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EMP and Geomagnetic Storm Protection of Critical Infrastructure

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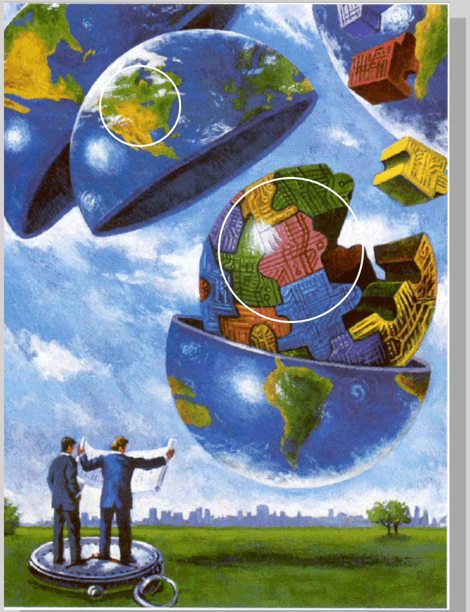
EMP and Geomagnetic Storm Protection of Critical Infrastructure – Where Do We Start?

Outline

- Wide-Area Electromagnetic Environments and Effects
- Related National Security Issues
- Critical Infrastructure Challenges
- The Way Forward
- Some Recent Hopeful Developments



