EPRI Electromagnetic Pulse Research

Overview

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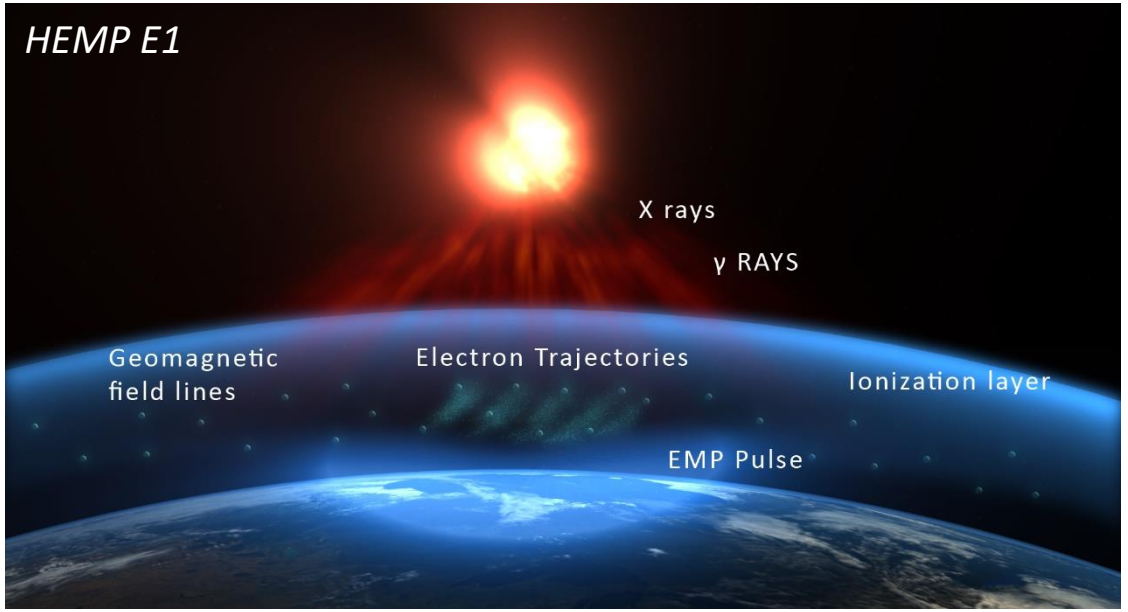
High-Altitude Electromagnetic Pulse (HEMP)

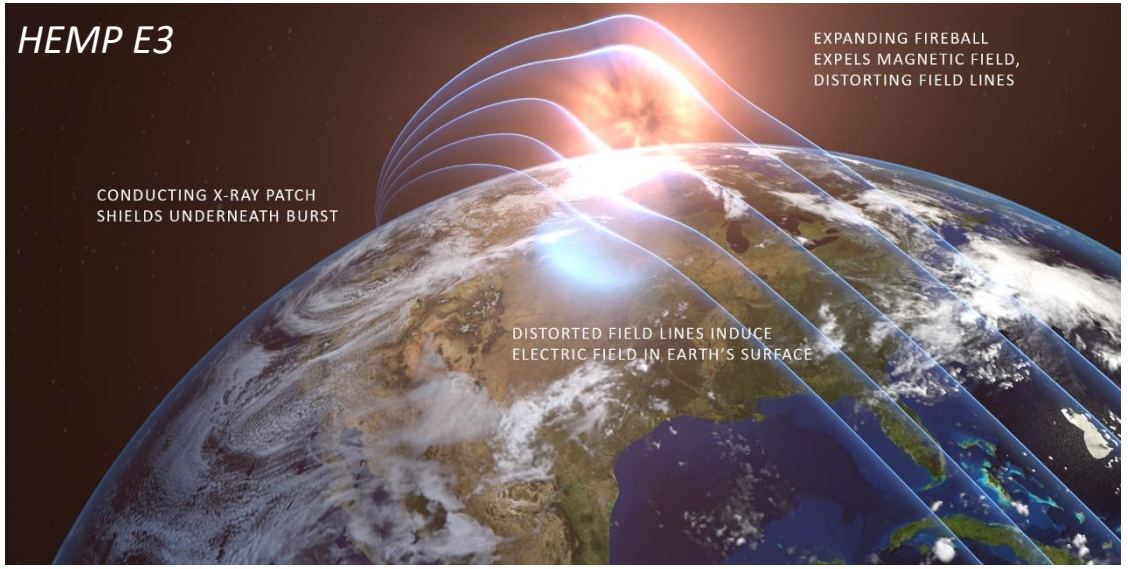
- **Created by the detonation of a nuclear weapon at high-altitude or in space**

- **E1: Early-time Pulse**
  - 50 kV/m, 2.5 nsec rise time (at worst location on ground)
  - Can affect large geographic areas
  - Potential impacts to electronics, insulation flashover

- **E2: Intermediate-time Pulse**
  - 0.1 kV/m, waveform and effects similar to nearby lightning strike
  - No transmission system impacts expected

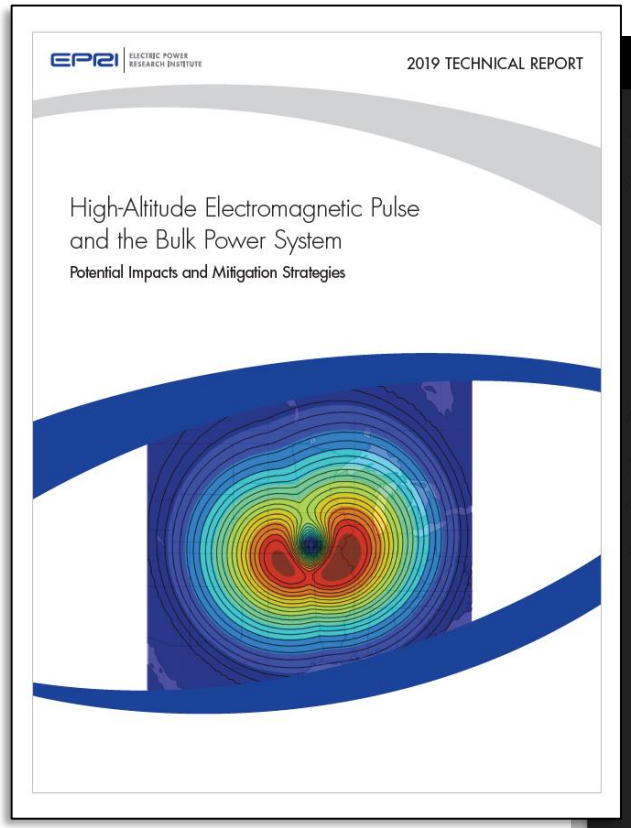
- **E3: Late-time Pulse**
  - 10's V/km (at worst location on ground)
  - Similar to severe GMD event
  - Voltage collapse, transformer damage possible

