Electromagnetic Pulse (EMP) Grid Resiliency Project

ERCOT Grid Resilience Working Group
Austin, TX
October 20, 2016

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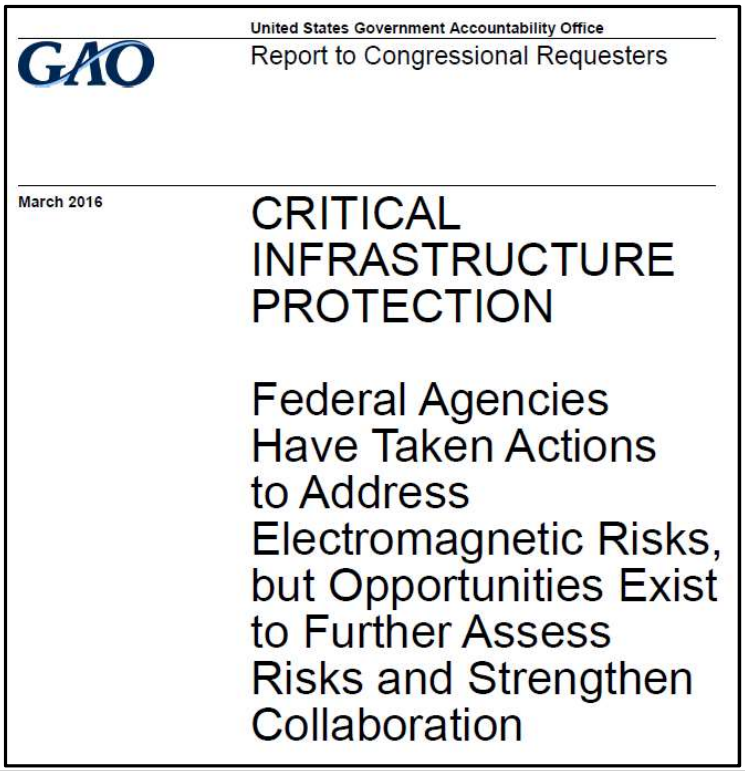
Transmission and Substations

Outline

- EMP and the Case for Industry Leadership
- EMP Background
  - What is EMP?
  - What about GMD?
  - What about IEMI?
- EPRI's EMP Research
  - Project Plan
  - Project Status
    - Participation
    - Collaboration
    - Recent & Pending Deliverables

EMP and The Case for Industry Leadership

- There is a need to improve clarity about EMP assertions
  - Advocates assert an attack is probable, and impact would be catastrophic
  - They are influencing industry regulators and legislators
- The industry needs an unclassified, science-based approach for:
  - Threat characterization
  - Testing results
  - Modeling and simulation
  - Recommended strategies
  - Prudent and practical hardening and recovery options


United States Government Accountability Office

GAO

Report to Congressional Requesters

March 2016

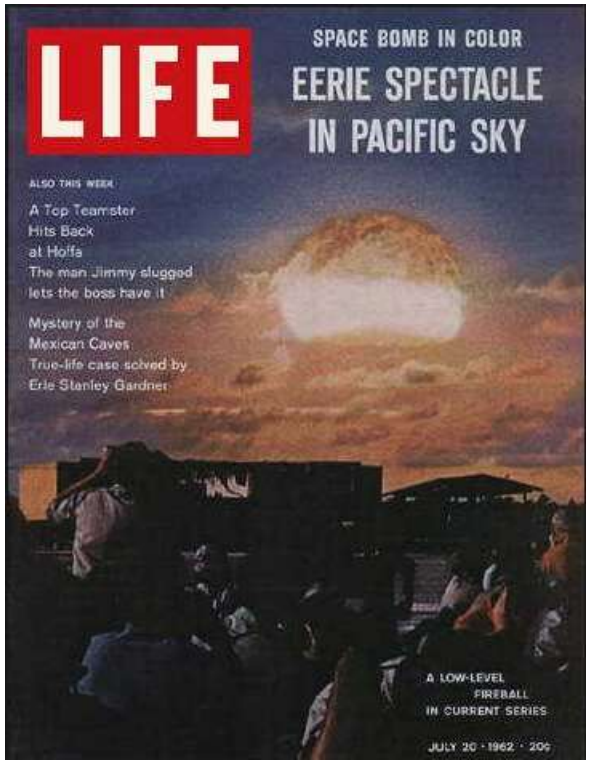
CRITICAL INFRASTRUCTURE PROTECTION

Federal Agencies Have Taken Actions to Address Electromagnetic Risks, but Opportunities Exist to Further Assess Risks and Strengthen Collaboration