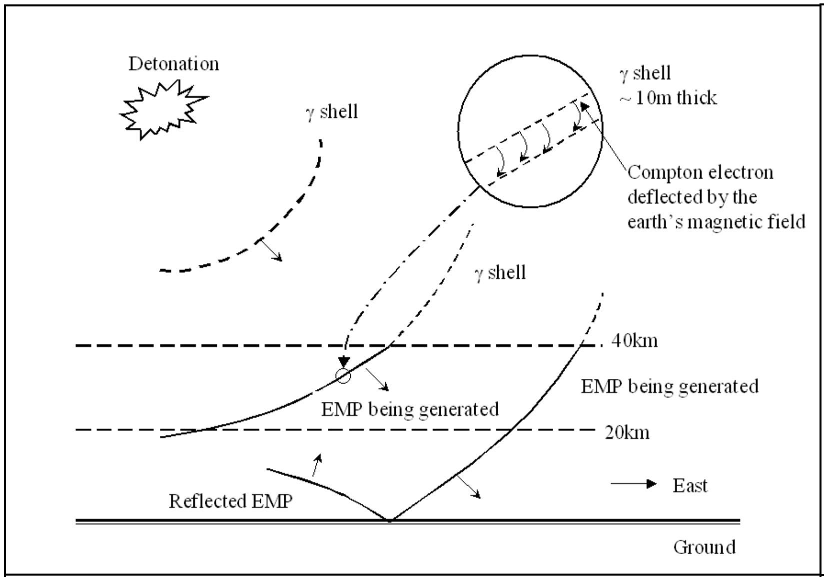
Concerns

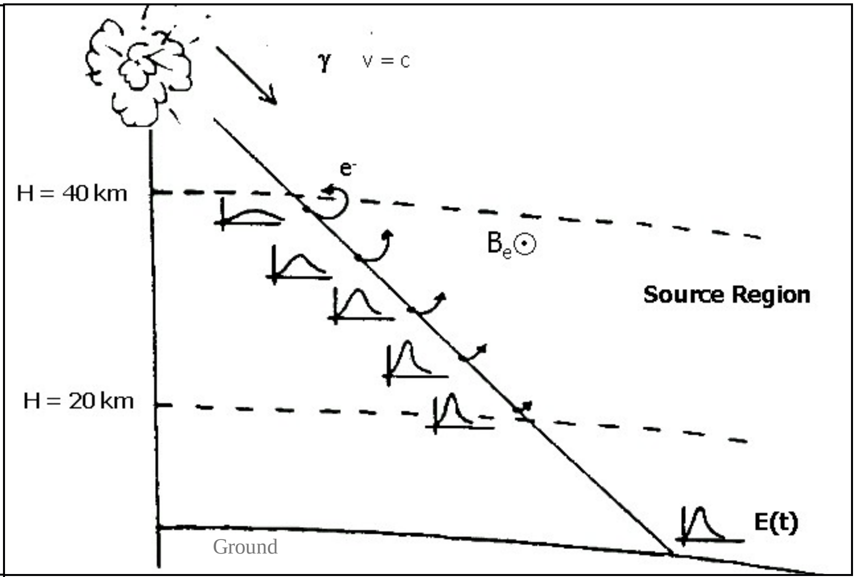
- Two electromagnetic threats have potential to create continental-scale disasters
  - Solar Tsunamis
  - High-altitude nuclear detonations
- Both phenomena cause debilitation of electrical and electronic systems necessary for the operation of infrastructure systems and services
  - Infrastructure systems comprised of long-line conductor networks are the most vulnerable
    - Electric power, land-line communications, pipelines are prime examples
    - Cascading effects to most other infrastructures due to their dependence on long-line infrastructure systems
  - Smaller, self-contained, self-powered infrastructure systems are also vulnerable, but to a lesser degree (vehicles, hand-held radios, etc)

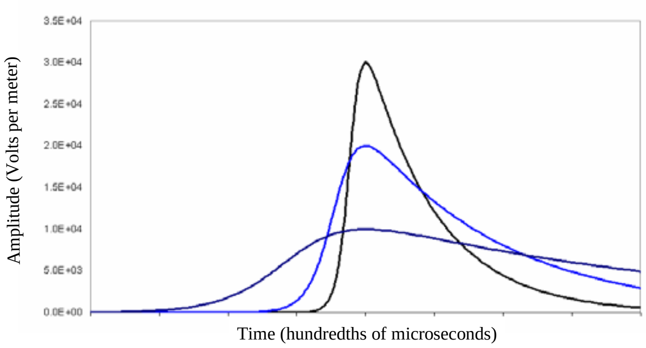
This brief will focus on ground systems – recognize that there are also important associated radiation effects on satellites

WIDE-AREA ELECTROMAGNETIC ENVIRONMENTS AND EFFECTS
–
BRIEF PHYSICAL OVERVIEW

Prompt EMP (E1) Physics







$$E(t) = \left(1+\frac{\alpha}{\beta}\right)\frac{Ae^{\alpha t}}{1+\frac{\alpha}{\beta}e^{(\alpha+\beta)t}}$$