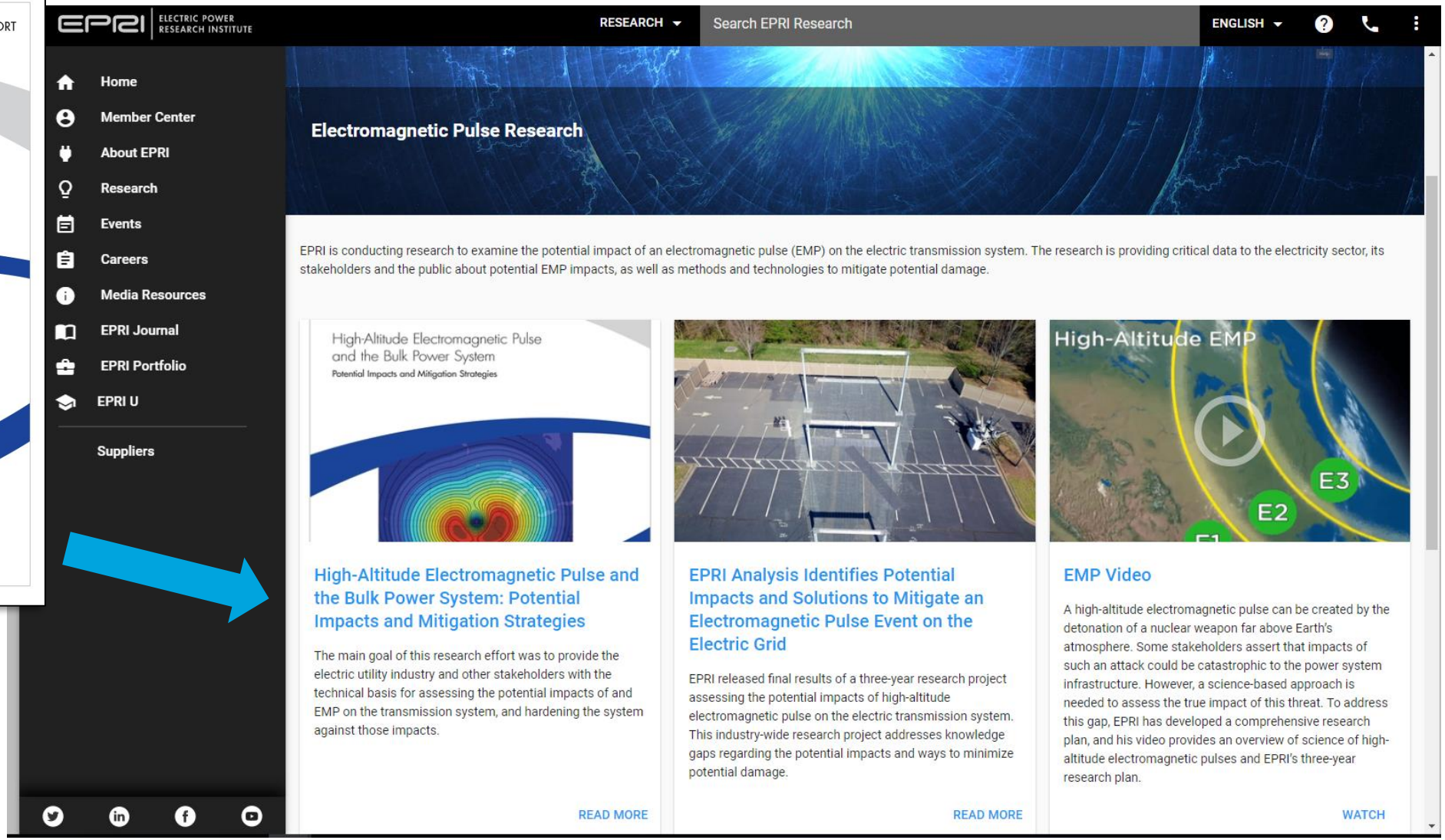




EPRI Final Report

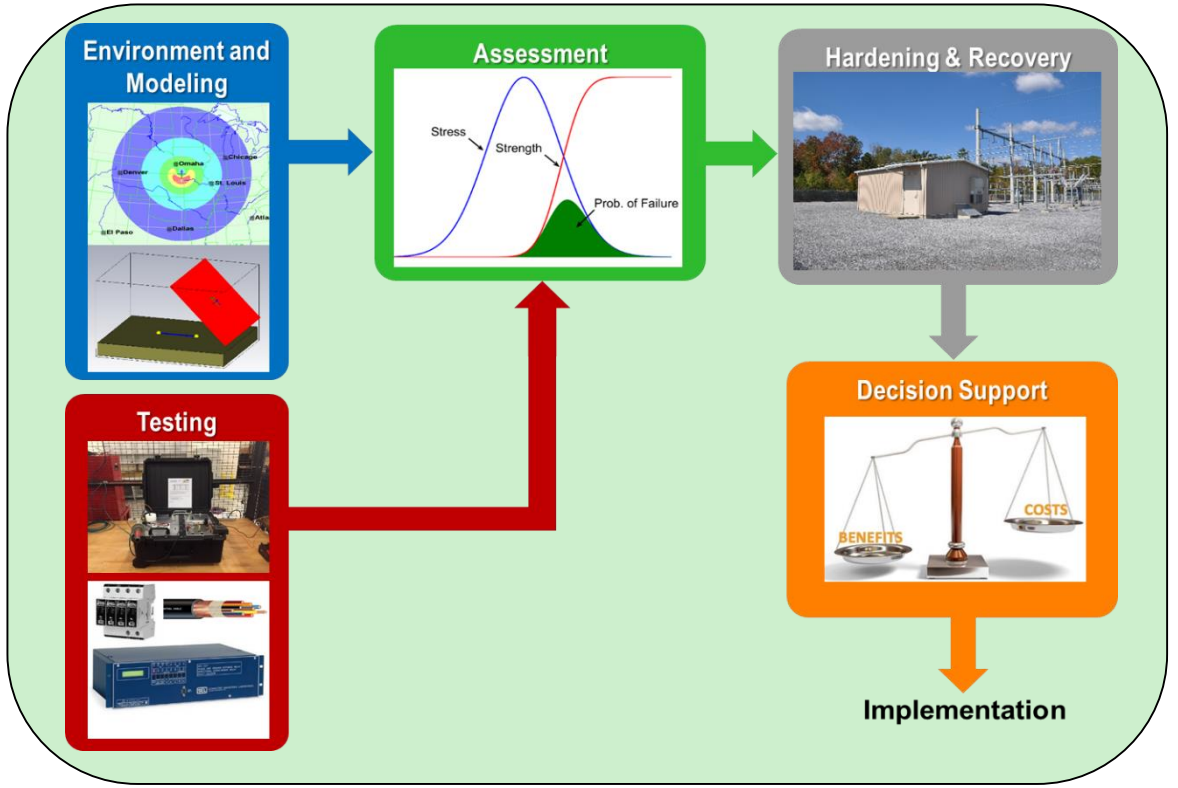
https://www.epri.com/#/pages/sa/emp?lang=en-US