EMP Background

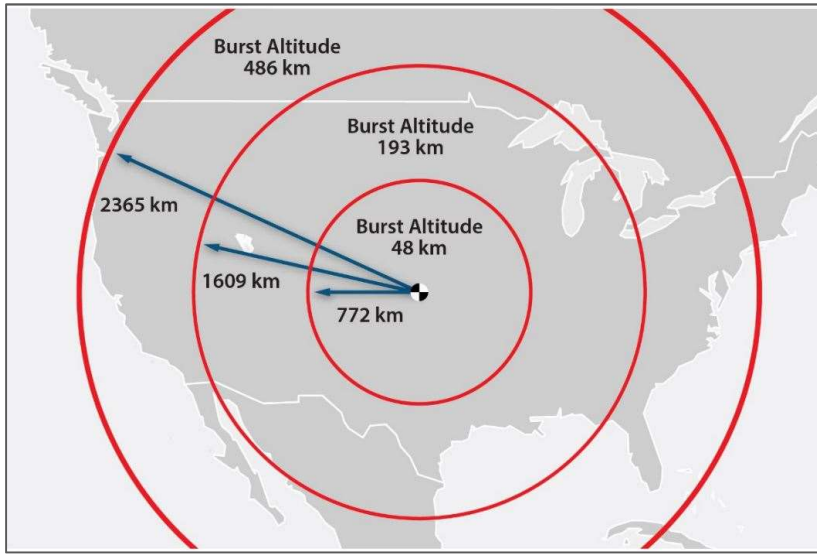
Brief History

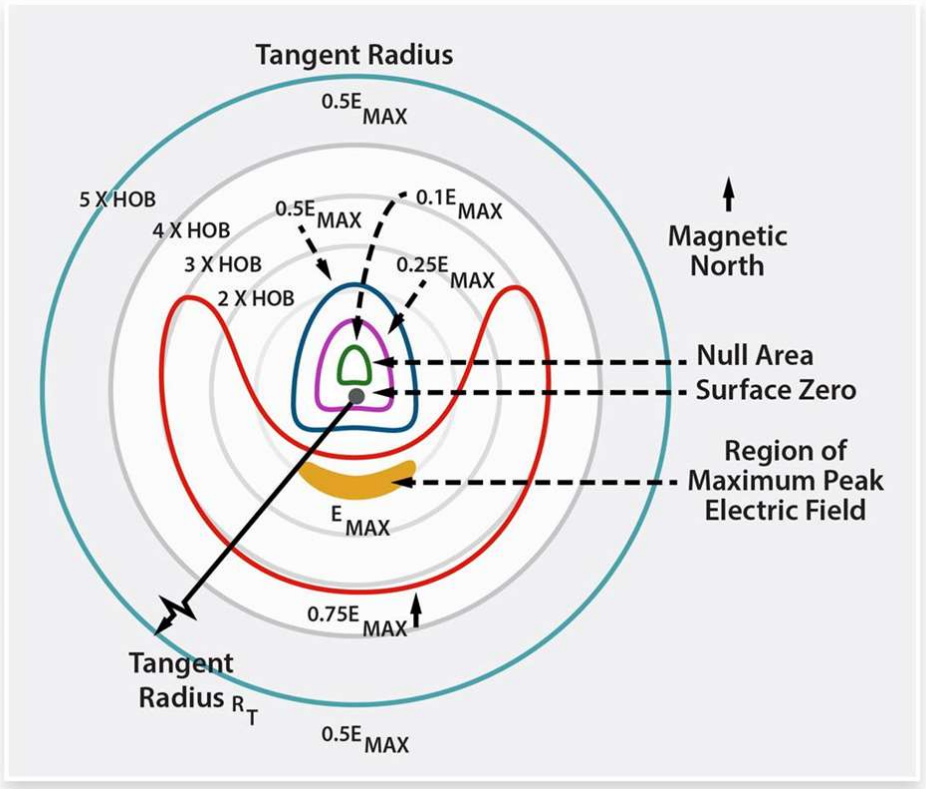
- The potential for nuclear weapons to create an EMP has been known by the US (and others) for decades
- Several US high-altitude nuclear tests in the 1950's and early 1960's explored impacts to the military and communications
- The most famous of these was Starfish Prime (Operation Fishbowl)
  - A 1.4 MT weapon was detonated approximately 400 km above Johnston Atoll in the South Pacific
  - Disruption to some long-distance communications, damage to several satellites, and impacts to streetlights and burglar alarms in Hawaii (~ 800 mi away) were reported



Impact Area (E1/E2)

- A high-altitude nuclear burst can illuminate a very large region (line of sight of burst location)
- But, electric field is highly non-uniform within the area of illumination (i.e. not all locations “see” the maximum field)





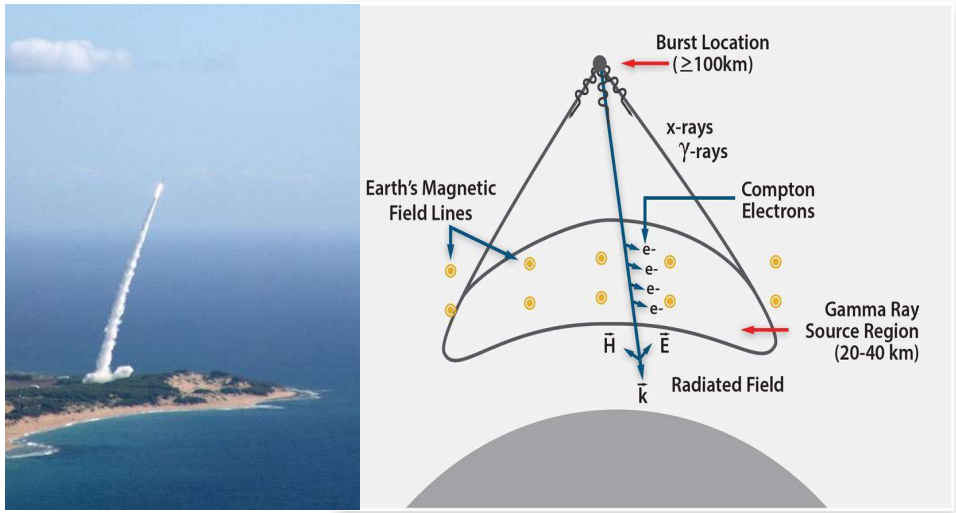
High-Altitude Electromagnetic Pulse (HEMP)

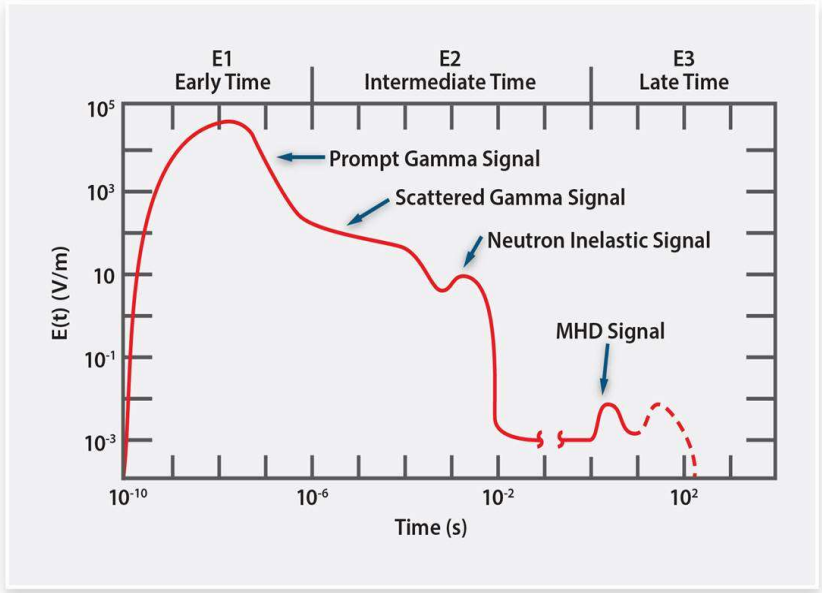
HEMP consists of three components:

- **E1: E_{peak} ~ 50 kV/m (nsec rise time)** can result in damage to electronic components (directly or by coupling to the attached wires) with the potential flashover of lower voltage transmission insulation
- **E2: E_{peak} ~ 100 V/m (nsec rise time)** is similar to lightning but has a different coupling mechanism and much lower E-field, considered a continuation of E1
- **E3 (MHD-EMP): E_{peak} ~ 10's V/km (10's mV/m)**, similar to GMD but much shorter duration with 2 potential impacts

  1) voltage collapse due to increased reactive power consumption and misoperation of protection systems caused by harmonics