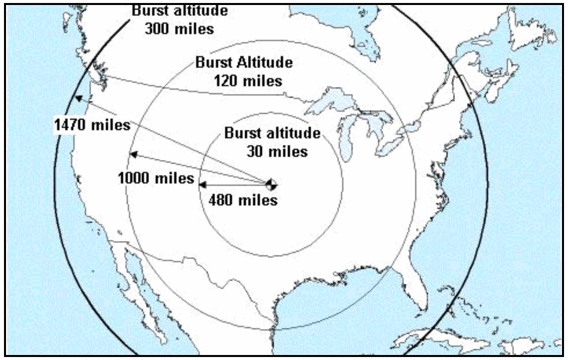
where A = peak amplitude

α = rise rate

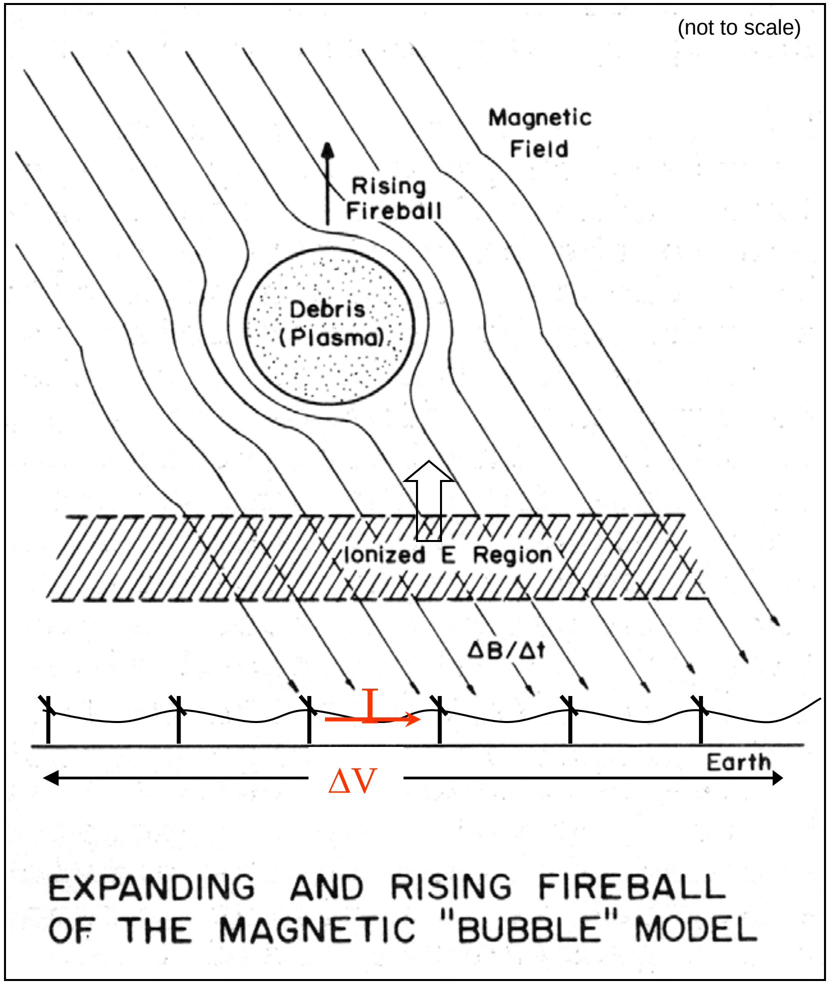
β = decay rate

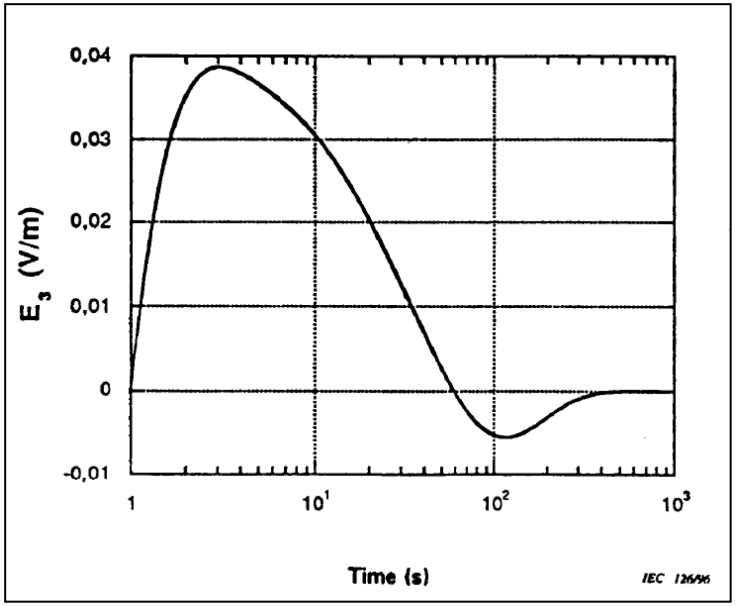
Typical values are $A = 3\times10^{4} V/m$; $\alpha = 10^{8}\ \mathrm{sec}^{-1}$; and $\beta = 10^{7}\ \mathrm{sec}^{-1}$

- Broad-band frequency content
- Couples efficiently to short and long conductors



Late-Time EMP (MHD EMP or E3) Physics





- Very slow, low frequency waveform analogous to solar storm geomagnetic perturbation waveform
- Couples efficiently only to very long conductors (kilometers in length)

