EMP and Solar GMD Protection for the North American Grid

G. H. Baker

GEOMAGNETIC DISTURBANCE WORKSHOP

IDAHO NATIONAL LAB

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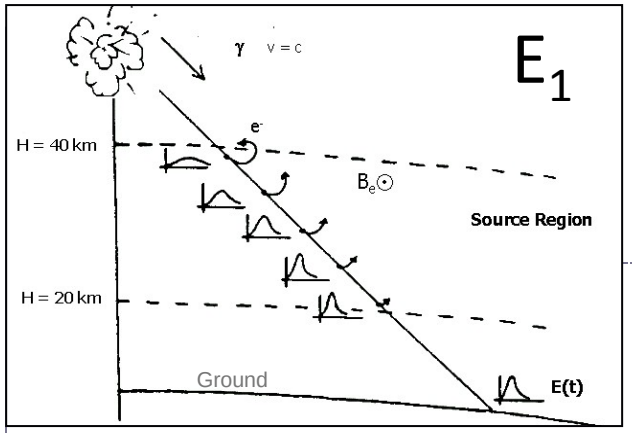
Presentation Outline

- Electromagnetic Threats, Effects and Consequences
- System Prioritization
- Protection Approaches
- Time/Field Expedient Solutions
- Grid Monitoring
- Where do we go from here?

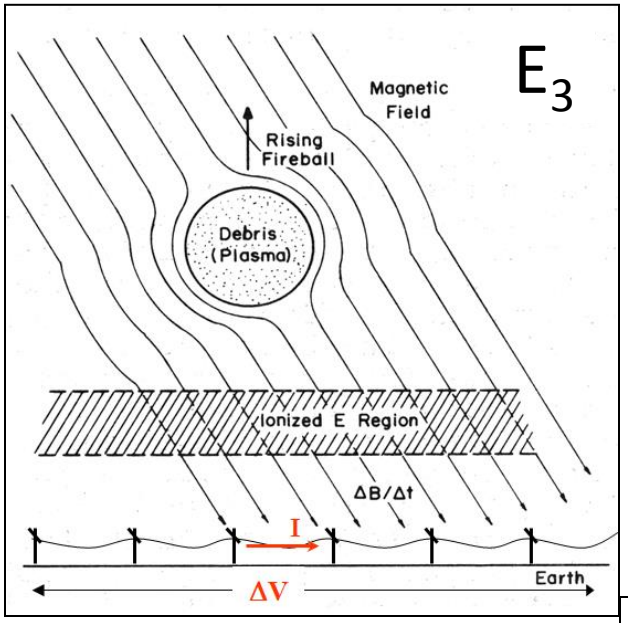
Concerns

- Three electromagnetic effects have the potential to debilitate the electric power grid over large regions
  - Solar Superstorm Geomagnetic Disturbance (GMD)
  - High Altitude Burst Nuclear EMP
  - Radiofrequency Weapons (RFWs)
- Effects are known to cause failure of electrical and electronic systems necessary for the operation of the electric power grid
- Protection efforts should address these in an integrated fashion
- Unclear federal lead puts a premium on State and local-level initiatives.

High Altitude Burst EMP Environments

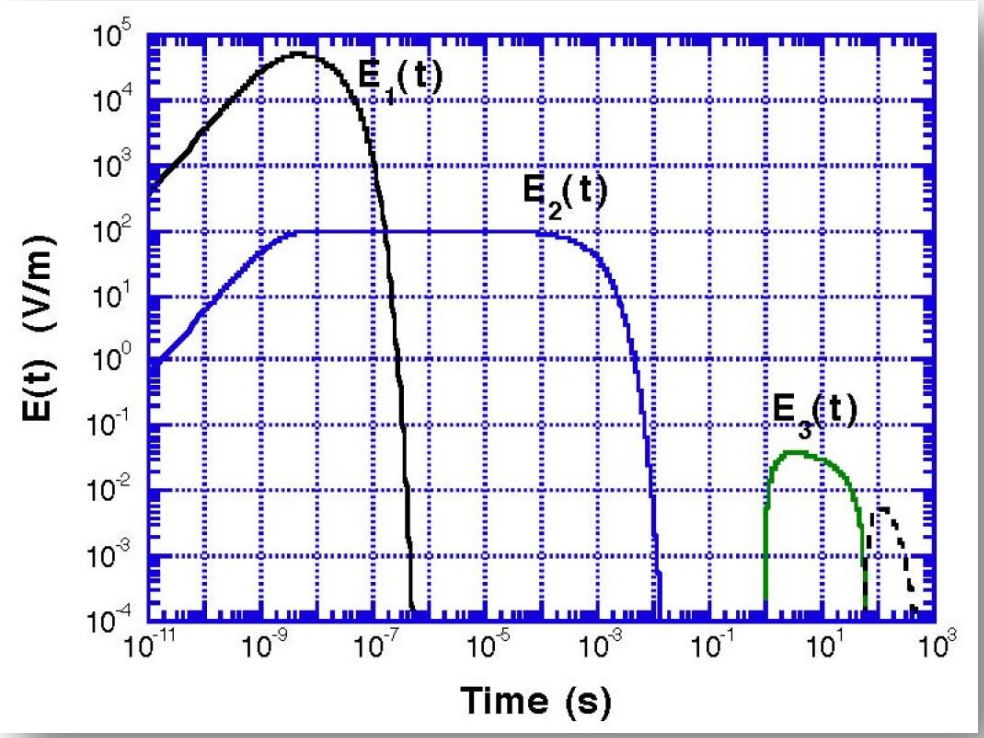


- Short duration, high peak field
- Broad-band frequency content
- Couples efficiently to short and long conductors