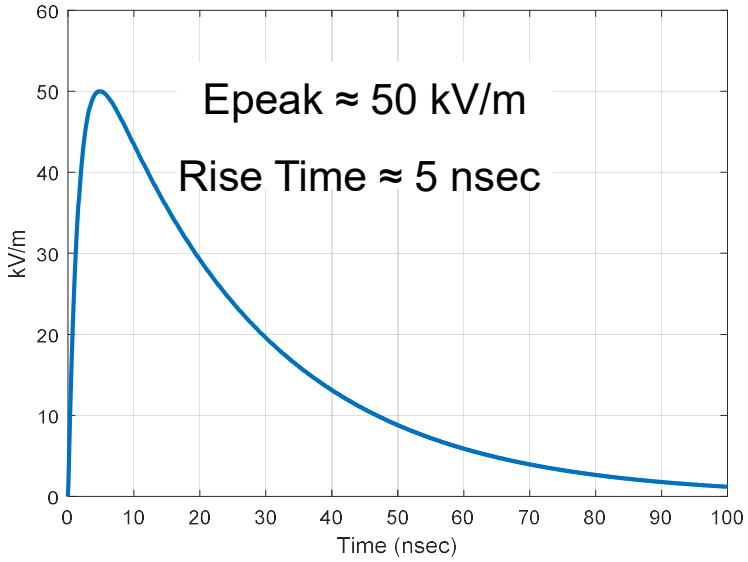
  2) additional hotspot heating in transformers



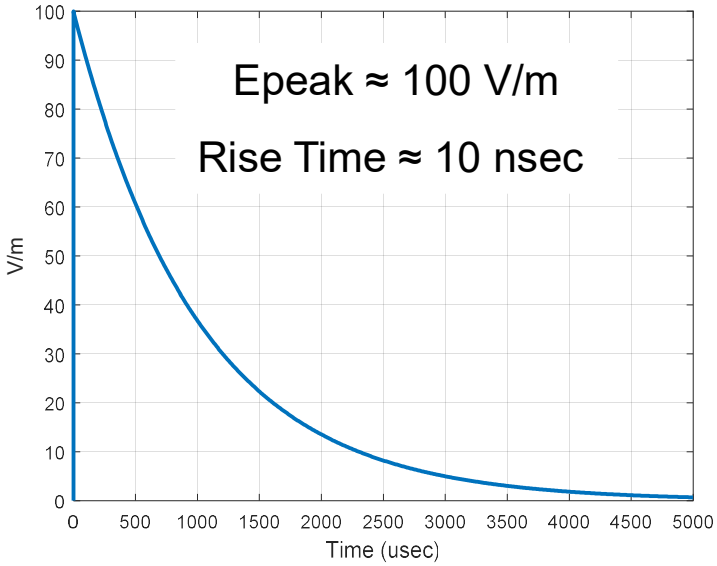


Unclassified EMP Waveforms: IEC 61000-2-9

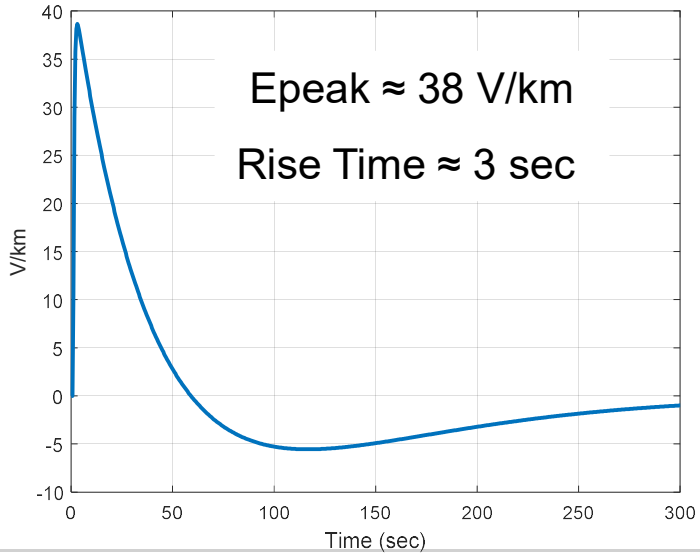
E1



E2

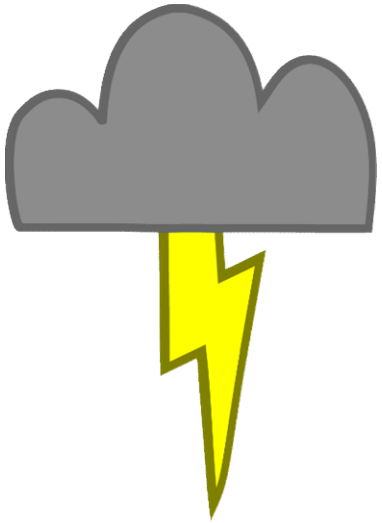


E3



High-Altitude Electromagnetic Pulse (HEMP)

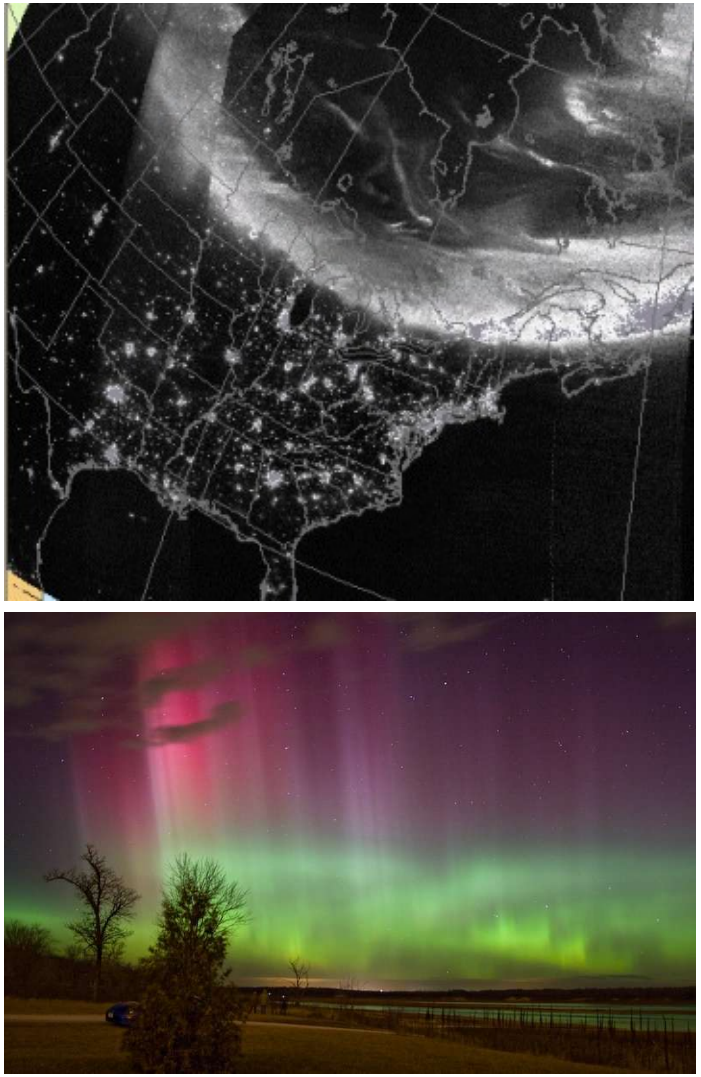
- **E2**
  - The wave shape is similar to what utilities routinely experience with lightning
  - It has the same coupling with lines, bus work, and cables as the E1 wave
  - This does not mean:
    - a non-stop lightning storm
    - everything suddenly turns into a lightning rod