EPRI EMP Research

- 3-year project launched in April 2016 with 63 U.S. utilities
- Answering two important questions:
  - What are the potential impacts of a HEMP attack on the electric transmission system?
  - If impacts are severe, can they be mitigated in cost-effective ways?
- Close collaboration with U.S. EMP Community and ESCC



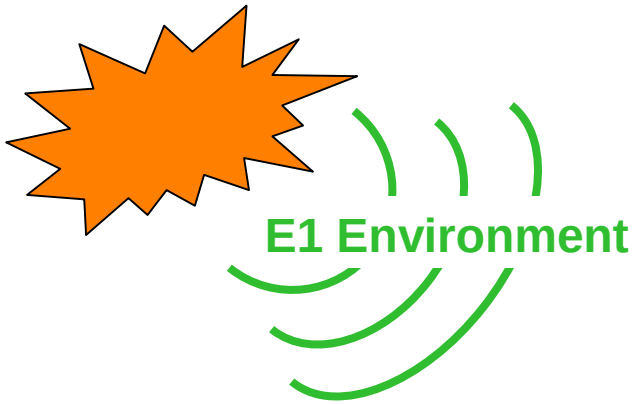
Sandia National Laboratories

Los Alamos NATIONAL LABORATORY EST. 1943

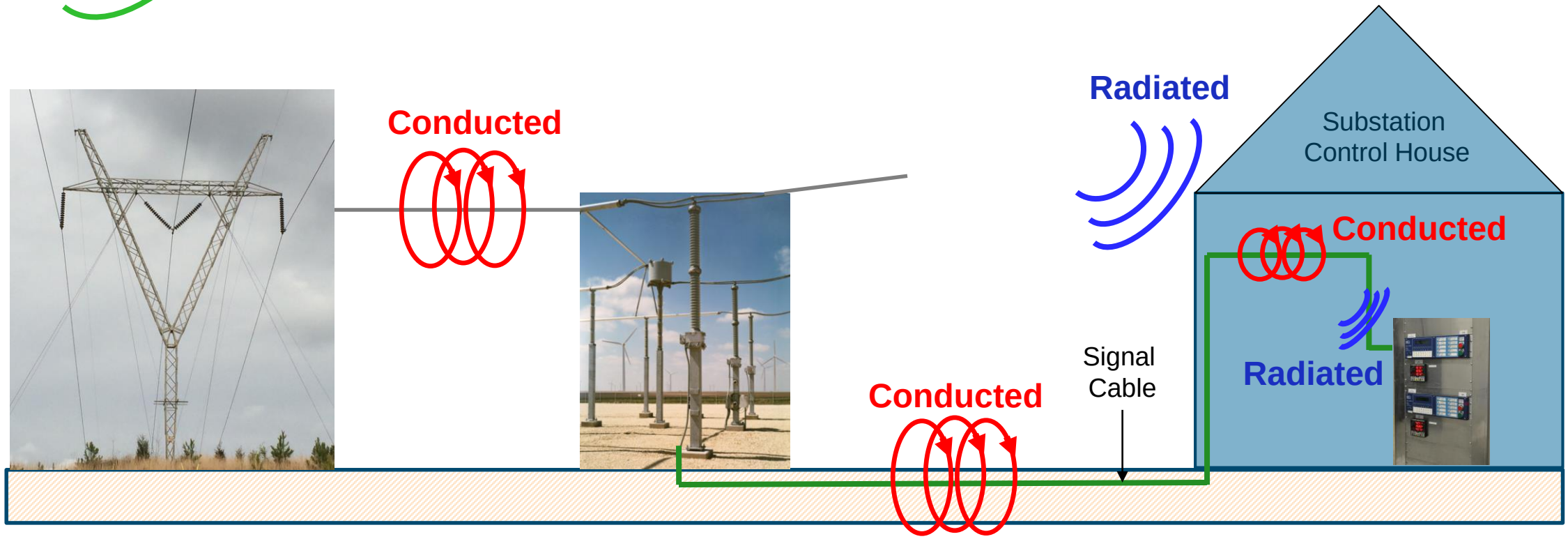
ESCC Electricity Subsector Coordinating Council

Lawrence Livermore National Laboratory

E1 Threat to Substations



- Conductors act like antenna and absorb EMP energy **(conducted threat)**
- Plane wave radiates the component directly **(radiated threat)**