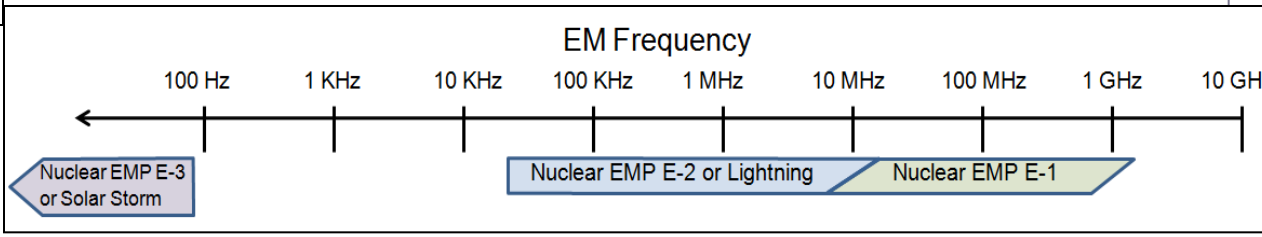


- Long duration, low peak field
- Very low-frequency energy
- Couples efficiently *only* to very long conductors (kilometers in length)

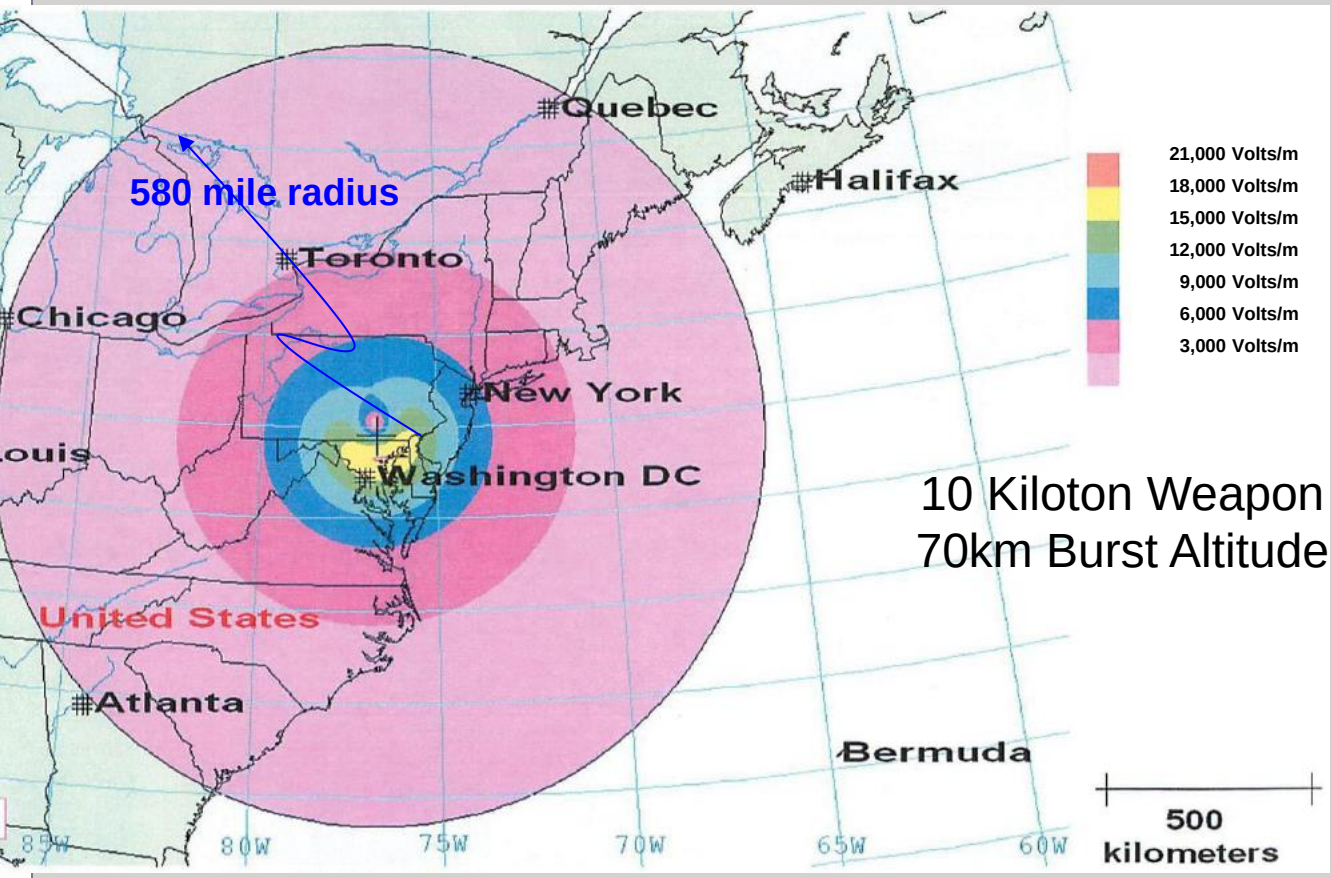
Waveform



Power Spectra



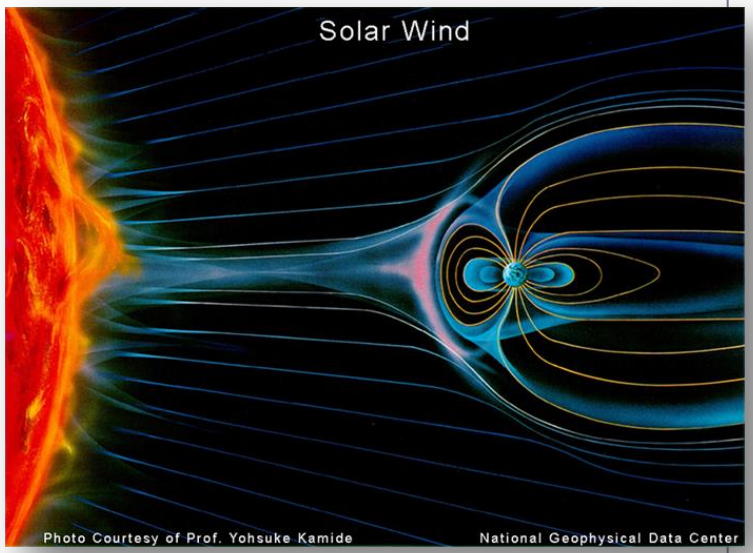
EMP Distinguishing Feature: Single Weapon Produces Effects Over Large Regions