- **E3**
  - Key item is the thermal response
  - Consider passing your hand through a flame (HEMP) vs. holding your hand in the flame (GMD)
    - 1989 GMD blackout ~1-2 V/km
    - HEMP ~24 V/km

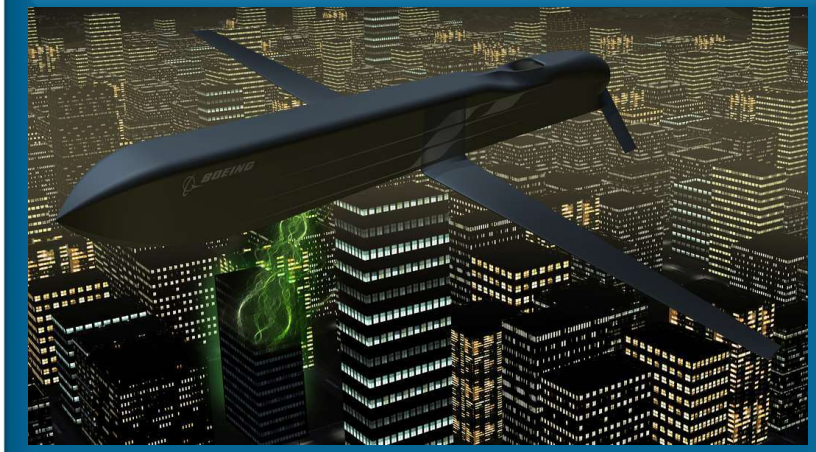
Geomagnetic Disturbance (GMD)

- Similar to EMP *E3*, but much longer duration
  - Induces quasi-dc currents
  - Potential for voltage collapse from reactive power (Mvars) consumption
  - Potential for misoperation of protection systems (by harmonics)
  - Heating in transformers
- NERC Standards
  - EOP-010-1
  - TPL-007-1
  - The industry is responding
- Some utilities are looking into (or already testing) blocking devices
  - New Executive Order – 10/13/16



December 2006 storm

Intentional Electromagnetic Interference (IEMI)



Boeing's CHAMP missile test flight knocks out electronic devices with a burst of energy (Gizmag – 2012)

Diehl Munitions Interference System

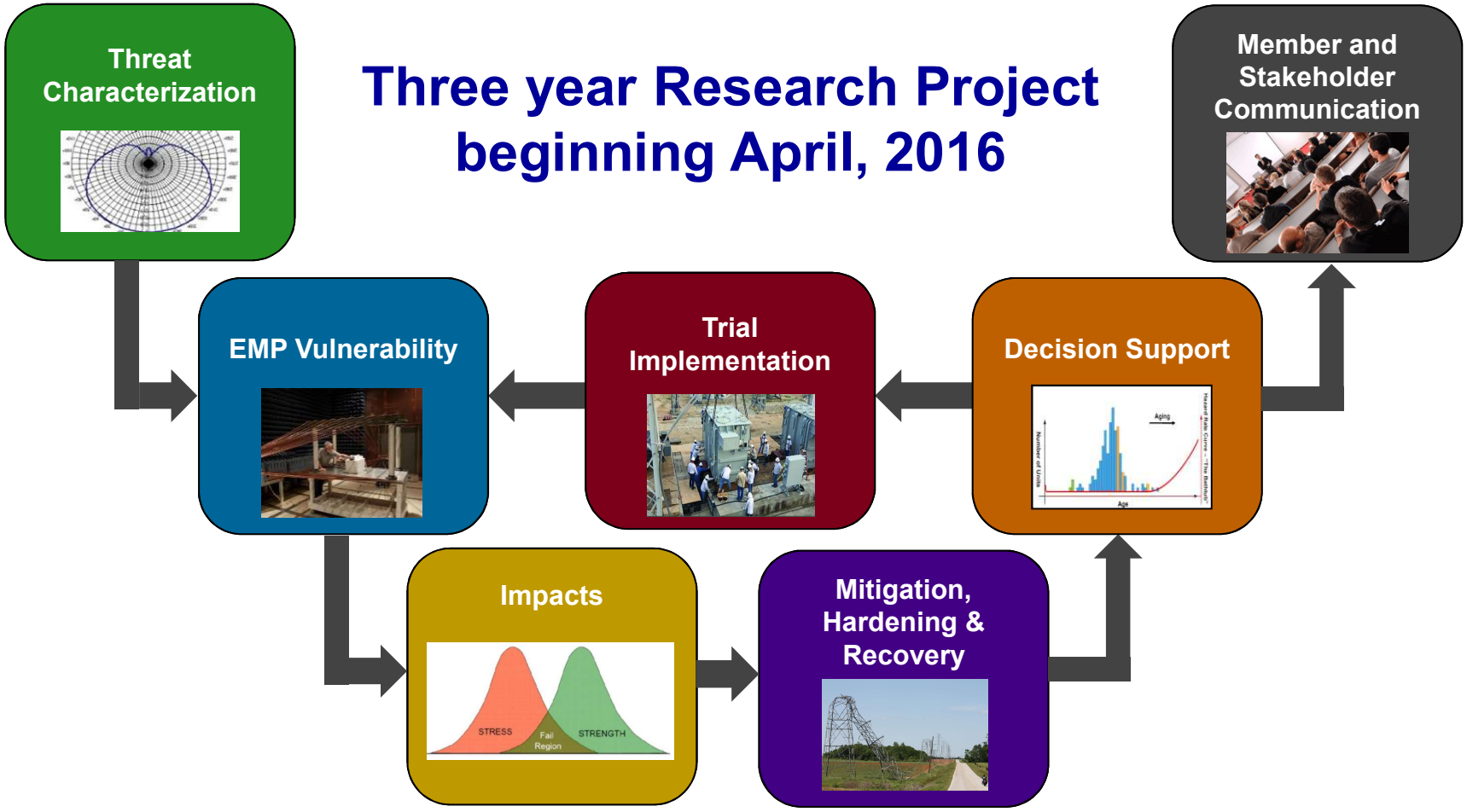
- IEMI is a form of EMP
  - Similar frequency content
  - Mainly in the E1 region
- IEMI attacks do *not* result in E2 and E3 fields or their effects
- IEMI devices (compared to EMP)
  - Smaller, more portable, less sophisticated, and less expensive
- IEMI impact (compared to EMP)
  - Deliver a geographically focused impact
  - A coordinated attack in numerous locations would be necessary to create a widespread impact on the grid