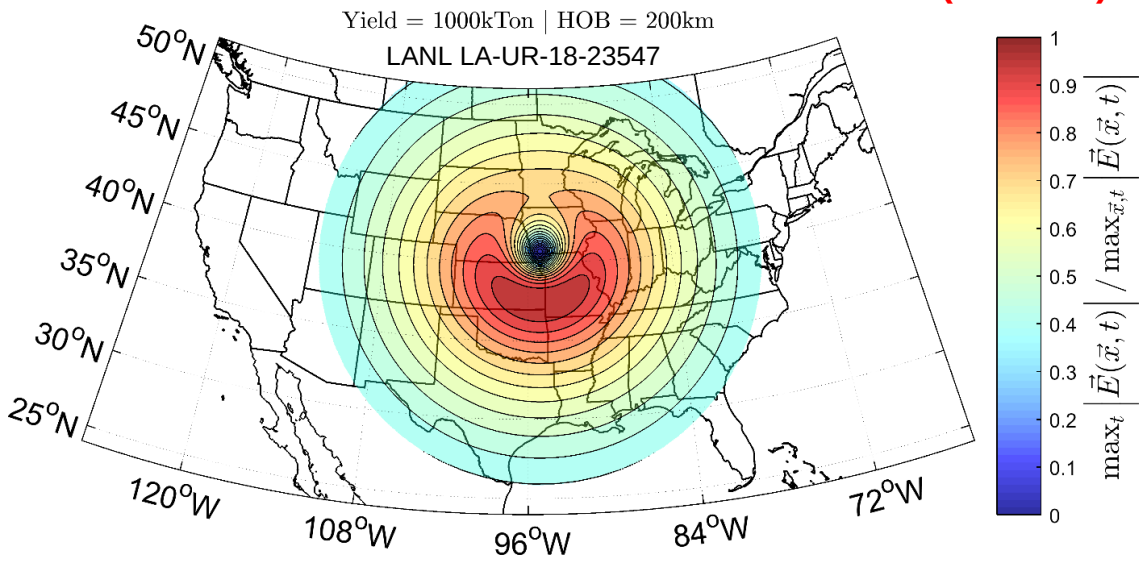


E1 Environment

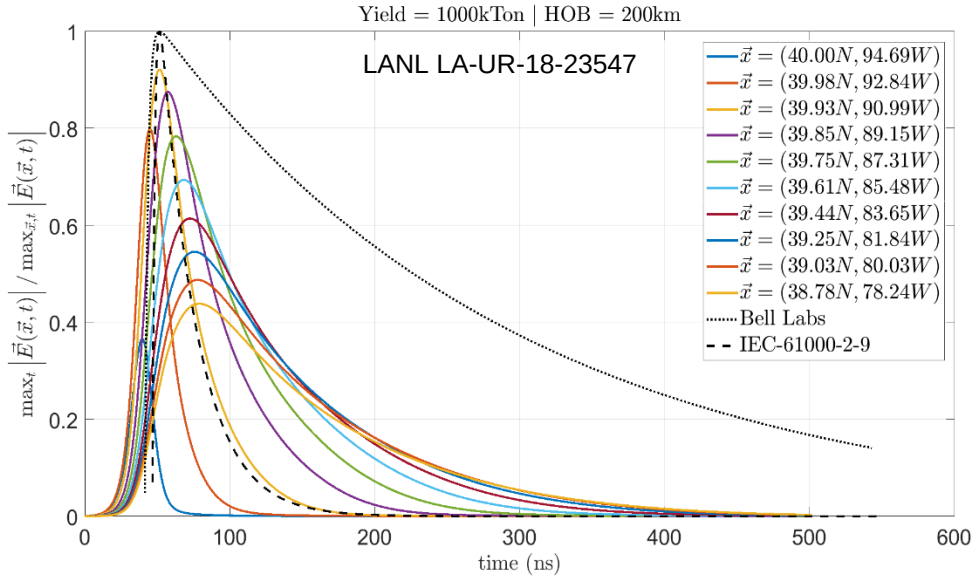
- Los Alamos National Laboratory (LANL) provided an unclassified (OUO) E1 environment based on a notional 1MT detonation at 200 km
- Provided parameters that are critical for interconnection-scale E1 assessments
- Two threat levels were considered: 25 kV/m peak (LANL nominal), 50 kV/m peak (IEC)

Example Smile Diagram

Epeak ~ 25 kV/m (nominal)



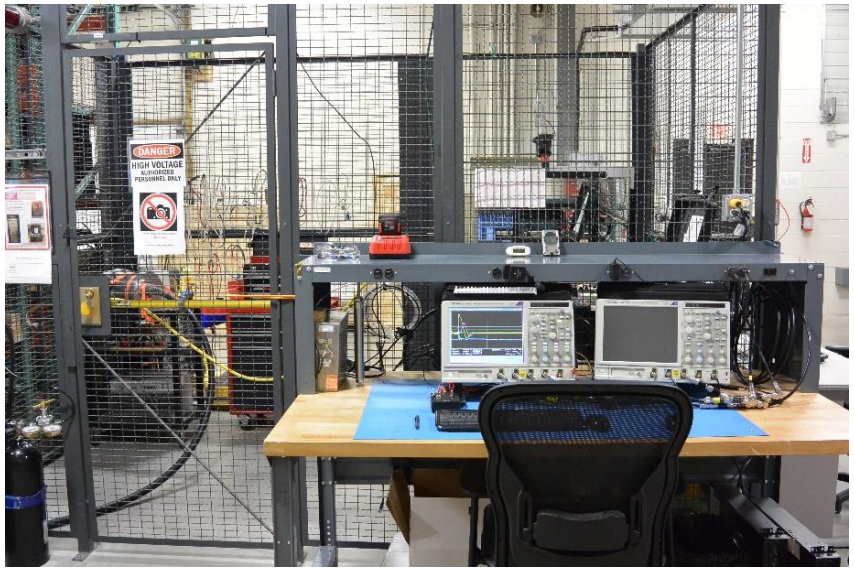
Example E1 EMP Waveforms With Comparison of IEC and Bell Labs Waveforms



E1 Testing: Charlotte and Knoxville Lab Facilities

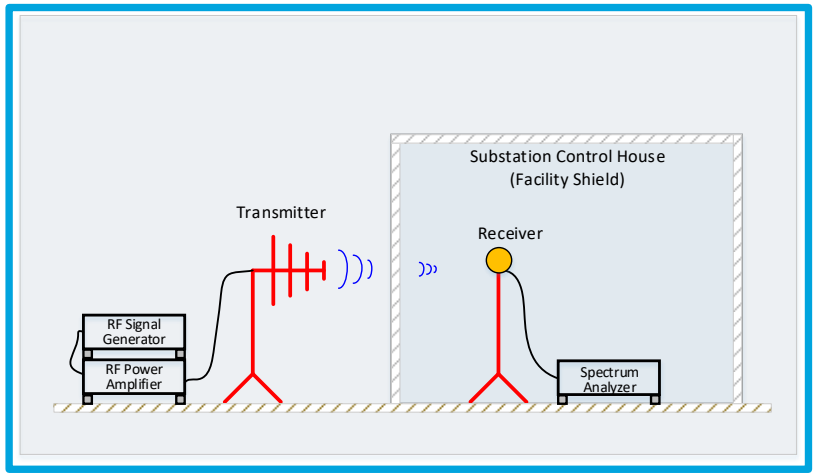
Field Illumination Testing (Radiated Threat) EPRI – Charlotte, NC