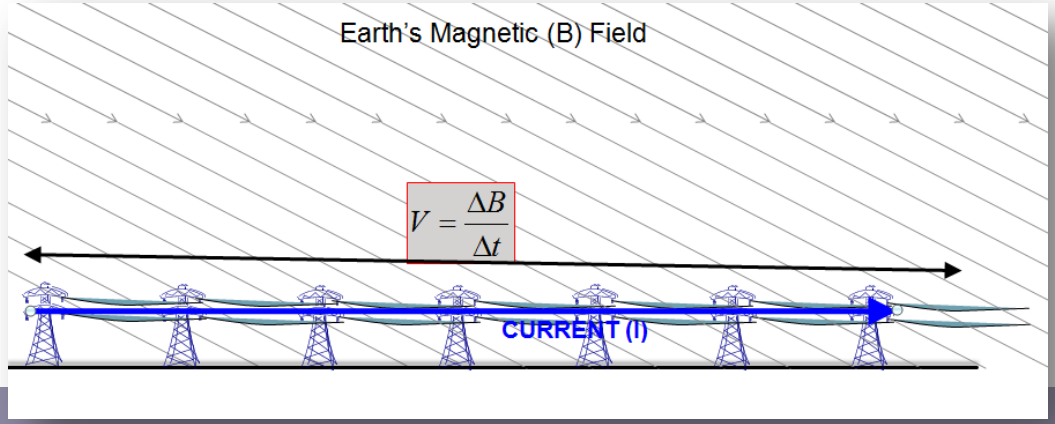


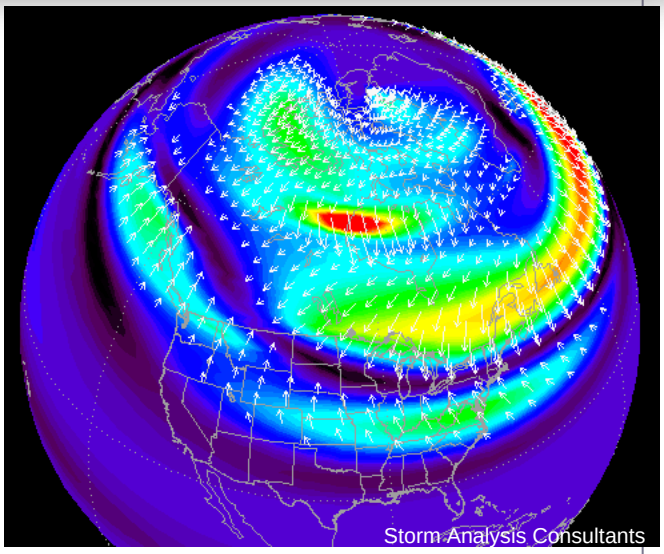
- Even a modestly sized EMP weapon could affect a large region of the United States.
  - A relatively low-yield weapon – 10 kilotons in this case – detonated at an altitude of 70 km above the earth, would generate an electromagnetic pulse a circular area of more than 1000 mile diameter
  - Graphic shows the strength and area that would be affected by an EMP weapon targeted at DC area
  - Infrastructure would be debilitated across the northeast corridor

Solar Storm Physics and Effects

- Waveform, earth coverage and system effects comparable to EMP/E3 in waveform
- Solar storms are the result of excursions in the flux levels of charged particles from the Sun (comprising the "solar wind") interacting with the earth's magnetic field.
  - Protons are the chief component.
  - There is also an *x*-ray flux precursor useful for warning.
- Distortion of earth's magnetic field induces voltages in long lines analogous to EMP/E3
  - Effects: over-voltages in long conducting lines affecting electric power grid, communication systems, and pipeline operation
  - Long Term Outages possible if systems are damaged

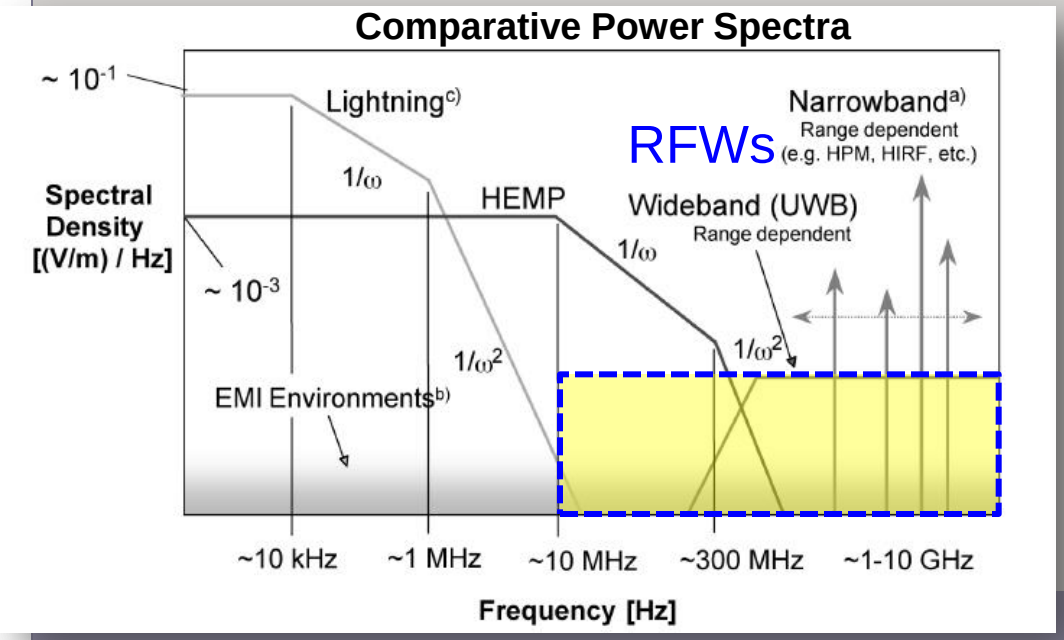






Radiofrequency Weapon (RFW) Characteristics

- Environment and effects comparable to EMP/E1, except:
  - Design frequency range extends higher [10 MHz – 10 GHz]
  - Local effects only:
    - RF energy falls off as $1/r^2$
    - Effective range from 1 meter to few km depending on weapon size
  - May be narrow-band (sinusoidal waveform) or wide-band (pulsed waveform)