Research Plan

EMP Project Overview

- EPRI has developed a three year research project to address this potential threat
- Expectation of this research project is to provide technically-based information that can be used to:
  - **Assess** the impact of a HEMP attack on the bulk-power system
  - **Harden** new and existing assets against the effects of E1, E2, and E3
  - **Identify advanced recovery options** to supplement hardening and mitigation efforts

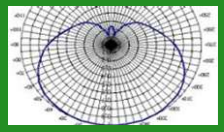
EMP Project Plan



EMP Project Plan

- Identify conservative, unclassified HEMP environment(s) (E1,E2,E3) to assess the potential impacts on bulk-power system components
- Investigate the physics of HEMP propagation and coupling to power system infrastructure

Threat Characterization

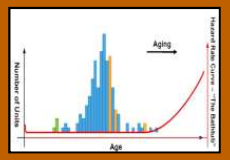


Member and Stakeholder Communication

EMP Vulnerability

Trial Implementation

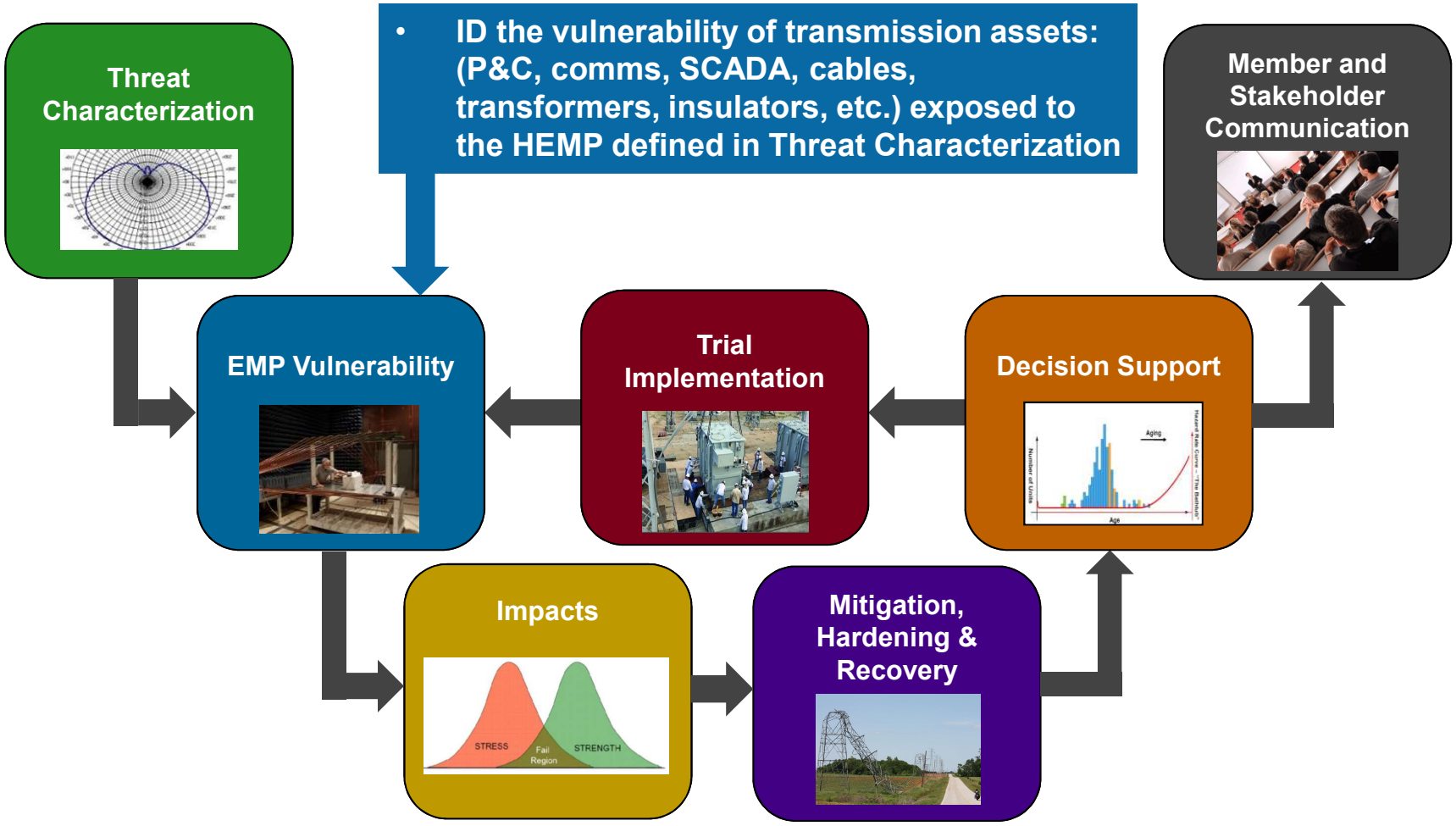
Decision Support



Impacts

Mitigation, Hardening & Recovery

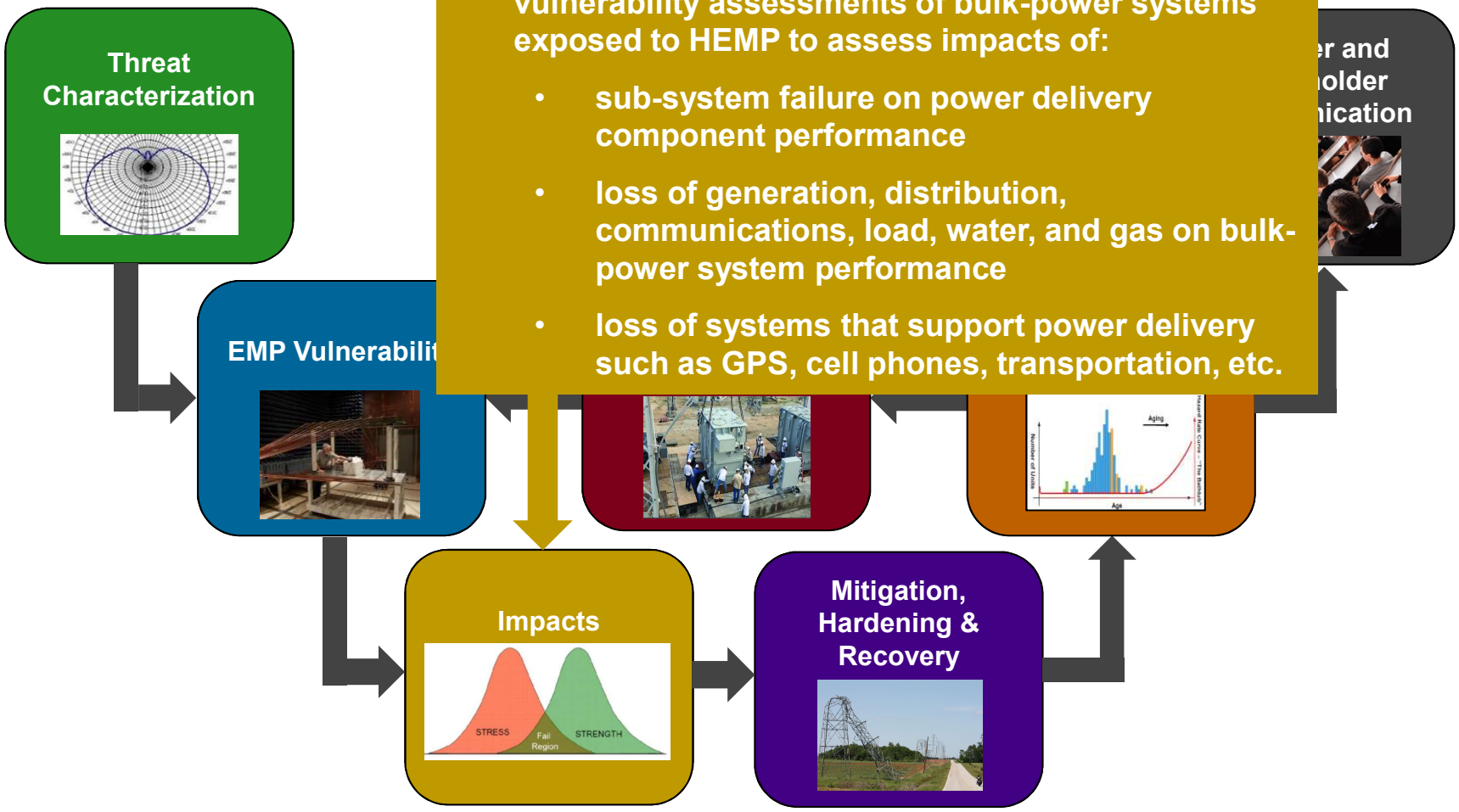
EMP Project Plan



EPRI ELECTRIC POWER RESEARCH INSTITUTE

EMP Project Plan

- Develop criteria and techniques for performing vulnerability assessments of bulk-power systems exposed to HEMP to assess impacts of:
  - sub-system failure on power delivery component performance
  - loss of generation, distribution, communications, load, water, and gas on bulk-power system performance
  - loss of systems that support power delivery such as GPS, cell phones, transportation, etc.



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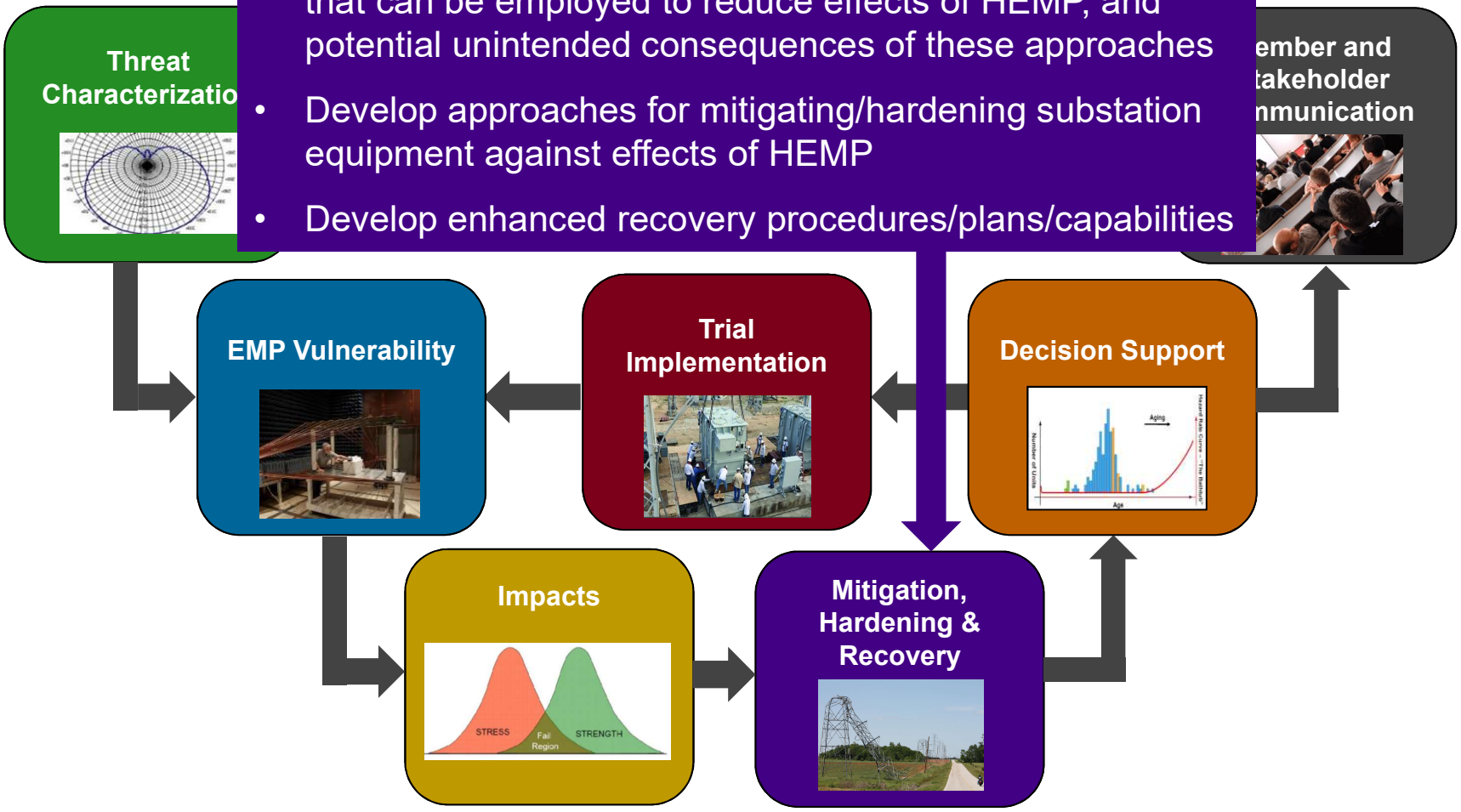
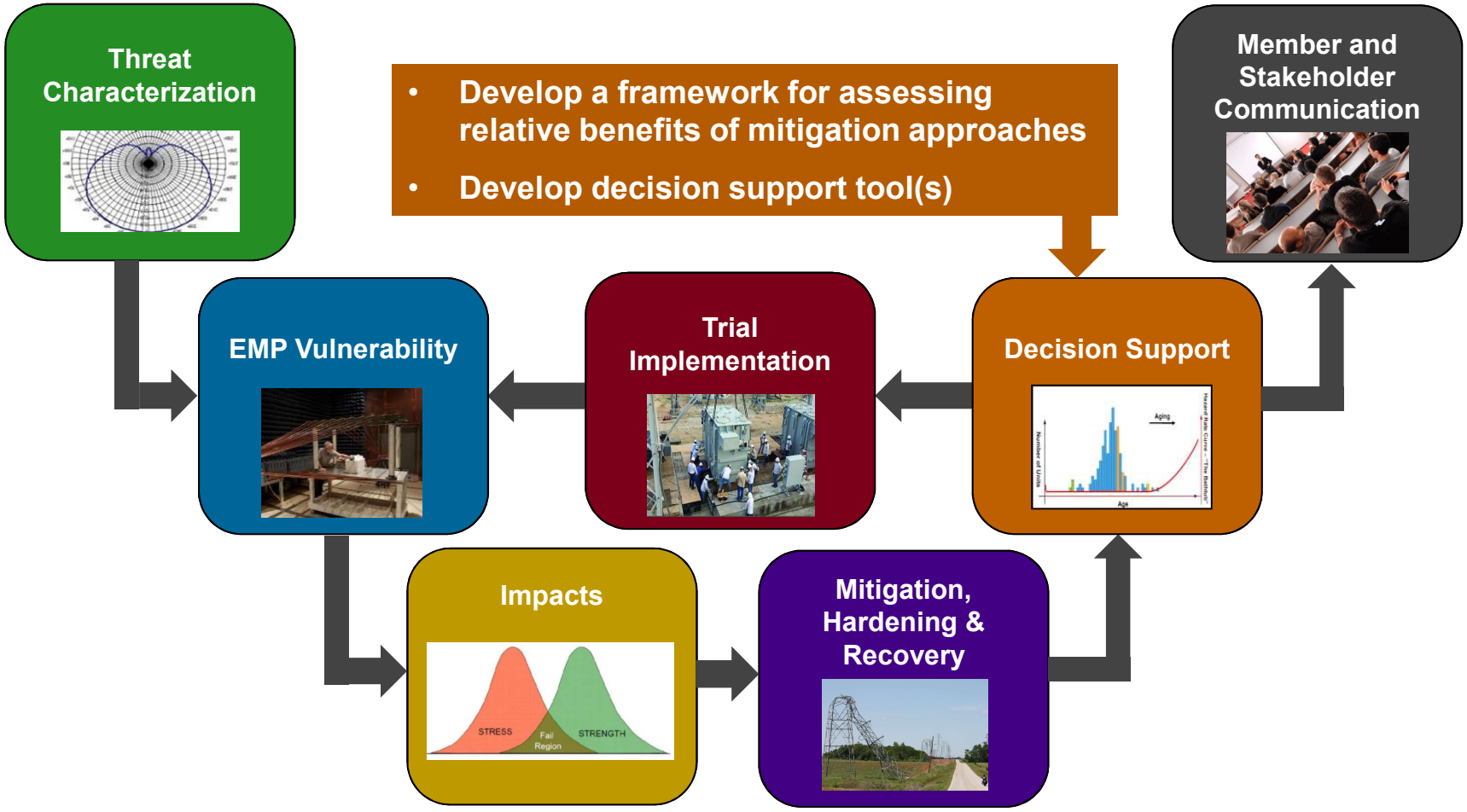
EMP Project Plan