Direct Injection Testing (Conducted Threat) EPRI – Knoxville, TN

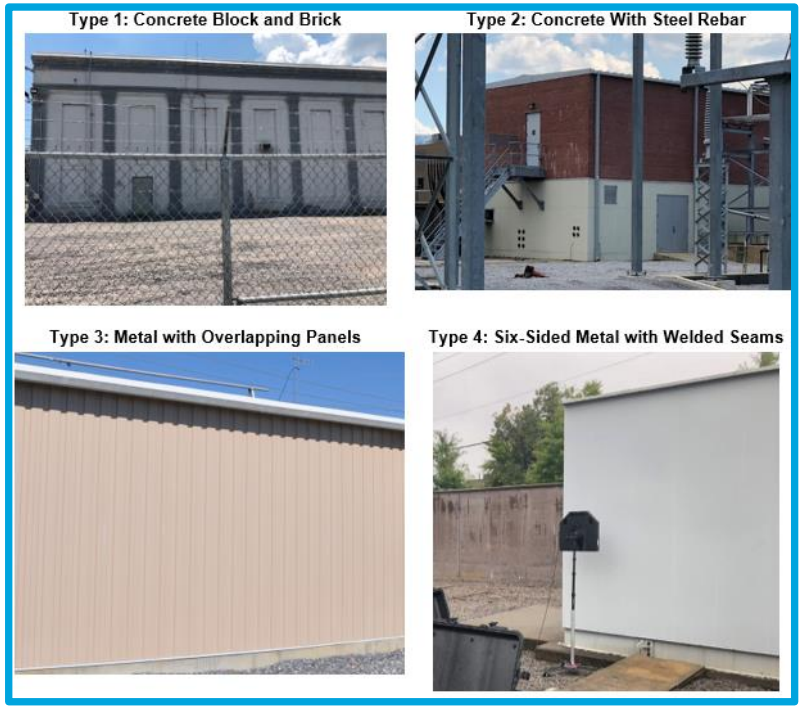


E1 Testing: Shielding Effectiveness (On Site)

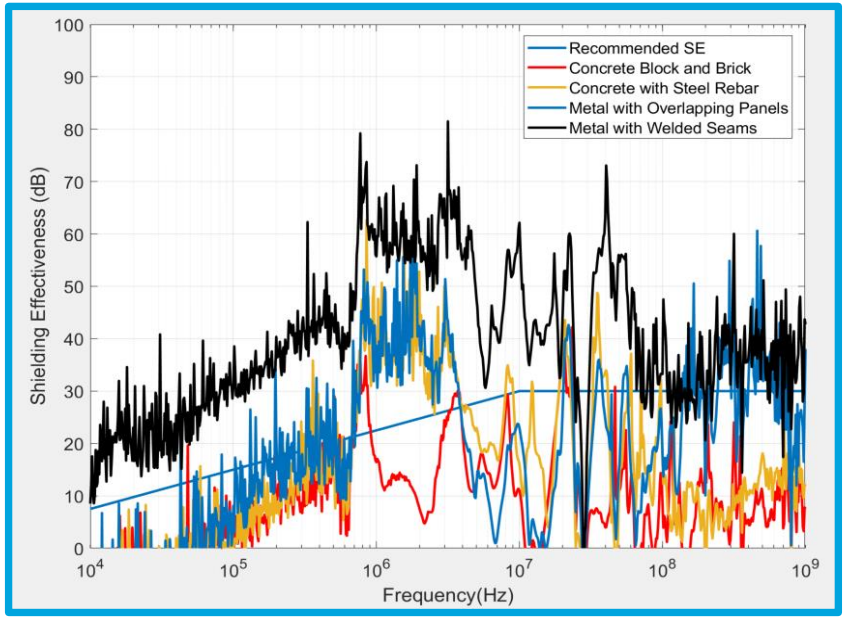
Shielding Effectiveness Test



Typical Control House Designs



Example Measurement Data

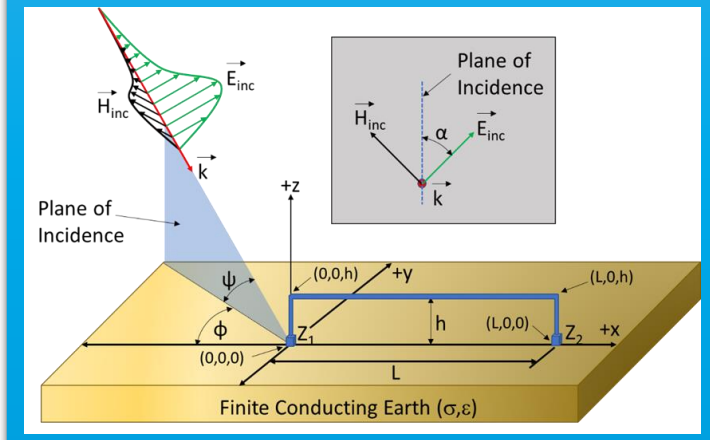


Performance of designs varied – 6 sided metal building performed best and was able to provide adequate protection of digital protective relays

Assessment of E1 Impacts

Simulated Coupling to Overhead Lines and Cables

Coupled Voltages Higher than Expected

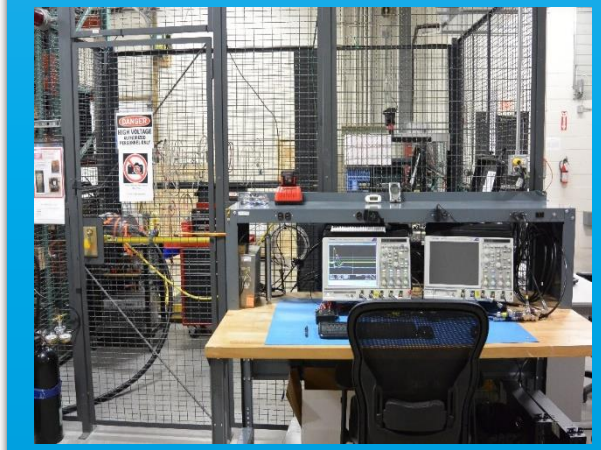


Modeling (Stress)

VS.