Gigawatt-Class Truck-Mounted RFW

Kilowatt- Class Briefcase RFW

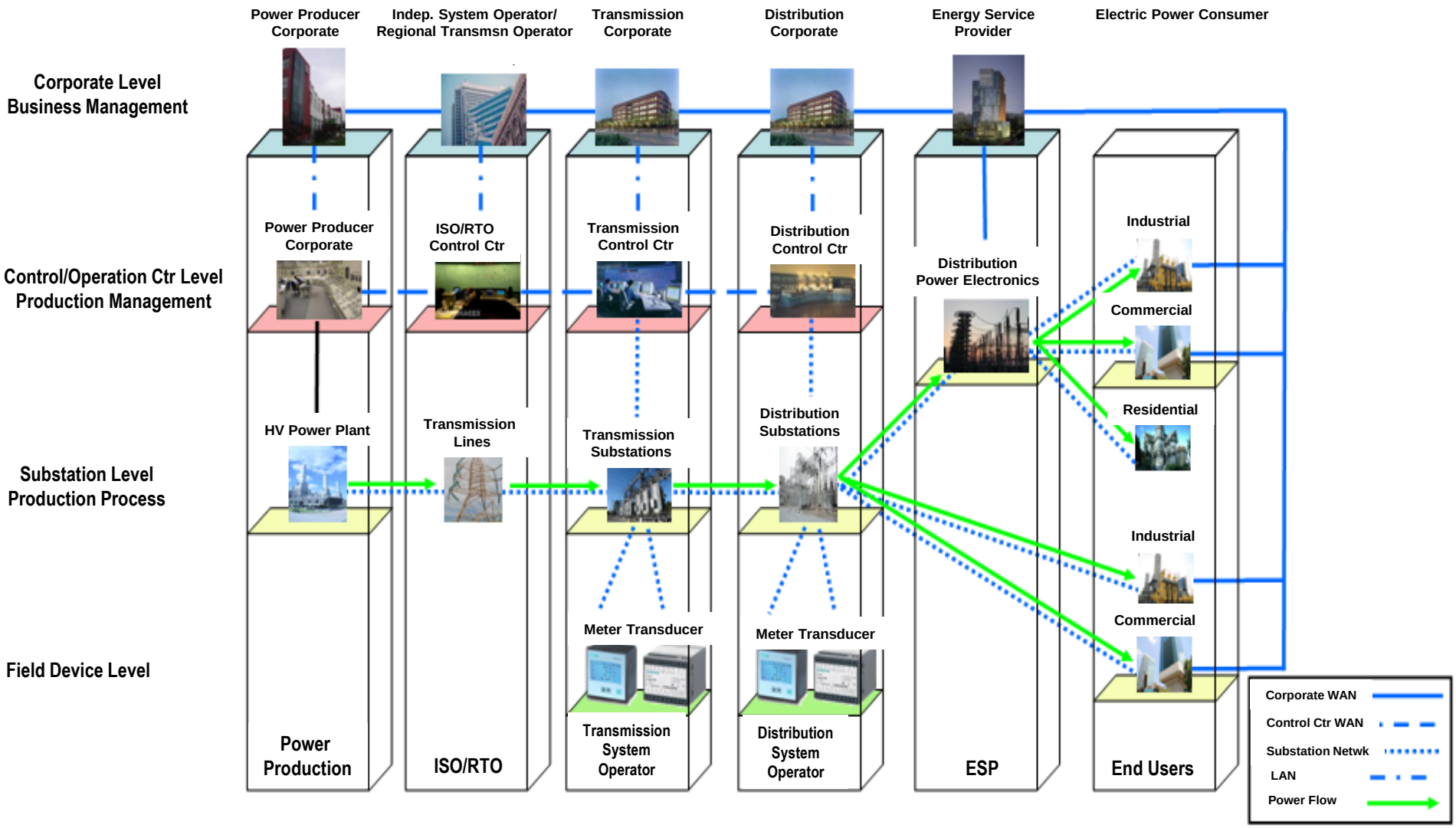
Direct System Effects vs. Threat

System Type	EMP/E3 or GMD Vulnerability	EMP/E1 Vulnerability	RF Weapon Vulnerability
Grid Power Transmission/Distribution	3	3	2
Electric Power Grid Electronic Control, Monitor Systems	1*	3	3
Long-Haul Lines /Repeaters for Data Transmit	3	3	3
SCADA, Process Control Systems	1*	3	3
Vehicles, Ships, Aircraft Electronics	0	2	3
Hand-held Electronics	0	2	3

3 – High Vuln.
2 – Medium Vuln.
1 – Low Vuln.
0 – No Vuln.