Nuclear High Altitude Burst (HAB) System Effects

- Three system effects in play:
  - Prompt EMP (E1)
    - Effect types: broad-band properties enable coupling to electrical/electronic systems in general
    - Effects duration: indefinite if systems are damaged.
  - Late-time MHD EMP (E3)
    - Effect types: over-voltages in long conducting lines affecting electric power grid, communication systems, and pipeline operation
    - Effects duration: indefinite if systems are damaged
  - Perturbation of the electrical properties of the ionosphere (Atmospheric Effects)
    - Increase in the electrical conductivity of the upper atmosphere caused by thus changing radio wave propagation and reflection behavior
    - Similar to solar storm effects on HF/VHF/UHF communication and GPS
    - Effects duration: 10's of hours.

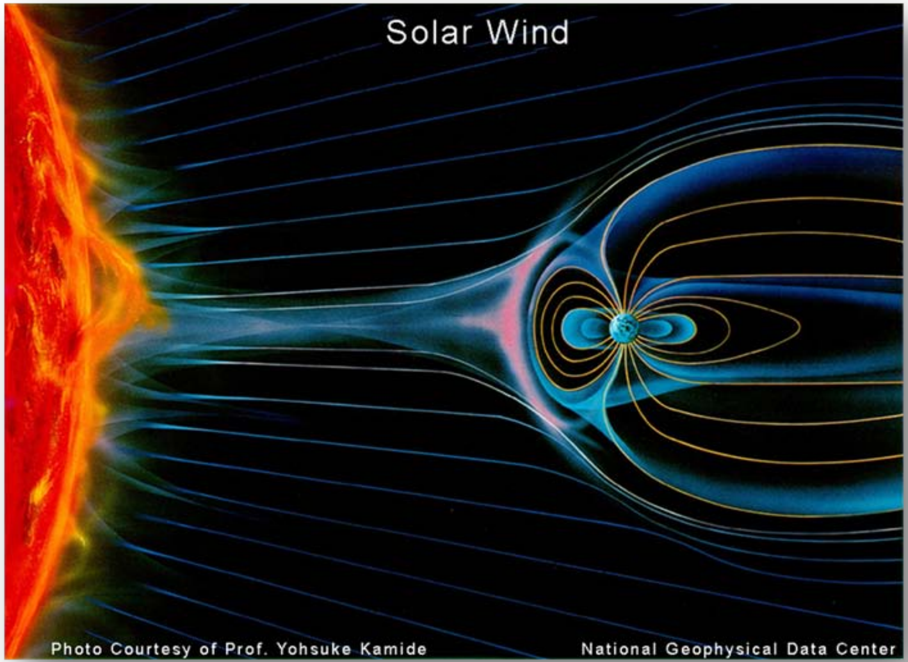
EMP Coupling – Long Line Levels

MIL-STD-188-125 – Selected Levels

Class of Electrical POE		Type of Injection	Peak Short-Ckt Current (A)	Risetime (s)	FWHM[2] (s)
Commercial Power Lines (Intersite)					
Short Pulse		Common mode	5,000 }E1	$\le 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Short Pulse		Wire-to-ground	2,500	$\le 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Intermediate Pulse	Electric	Common mode	250 }E2	$\le 1.5\times10^{-6}$	3×10^{-3}–$5x10^{-3}$
Intermediate Pulse	Power	Wire-to-ground	250	$\le 1.5\times10^{-6}$	3×10^{-3}–$5x10^{-3}$
Long Pulse		Common mode	1,000 }E3	≤ 0.2	20–25
Long Pulse		Wire-to-ground	1,000	≤ 0.2	20–25
Audio/Data Lines (Intersite)					
Short Pulse		Common mode	5,000 }E1	$\le 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Short Pulse		Wire-to-ground	$5{,}000/\sqrt{N}$ or 500	$\le 2\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Intermediate Pulse	Comms.	Common mode	250 }E2	$\le 1.5\times10^{-6}$	3×10^{-3}–$5x10^{-3}$
Intermediate Pulse		Wire-to-ground	250	$\le 1.5\times10^{-6}$	3×10^{-3}–$5x10^{-3}$
Long Pulse		Common mode	1,000 }E3	≤ 0.2	20–25
Long Pulse		Wire-to-ground	1,000	≤ 0.2	20–25