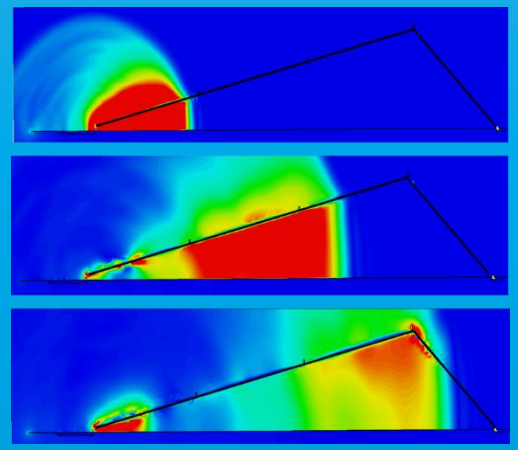
Direct Injection

Observed Failures @ Voltages Lower than Expected



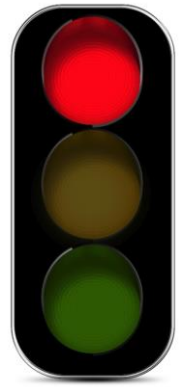
Field Illumination

Less Susceptible than Expected



Testing (Strength)

E1 Impacts Possible

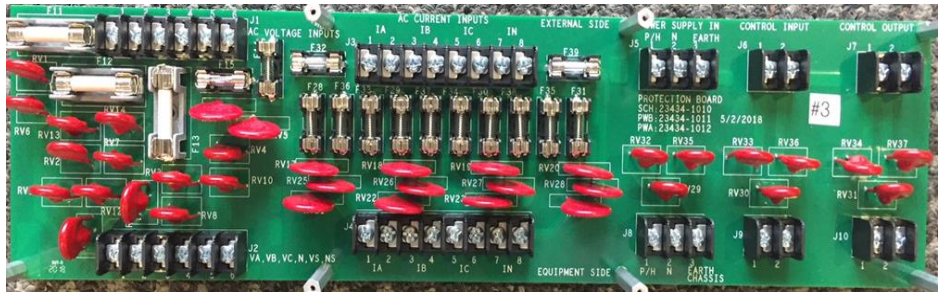


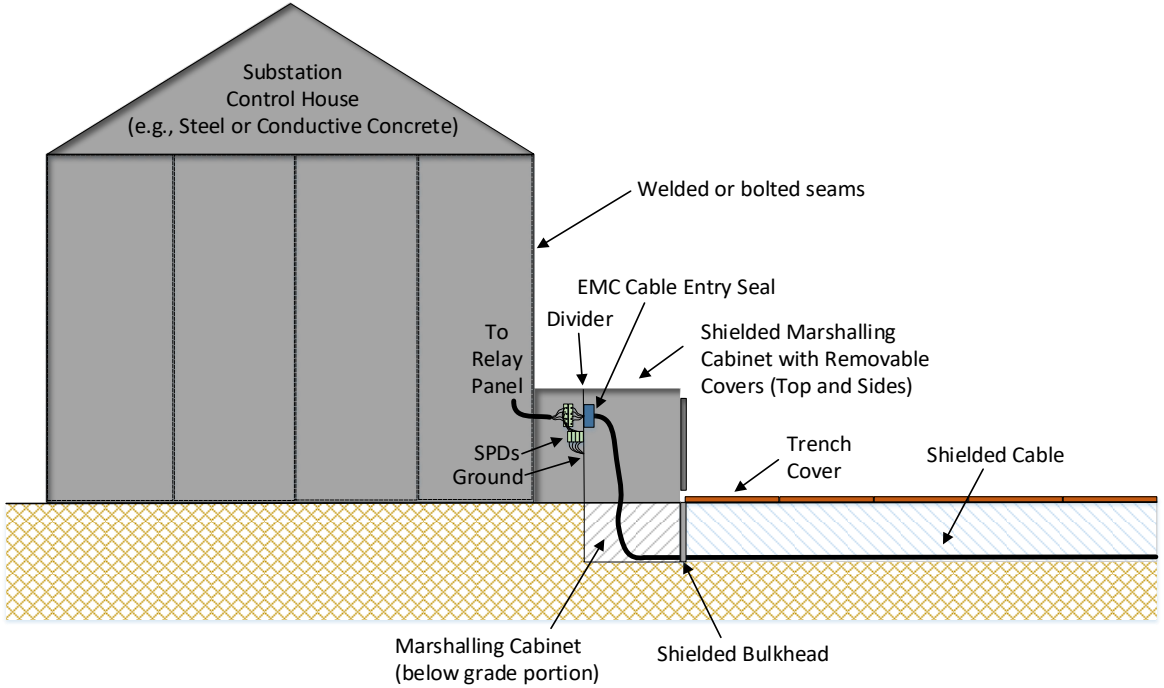
E1 EMP Mitigation Options

- Low-voltage surge suppression devices and filters
- Shielded or fiber optic cables
- Substation control house design modifications
- Grounding/bonding enhancements

Identifying and managing unintended consequences is critical.

Example of a Prototype Low-voltage Surge Suppression Device

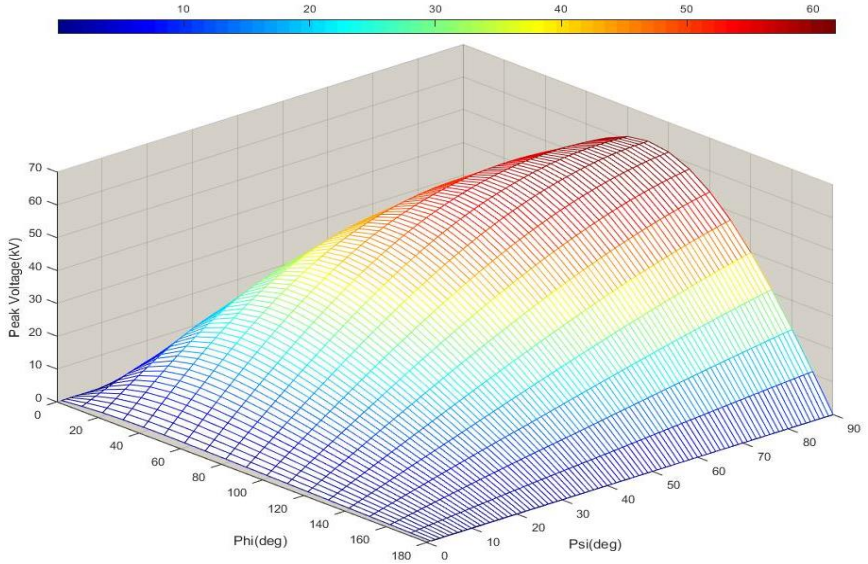




Assessment of E2 Impacts

- Assessed potential impacts of E2 on substations.
- Results indicate that E2 is not a threat to high-voltage infrastructure or digital protective relays.
- No specific mitigations provided.