*Vulnerable to transformer saturation harmonics

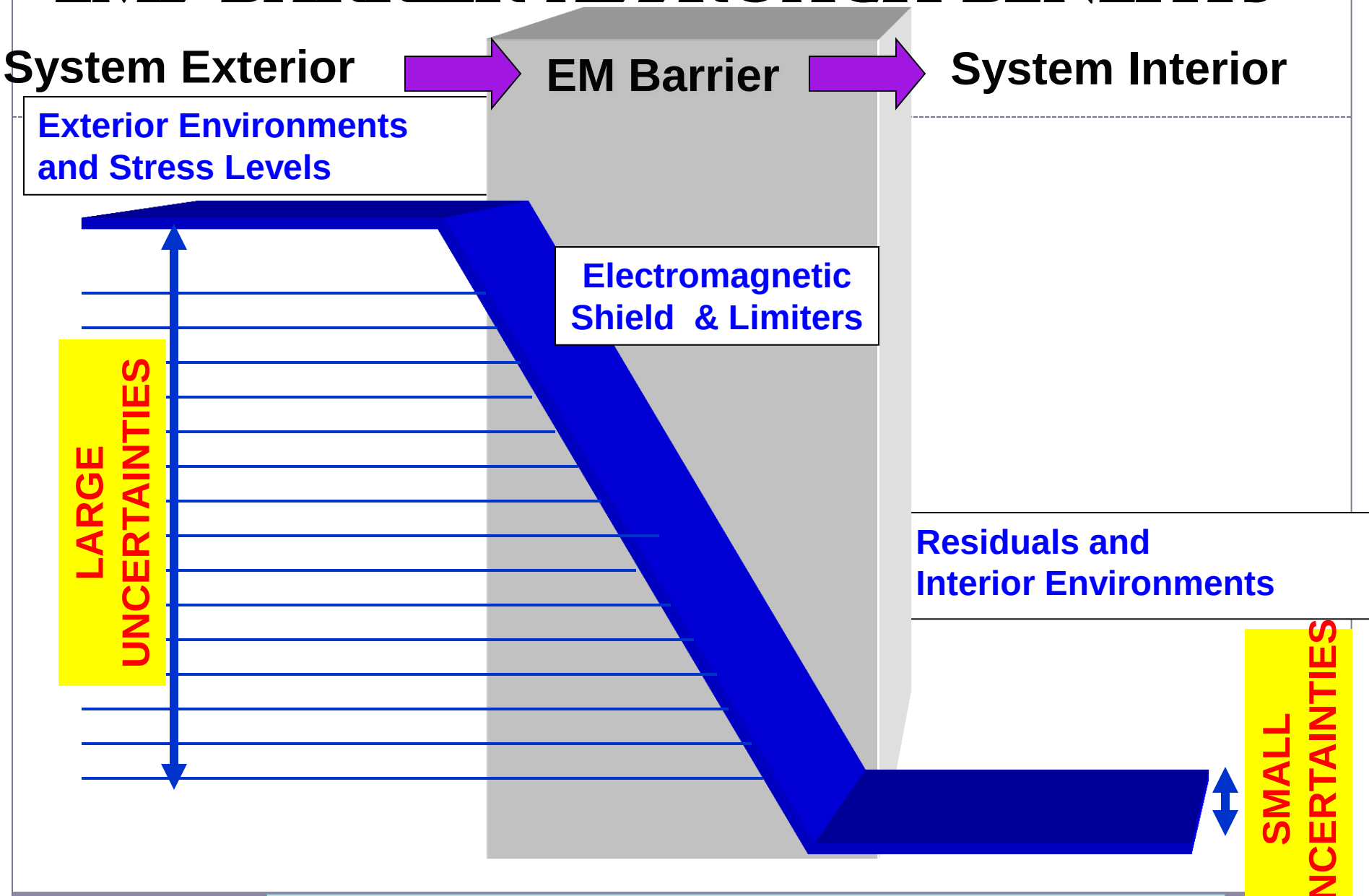
Top-Level Protection Prioritization Required



Electric Power Grid Asset List in Suggested Order of Priority

- List can be implemented in sequence, one-by-one based on available budget
  1. Major grid communication/control centers for situational awareness
  2. Black-start generation plants and generation stations supplying back-up cooling power for nuclear power plants
     - Nuke cooling power critical to avoid Fukushima-like disasters
  3. High voltage transformers within the bulk power transmission grid
  4. Remaining generation plants by priority of infrastructures serviced
  5. Local distribution networks based on utility/community priority list