Solar Storm Physics

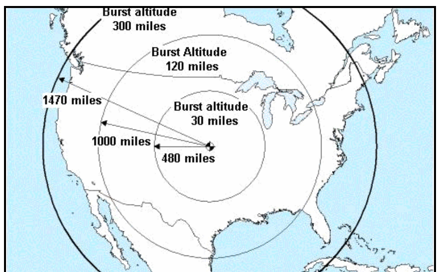
- Solar storms are the result of excursions in the flux levels of charged particles from the Sun (comprising the "solar wind") impinging on the earth's atmosphere and interacting with the earth's magnetic field.
  - Protons are the chief component.
  - There is also an *x*-ray flux precursor useful for warning.

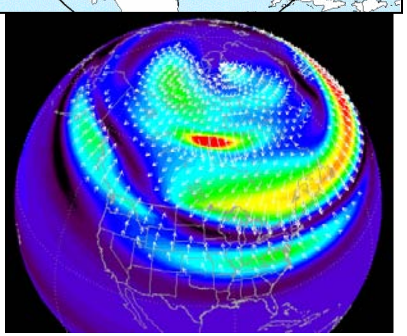


Solar Storm System Effects

- Two main effects in play:
  - Perturbation of earth's magnetic field leading to voltages induced in long lines via Faraday's law (voltage is directly proportional to the rate of change of the earth's magnetic field)
    - Effects: over-voltages in long conducting lines affecting electric power grid, communication systems, and pipeline operation
    - Indefinite duration of effects if systems are damaged
  - Perturbation of the electrical properties of the ionosphere
    - Increase in the electrical properties of the upper atmosphere caused by *x*-ray and proton impact on molecules in the upper atmosphere that causes change in its propagation and reflection properties vis-à-vis radio waves.
    - Effects – interference with
      - HF, VHF and UHF radio communications
      - Navigation signals from GPS satellites affecting vertical navigation of aircraft (typically ~30 hours during solar disturbance…horizontal navigation unaffected)