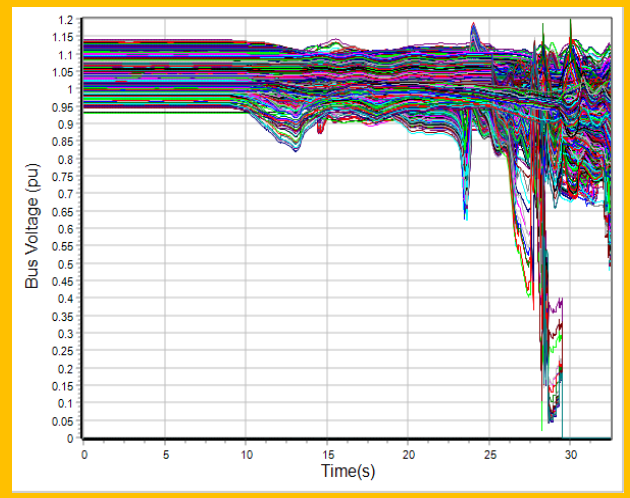
Example Simulation Results



Assessment of E3 Impacts

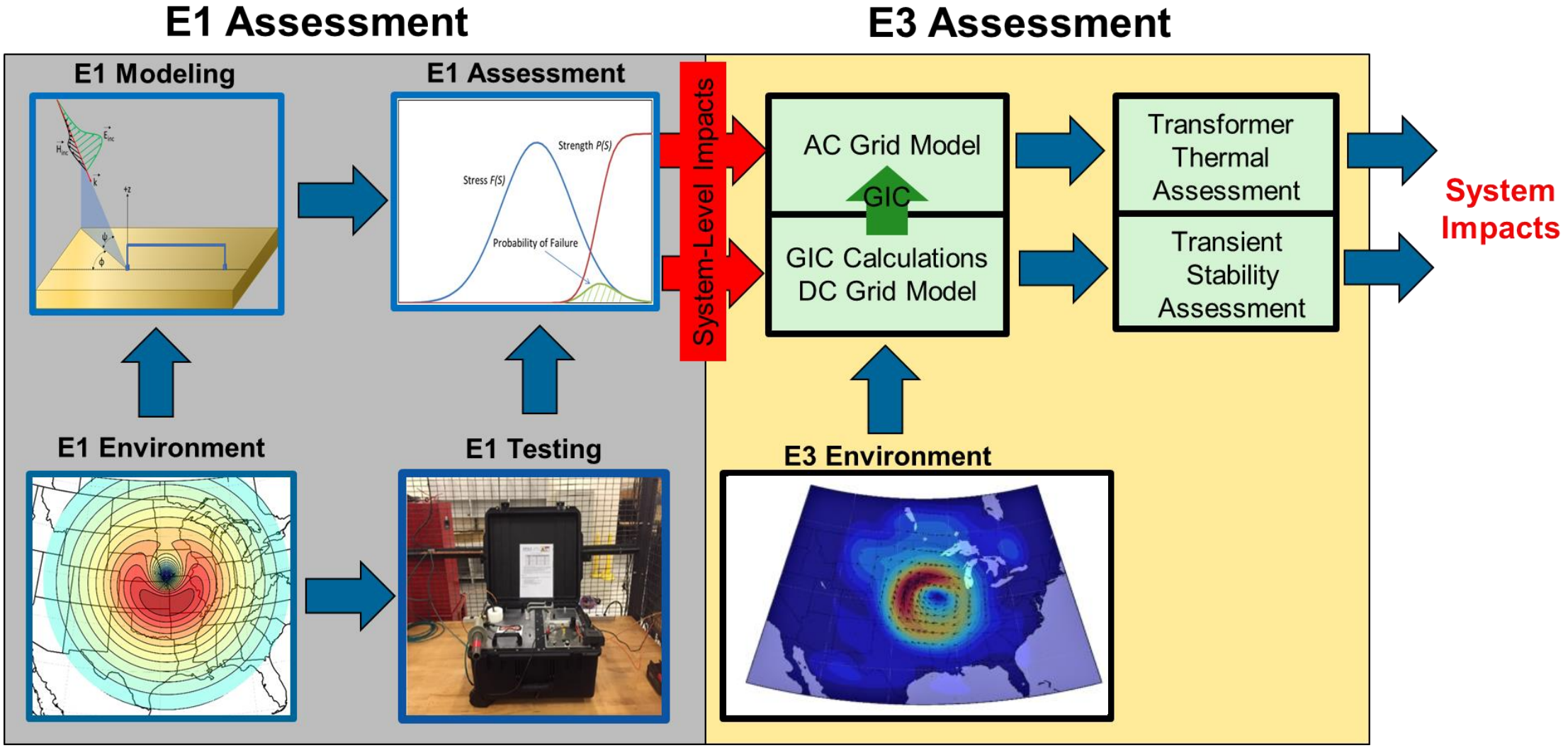
- EPRI analysis leveraged extensive GMD analysis capability to reconcile differences between prior studies
- Studied 11 notional target locations
- Final analysis used high-fidelity E3 environment from LANL (35 V/km)

- **Widespread damage to large power transformers <u>unlikely</u>**



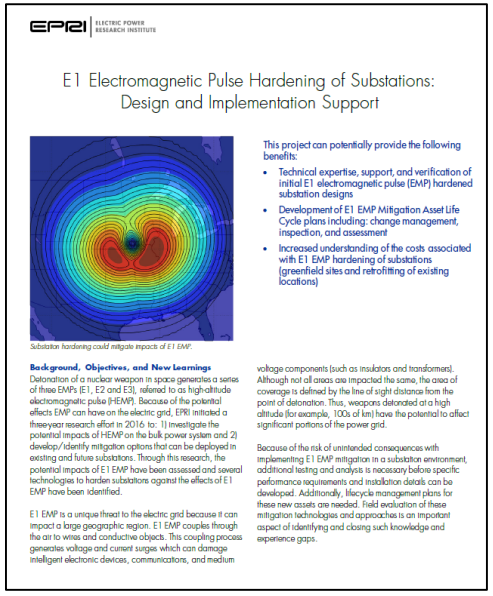
- **Regional voltage collapse <u>possible</u>**
- **Recovery expected to be similar to prior events <u>if</u> E1 hardening measures are employed**