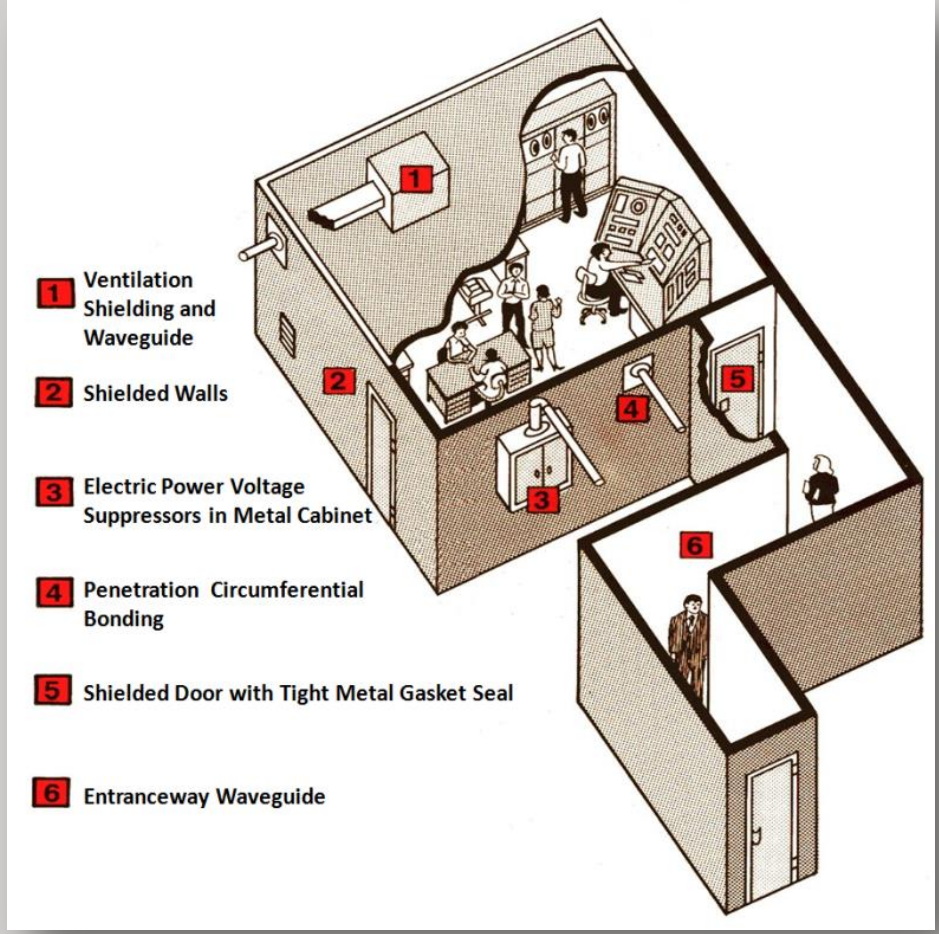
EMP BARRIER APPROACH BENEFITS



Capacitor Blocking Devices Perform Similar Function

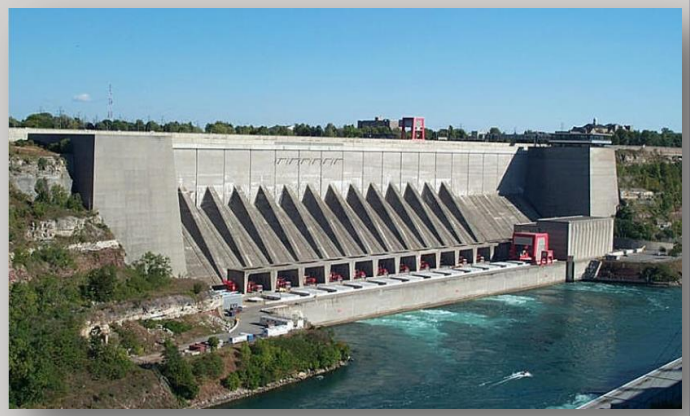
Protection of Communication/Control/Data Systems

- EMP protection methods are understood and feasible
- Low-risk system and facility shielding approach
  - Shielded enclosures
  - Limit and protect cable and doorway penetrations
  - Use optical fiber instead of metal cables
  - Backup power systems
  - Good grounding techniques
- The military has experience in successful implementation since 1960s (see MIL-STD-188-125 and MIL-HDBK-423)



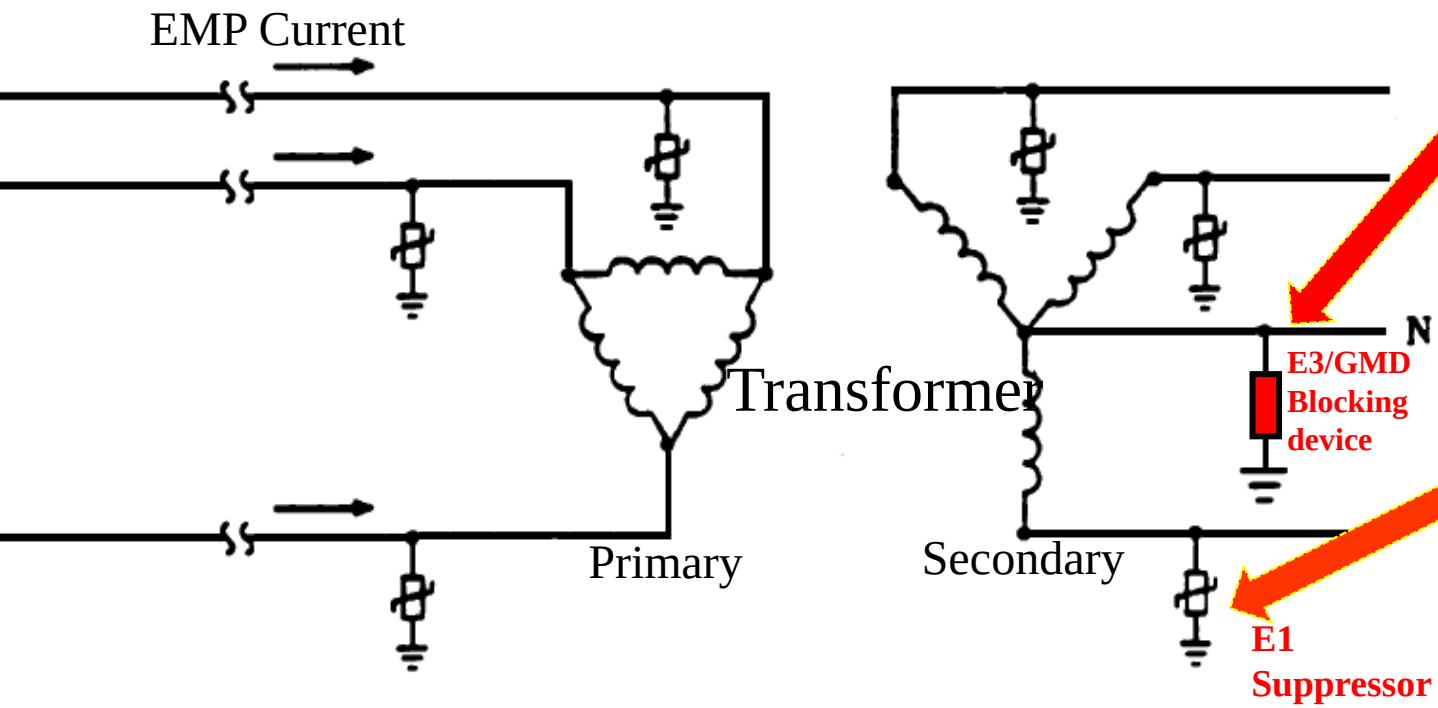
Protection of Blackstart Generator Plants

- Protect Step-Up Transformers – many have lightning protection – add GIC blocking devices
  - Provide overvoltage protection on transformer primaries ("Y" side)
- Maintain manual/mechanical control systems if at all possible
  - Mechanical governors
  - Electrical relay transfer switches
- Protect generator electronic control systems
  - Enclose within shielded cabinets or rooms
  - Protect penetrations
  - Use optical fiber interconnects
- Implement and practice mechanical/manual workaround procedures
  - Restarting generation machinery
  - Islanding the local grid