- Identify and assess mitigation and hardening approaches that can be employed to reduce effects of HEMP, and potential unintended consequences of these approaches
- Develop approaches for mitigating/hardening substation equipment against effects of HEMP
- Develop enhanced recovery procedures/plans/capabilities



EMP Project Plan



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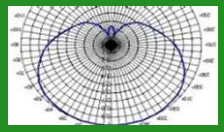
EMP Project Plan

- **Share effectiveness of HEMP mitigation methods/implementations including:**
  - ✓ **Current practices**
  - ✓ **Options identified in this project**

Threat Characterization



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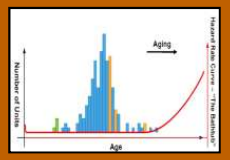
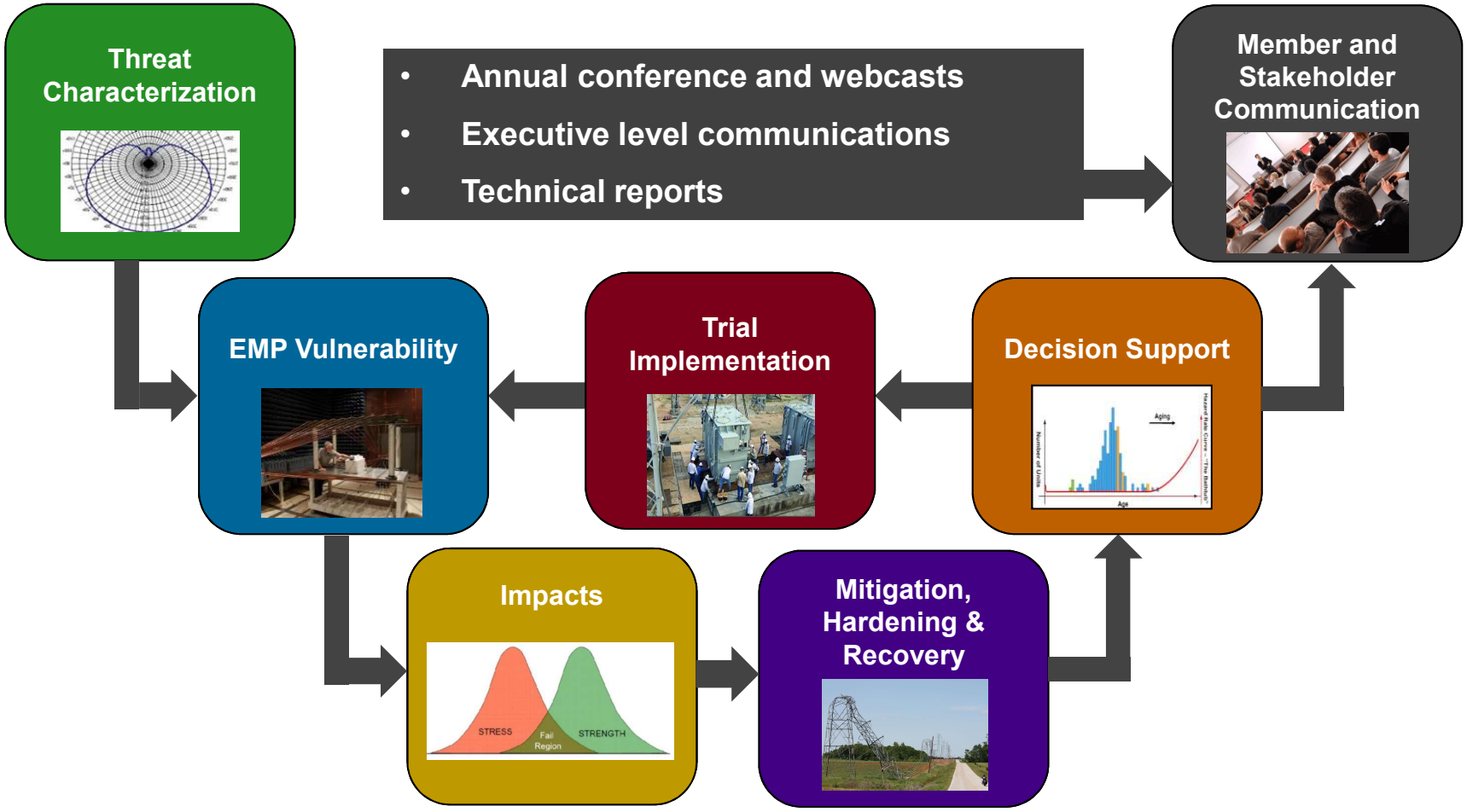