E1 + E3 Assessment



Next Steps

- Technical support and field evaluation of E1 hardening options
  https://www.epri.com/#/pages/product/3002014867/
- Continue E1 investigation to include generating facilities
  https://www.epri.com/#/pages/product/3002015354/
- Work with other Critical Infrastructures to transfer initial results and investigate other technical options



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E1 Electromagnetic Pulse Hardening of Substations: Design and Implementation Support

This project can potentially provide the following benefits:

- Technical expertise, support, and verification of initial E1 electromagnetic pulse (EMP) hardened substation designs
- Development of E1 EMP Mitigation Asset Life Cycle plans including: change management, inspection, and assessment
- Increased understanding of the costs associated with E1 EMP hardening of substations (greenfield sites and retrofitting of existing locations)

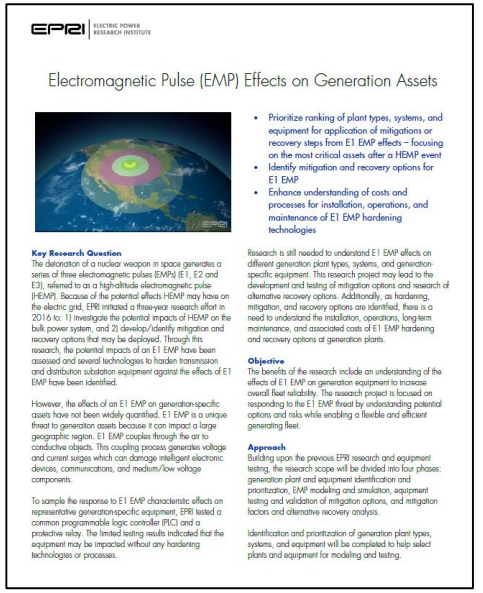
Substation hardening could mitigate impacts of E1 EMP.

Background, Objectives, and New Learnings

Detonation of a nuclear weapon in space generates a series of three EMPs (E1, E2 and E3), referred to as high-altitude electromagnetic pulse (HEMP). Because of the potential effects EMP can have on the electric grid, EPRI initiated a three-year research effort in 2016 to: 1) investigate the potential impacts of HEMP on the bulk power system and 2) develop/identify mitigation options that can be deployed in existing and future substations. Through this research, the potential impacts of E1 EMP have been assessed and several technologies to harden substations against the effects of E1 EMP have been identified.

E1 EMP is a unique threat to the electric grid because it can impact a large geographic region. E1 EMP couples through the air to wires and conductive objects. This coupling process generates voltage and current surges which can damage intelligent electronic devices, communications, and medium voltage components (such as insulators and transformers). Although not all areas are impacted the same, the area of coverage is defined by the line of sight distance from the point of detonation. Thus, weapons detonated at a high altitude (for example, 100s of km) have the potential to affect significant portions of the power grid.

Because of the risk of unintended consequences with implementing E1 EMP mitigation in a substation environment, additional testing and analysis is necessary before specific performance requirements and installation details can be developed. Additionally, lifecycle management plans for these new assets are needed. Field evaluation of these mitigation technologies and approaches is an important aspect of identifying and closing such knowledge and experience gaps.



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Electromagnetic Pulse (EMP) Effects on Generation Assets

- Prioritize ranking of plant types, systems, and equipment for application of mitigations or recovery steps from E1 EMP effects – focusing on the most critical assets after a HEMP event
- Identify mitigation and recovery options for E1 EMP
- Enhance understanding of costs and processes for installation, operations, and maintenance of E1 EMP hardening technologies

Key Research Question

The detonation of a nuclear weapon in space generates a series of three electromagnetic pulses (EMPs) (E1, E2 and E3), referred to as a high-altitude electromagnetic pulse (HEMP). Because of the potential effects HEMP may have on the electric grid, EPRI initiated a three-year research effort in 2016 to: 1) investigate the potential impacts of HEMP on the bulk power system, and 2) develop/identify mitigation and recovery options that may be deployed. Through this research, the potential impacts of an E1 EMP have been assessed and several technologies to harden transmission and distribution substation equipment against the effects of E1 EMP have been identified.

However, the effects of an E1 EMP on generation-specific assets have not been widely quantified. E1 EMP is a unique threat to generation assets because it can impact a large geographic region. E1 EMP couples through the air to conductive objects. This coupling process generates voltage and current surges which can damage intelligent electronic devices, communications, and medium/low voltage components.

To sample the response to E1 EMP characteristic effects on representative generation-specific equipment, EPRI tested a common programmable logic controller (PLC) and a protective relay. The limited testing results indicated that the equipment may be impacted without any hardening technologies or processes.

Research is still needed to understand E1 EMP effects on different generation plant types, systems, and generation-specific equipment. This research project may lead to the development and testing of mitigation options and research of alternative recovery options. Additionally, as hardening, mitigation, and recovery options are identified, there is a need to understand the installation, operations, long-term maintenance, and associated costs of E1 EMP hardening and recovery options at generation plants.

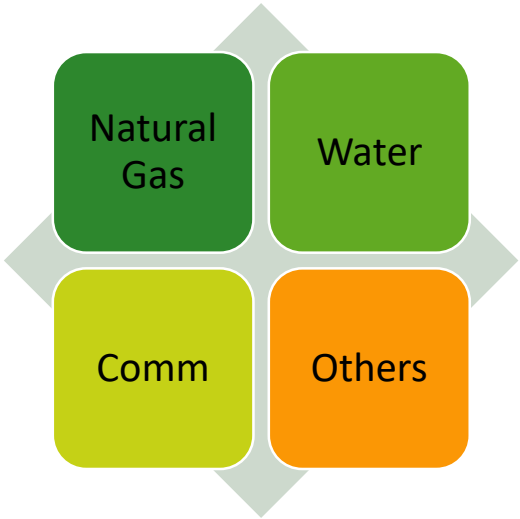
Objective

The benefits of the research include an understanding of the effects of E1 EMP on generation equipment to increase overall fleet reliability. The research project is focused on responding to the E1 EMP threat by understanding potential options and risks while enabling a flexible and efficient generating fleet.

Approach

Building upon the previous EPRI research and equipment testing, the research scope will be divided into four phases: generation plant and equipment identification and prioritization, EMP modeling and simulation, equipment testing and validation of mitigation options, and mitigation factors and alternative recovery analysis.

Identification and prioritization of generation plant types, systems, and equipment will be completed to help select plants and equipment for modeling and testing.



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