Transformer Protection

- Transformers need protection from E1, E3 and GMD
  - MOVs or vacuum valves provide E1 overvoltage suppression
  - Ground Induced Current (GIC) blockers provide E3/GMD protection



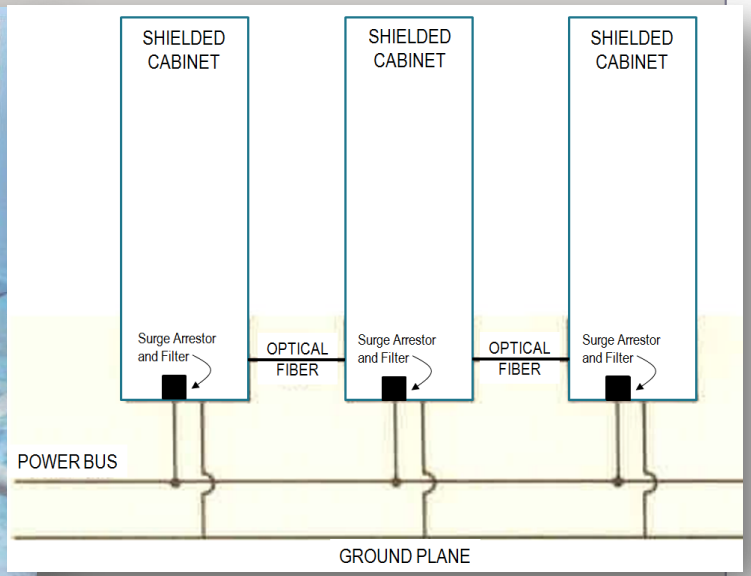
E3/GMD Ground Induced Current Blocking Device

Gapless MOV Arrestors

RFW/EMP Protection
Cost Reduction Methods

- Global shielding can be accomplished without shielding entire buildings:

Shielded Room Installation



Shielded Cabinet Installation

Example Protection Hardware

Shielded Enclosures

Shielded Doors

Power and Signal Line Filters

Hardened Modular Data Centers

Shielded Cabinets

Communication/Data Center Protection Costs

Vendor ROM Costs / Enclosure Type	Vendor A	Vendor B	Vendor C	Vendor D
Primary Data Center (4000-6000 sq. ft.)	$300,000 to $450,000	$ 645,000 (6000 sq.ft.)	$350k	$1,611,000 (4000 sq.ft.) $2,286,000 (6000 sq.ft.)
Secondary Data Center (1000-2000 sq. ft.)	$75,000 to $150, 000	$ 360,000 for 2000 sq.ft.	$275k	$527,000 (1000 sq.ft.) $913,000 (2000 sq.ft.)
Aggregation Radio Hub (10x10 sq.ft.)	$75,000 $275,000 with AC and backup gen	$ 132,000	$15k - $20k $35k to $55k with AC and backup gen	$571,000 (with AC and backup gen)
Cell Site Shelter 84”H x 50” W X 34” D	Approx $100,000 (includes EMP filters)	$ 19,000 (excludes installation)	$10,000	$360,000 – cost of prototype. Includes battery backup and generator and EMP filter.

GMD and EMP Monitors for Situational Awareness

- Monitors important for
  - Normal operational monitoring
  - Correlation of GIC current to GMD field levels for grid modeling and establishing equipment malfunction thresholds
  - Warning in event of natural or human-caused system insults

Transformer Temp/GIC Monitors [Advanced Power Technologies]

EMP/RFW Detector (EMPrimus)

