied within the facility and documented in a configuration management plan. The plan should include a personnel list and a description of the potential adverse effects of modifications to the building shielding and/or to the protected equipment the facility houses. Personnel should be notified of modifications such as the addition of a new POE.

The CONOPS should be exercised periodically through a training program.

- Training needs will vary according to whether the enclosures are attended or unattended, and according to personnel roles.
- Training for emergency backup shelter operations should be conducted once or twice per year with the personnel listed in the CONOPS roster.
- New personnel added to the roster should receive training immediately.
- Training should reflect realistic emergency operations.
- Training should be conducted with the protected MCE to ensure personnel are familiar with facility access and equipment operation.
- Training should incorporate equipment replacement using the spare parts provided in the facility.
- Equipment that fails to operate correctly during training should be reported to the facility maintenance organization.

CI owners and operators should also conduct realistic simulation exercises that cover facility operations and use trained personnel. These exercises should be conducted at least once per year. The facility owner and operator can conduct them separately or they could be planned in conjunction with national Federal or CI Sector EMP exercises.

3.0 CONCLUSION

As noted in the 2017 EMP Commission Report, the EMP threat to the United States is "present and continuing."[10] Just as CI owners and operators have taken significant strides to address cyber threats, they should now consider addressing EMP threats within their risk assessment program.

CI owners and operators can implement EMP protections in many ways, but critical, time-urgent systems should be housed in an overall EMP barrier with protected POEs. This document presents three low-risk EMP protection approaches: equipment enclosures for small groups of collocated equipment, shelters for clusters of MCE, and rooms or buildings for protecting an entire system.

CI owners and operators can implement the approaches described in this document in either retrofit or new installation mode. Furthermore, many commercial-off-the-shelf products are available. Collocating equipment simplifies design and maintenance actions while providing the flexibility to add future capabilities, make design changes, and incorporate new technologies without concern for the EMP protection of specific equipment.

10 Ibid 5

APPENDIX A. ADDITIONAL READING

The following references are provided as an additional resource for CI owners and operators.

- G.H. Baker, "EMP and Solar GMD Protection for the North American Grid," Geomagnetic Disturbance Workshop, Idaho National Lab, 7 April 2015.
- G.H. Baker, "Electromagnetic Pulses - Six Common Misconceptions," 5 November 2014. https://www.domesticpreparedness.com/commentary/electromagnetic-pulses-six-common-misconceptions/. [Link accessed September 13, 2021].
- G.H. Baker, "Evolution and Rationale for United States Department of Defense Electromagnetic Pulse Protection Standard," December 2016. http://commons.lib.jmu.edu/cgi/viewcontent.cgi?article=1004&context=isat. [Link accessed September 13, 2021].
- P. R. Barnes, et. al., "MHD-EMP Analysis and Protection," DNA-TR-92-101, September 1993, AD-A269 647. http://www.dtic.mil/dtic/tr/fulltext/u2/a269647.pdf. [Link accessed September 13, 2021].
- Idaho National Laboratory, "Strategies, Protections, and Mitigations for the Electric Grid from Electromagnetic Pulse Effects," Report No. INL/EXT-15-35582, January 2016. https://inldigitallibrary.inl.gov/sites/STI/STI/INL-EXT-15-35582.pdf. [Link accessed September 13, 2021].
- Electric Infrastructure Protection Handbook IV: Electromagnetic Pulse (EMP) Protection Best Practices Handbook, Electric Infrastructure Security (EIS) Council, 2021, pp. 144-160.
- Department of Homeland Security, "Electromagnetic Pulse (EMP) Protection and Restoration Guidelines for Equipment and Facilities," 22 December 2016. http://docplayer.net/49420460-Electromagnetic-pulse-emp-protection-and-restoration-guidelines-for-equipment-and-facilities.html. [Link accessed September 13, 2021].
- Department of the Army, "Electromagnetic Pulse (EMP) and Tempest Protection for Facilities," Pamphlet EP 110-3-2, 31 December 1990. https://www.jrmagnetics.com/security/specs/EP_1110-3-2.pdf. [Link accessed September 13, 2021].
- Foundation for Resilient Societies, "Protecting U.S. Electric Grid Communications from Electromagnetic Pulse,", April 2020. https://www.resilientsocieties.org/uploads/5/4/0/0/54008795/protecting_us_electric_grid_communications_from_emp.pdf. [Link accessed September 13, 2021].
- M. Korkali, et.al., "Reducing Cascading Failure Risk by Increasing Infrastructure Network Interdependence," Scientific Reports, 7.44499, DOI:10:1038/srep44499. https://www.nature.com/articles/srep44499.pdf. [Link accessed September 13, 2021].

ACRONYMS

Acronym	Definition
CBRNE	Chemical, Biological, Radiological, Nuclear, and Explosives
CONOPS	Concept of Operations
CI	Critical Infrastructure
DHS	Department of Homeland Security
DoD	Department of Defense
EIS	Electric Infrastructure Security
EMC	Electromagnetic Compatibility
EM	Electromagnetic
EMC	Electromagnetic compatibility
EMP	Electromagnetic Pulse
EO	Executive Order
EOC	Emergency Operating Center
EOF	Emergency Operating Facility
EPRI	Electric Power Research Institute
EPRO	Electric Infrastructure Protection
FEMA	Federal Emergency Management Agency
GMD	Geomagnetic Disturbance
HCI	Hardness Critical Items
HEMP	High Altitude Electromagnetic Pulse
HMI	Human Machine Interface
HVAC	Heating, Ventilation, and Air Conditioning
IPAWS	Integrated Public Alert and Warning System
MCE	Mission Critical Equipment
MHD	Magnetohydrodynamic
NCCIC	National Cybersecurity and Communications Integration Center
NPWS	National Public Warning System
POE	Points of Entry
S&T	Science & Technology
UPS	Uninterruptible Power Supply
U.S.	United States