Wide Area Electromagnetic Threats Summary

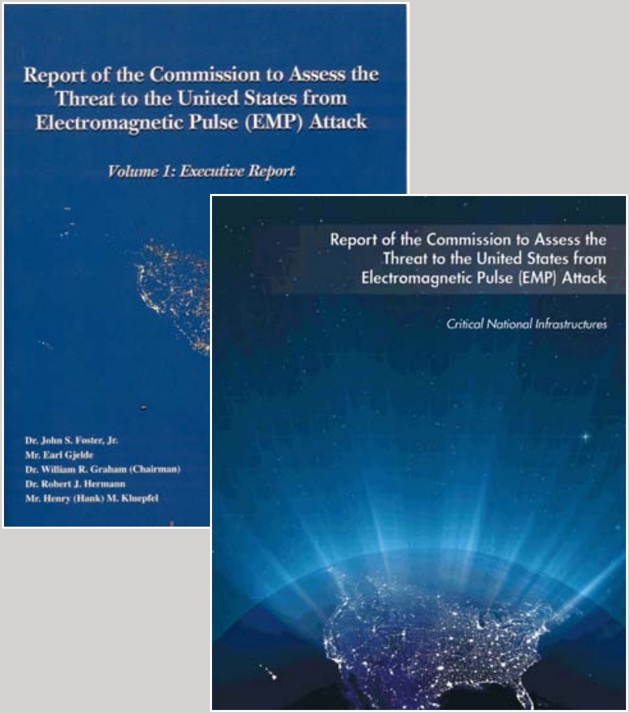




THREAT	Environments	Susceptible Systems	Effects / Duration
High Altitude Nuclear Burst	Gamma-induced EMP (E1)	All electrical, electronic systems	Component Damage / Indefinite
	Magnetohydrodynamic EMP (MHD EMP or E3)	Long-line network systems incl. Electric Power Grid, Terrestrial Comm. Lines, Pipelines	Component Damage / Indefinite
	Ionosphere Electrical Properties Perturbation	Radio communication systems and GPS	Wave path degradation / 10's of hours
Solar Tsunamis	Geomagnetic Perturbation (GMP)	Long-line network systems incl. Electric Power Grid, Terrestrial Comm. Lines, Pipelines	Component Damage / Indefinite
	Ionosphere Electrical Properties Perturbation	Radio communication systems and GPS	Wave path degradation / 10's of hours

Critical Infrastructure Issues

- Wide-area electromagnetic effects are challenging due to their near-simultaneous effects on wide array of infrastructures
- EMP Commission has made a compelling case for protection of critical infrastructure
- Conclusions apply to both nuclear and solar
- EMP Commission wrestled with focus
  - Recognized we can't protect everything
  - Commission charter forced broad approach
  - Commission not prescriptive in terms of protection priorities
- Begs questions – where to begin protection program?
- It helps to addresses this question from a "think big… start small" vantage



Critical Infrastructures

- Certain "critical" infrastructures are so vital that their incapacity or destruction would have a debilitating effect on defense, public health-safety and/or economic security[1,2]
  - Agriculture and Food
  - Water Utility
  - Public Health
  - Energy
  - Transportation
  - Banking and Finance
  - Chemical Industry and Hazardous Materials
  - Emergency Services
  - Information and Communication
  - Postal and Shipping
  - Gov't Services
  - Industrial Base

- U.S. DHS is pursuing a "risk-based" prioritization approach in developing general protection programs

[1]PCCIP Report [2]National Strategy for the Physical Protection of Critical Infrastructure

Infrastructure EMP Risk Quantification

$$\text{Risk} = E \times V \times C$$

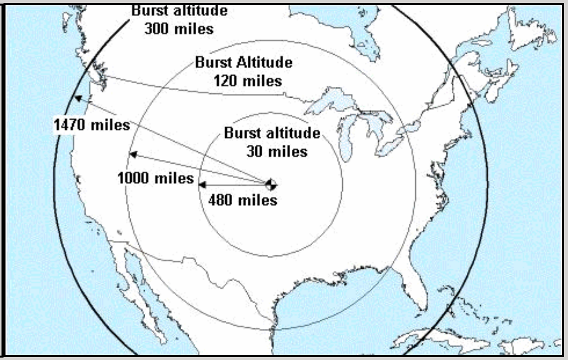
Exposure

- Access for attack
- Security against attack
- Attractiveness/visibility
- Capability and intent

Vulnerability

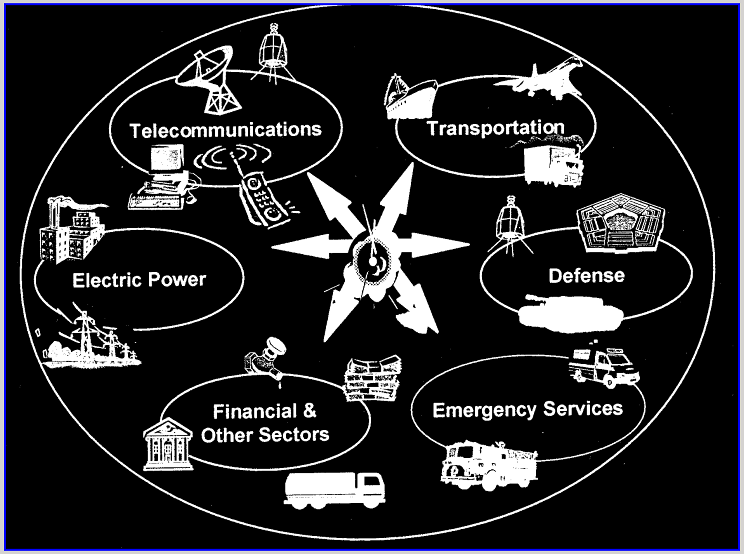
Criticality

- The EMP "Exposure" factor is similar for all civilian infrastructures due to seamless continental-scale coverage
- Vulnerability and Criticality are the sole determinant factors for wide-area electromagnetic effects risk