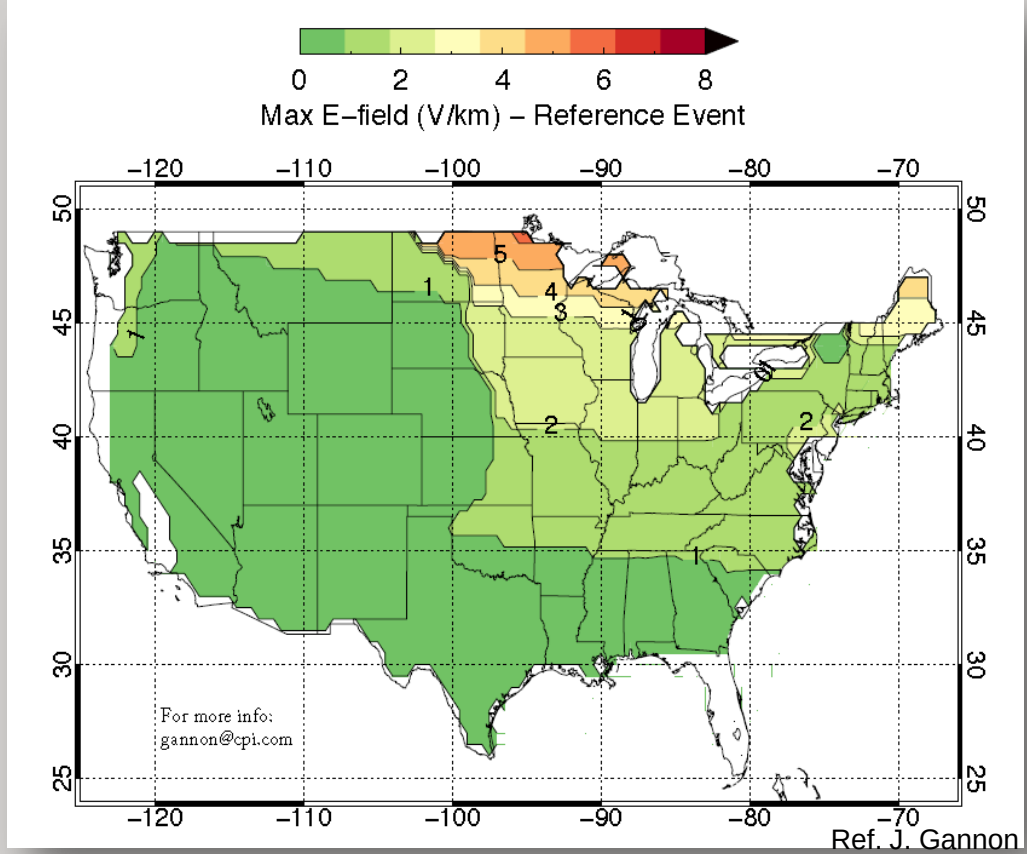
Backup Generators

- Recognizing that significant parts of the grid are likely to fail in an EMP or GMD scenario
  - It will be important to expand provision of back-up power systems for basic life functions
  - A lesson from Katrina emphasized by LTG Russel Honoré.
- Many medical, communication, financial facilities now have emergency generators
- Additional requirements should apply to:
  - Water systems
  - Gas stations
  - Food stores
  - Pharmacies
- Emergency generators relatively easy to protect against EMP and certify via test
- Premium on long-term backup fuel logistics

Several companies now manufacture EMP-certified generators

Low NERC Standard Formula Eliminates GMD Protection Requirements for Most Utilities

- NERC Standard TPL-007-1 has Benchmark GMD Event and scaling factors that effectively exempts most of CONUS grid from hardware protection requirements
- Exempted utilities will likely default to operational procedures



Ref. J. Gannon

Operational Procedures are Insufficient to Protect the Electric Power Grid

- Operational procedures inadequate during past, much simpler causes of large-scale blackouts (e.g. August 2003, Hurricane Sandy)
- 30-45 minute L1 warning time inadequate to coordinate operational procedures
- Catch 22 – Grid operators will be reluctant to shed load due to insurance rules.
  - If the grid goes down due to human action, power companies are liable.
- Operators will not have adequate information on the state of the larger grid to implement correct operational procedures.
  - No control center has large enough visibility; More sensors needed; Errors in past operational procedure actions have made matters worse
- Not possible to anticipate all grid failure points/combinations and time sequences in GMD events in order to adequately plan/exercise GMD event procedures.
- ISO's don't have cross-jurisdictional authority to enforce shutdown of neighboring grids – sometimes required to avoid large scale blackouts (ref.August 2003)
- Approved NERC Operational Procedure Standard, EOP-010 does not apply to generator authorities or load-balancing authorities. Portions of the grid operating below 200KV are excluded from draft operational procedures.

Concluding Points

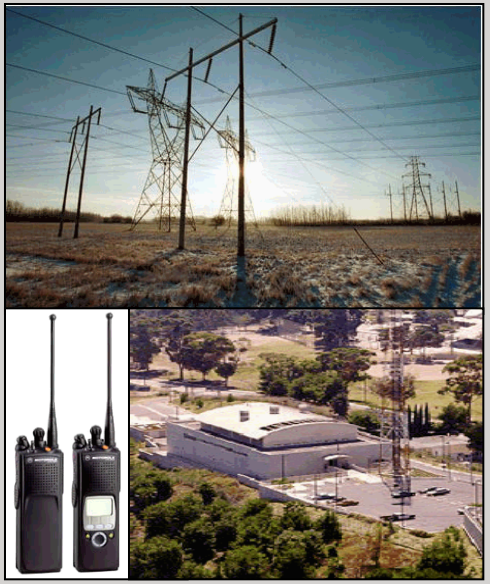
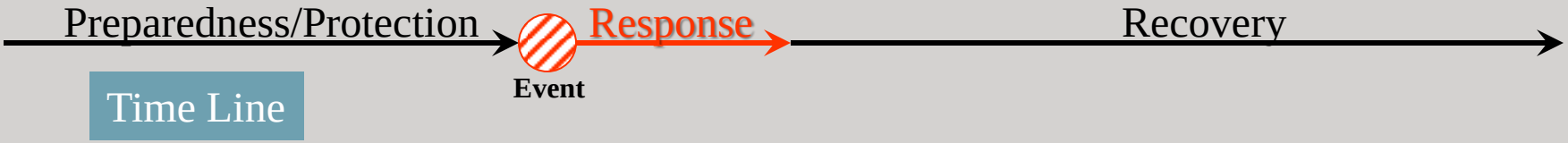
- EMP/RFW/GMD effects can collapse the power grid over large regions.
- Operational procedures do not suffice to prevent collapse – physical protection is required.
- Protection engineering methods are proven and costs are reasonable in comparison with value of catastrophic losses.
- Can't protect everything
  - Risk-based prioritization points to importance of protecting grid control centers, black-start generation plants, and nuclear plant coolant power
  - Programs to protect a limited set of highest risk infrastructure greatly reduce societal impact
- Federal/State/Local government and public-private partnership planning and implementation are essential to progress
  - Absence of Federal leadership places premium on State and Local preparedness initiatives
  - Incorporate effects in emergency exercises
- Public awareness of effects and preparedness measures is a top priority

Draft Vision for Wide-Area Electromagnetic Effects Future

[George H. Baker]

- Industry-Government working together to achieve an EPG that is inherently hard to GMD/EMP/RFW effects
- Utilities able to recapture costs associated with physical protection
- A unified model of national grid verified by shared GIC data
- A single national organization given overall authority for EPG EM protection.
- A uniform nation protection standard developed and enforced by an independent standards organization dominated by technical considerations rather than political
- A national, coordinated black start plan and resources that are exercised on a regular basis

Questions

Priority Infrastructures

- Debilitation of the electric power and information/communications infrastructures pose the highest risks to society from wide-area effects
  - Most vulnerable to EMP/RFW/GMD due to their organic long line networks and large coupling cross sections
  - Most necessary for operation of other infrastructures
  - Loss has instantaneous effects on other infrastructures
  - Critical re. reconstitution timeline
- Availability of emergency response communications infrastructure is particularly critical in the aftermath of an EMP or GMD event