Impacts

Mitigation, Hardening & Recovery

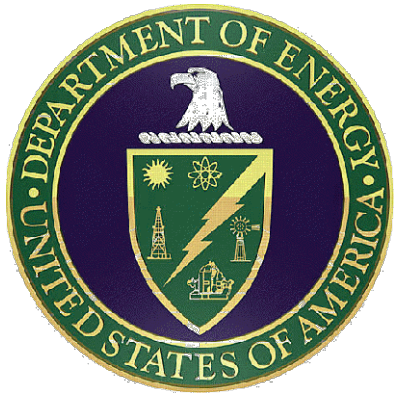
EMP Project Plan



Project Status

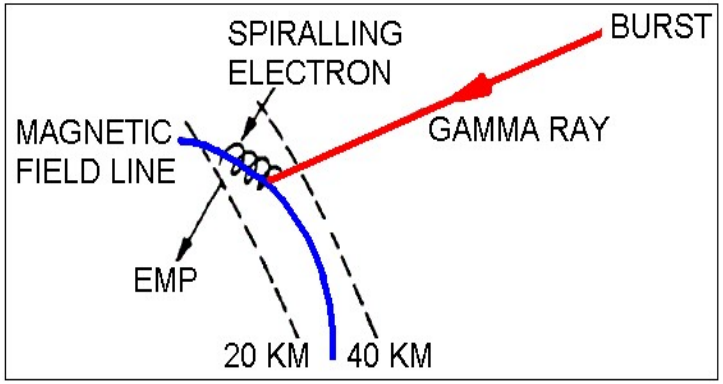
EPRI EMP Project Status

- Participation
  - 50+ Utilities
  - ~ $6 million of R&D Funding
- Collaboration
  - US Department of Energy (DOE)
    - Routine meetings and good coordination
    - Still working on their plans
    - Longer-range timeframe (finish 5+ years)
    - EPRI's findings can help inform DOE's research
  - US Department of Defense (DOD)
  - National Labs
  - EEI and NATF
  - Vendors



EPRI EMP Project Status

- Characterizing a nominal high-altitude EMP environment (E1 & E3) for use in bulk-power system vulnerability assessments
  - Working with government partners to improve threat scenarios
- Evaluating the impacts of E3 on the BPS
  - Performing voltage stability and transformer thermal assessments
  - Engaging members to perform in-service testing of large power transformers
- Engaging with experts to design and build an EMP testing facility (E1)
  - ID and procure devices/systems to test
- Simulating the effects of E1 on a typical HV substation to study the potential results of various mitigation measures

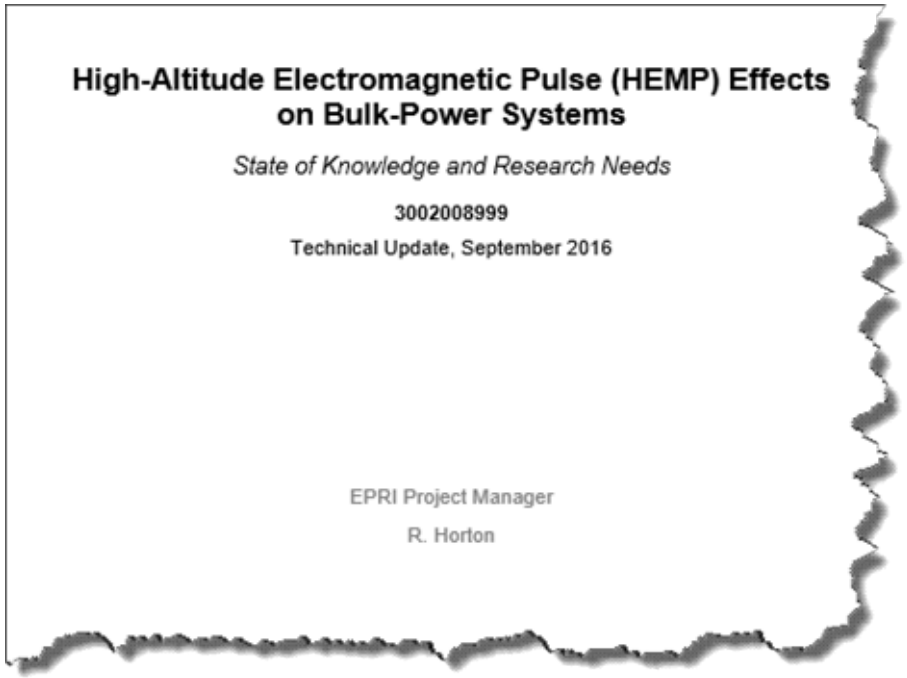


EPRI EMP Project Status

- Develop EPRI security protocols designed specifically for the EMP project to ensure the protection of sensitive data
- Continue E1/E2-related modeling and simulation activities, and E3 MHD-EMP assessments
- Continue to develop the capability of performing EMP testing of components and systems (using others for testing in near-term)
- Keep leveraging our governmental partners' expertise in modeling/simulating/testing for HEMP impacts to the grid
- Re-visit and update the research plan periodically

EPRI EMP Project Status

- Recent & Pending Activities Deliverables
  - High-Altitude Electromagnetic Pulse (HEMP) Effects on Bulk-Power Systems: State of Knowledge and Research Needs
    - (3002008999)
  - EMP Video with FAQ **4Q16**
  - MHD-EMP (E3) Assessment of the Continental U.S. Electric Grid: GIC and Transformer Thermal Assessment **4Q16 / 1Q17 (pending security review)**
  - EMP Workshop
    - Project funders only
    - **January 11-12, 2017 at EPRI's offices in Charlotte, NC**



Together…Shaping the Future of Electricity

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