Prioritization based on Risk

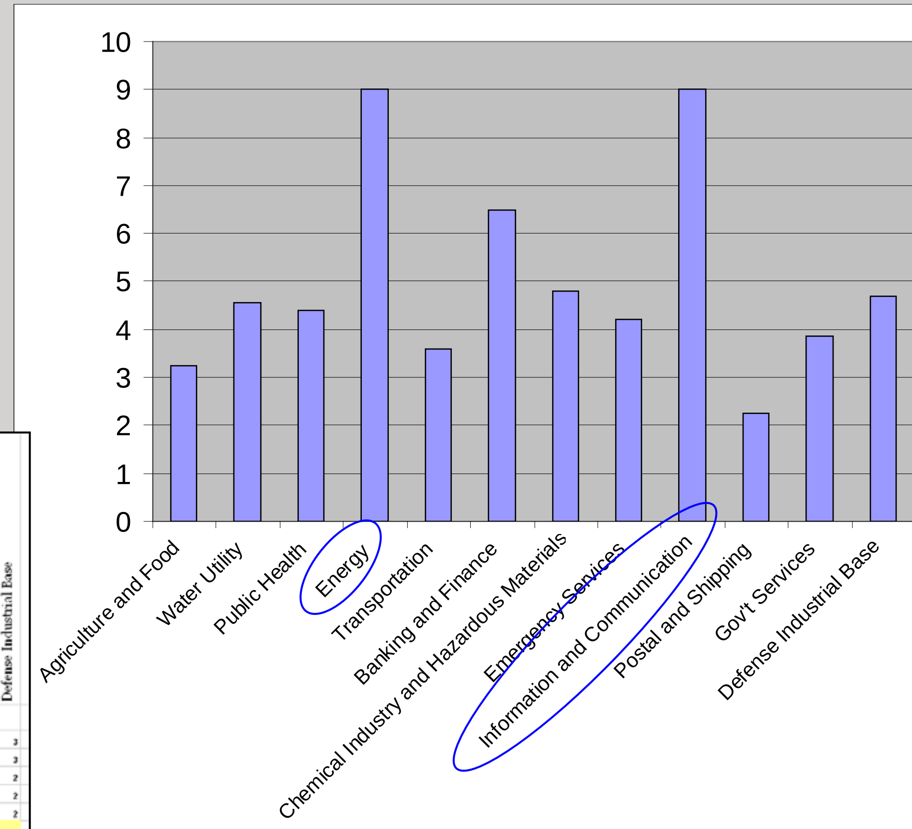
- EMP Vulnerability Factors
  - Infrastructure connectivity to long conducting lines?
  - Dependency on digital electronic control systems?
  - Lack of manual work-around procedures?
  - Time needed to repair, reconstitute system?
  - Difficulty of protection?



- EMP Criticality Factors
  - Number of other infrastructures affected?
  - Immediacy of effects on services?
  - Degree of economic impact?
  - Scope of human casualties?
  - Infrastructure necessary to enable repair/recovery of other infrastructures post-attack?

EMP Risk

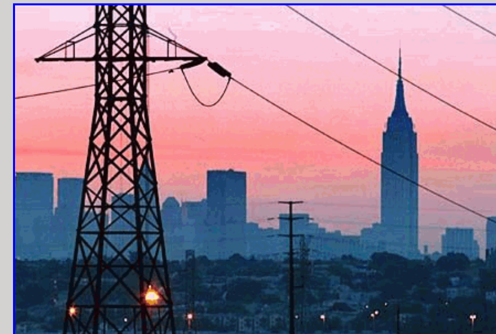
- Risk values based on scoring vulnerability and criticality factors using a scale of 1 - 3 for each critical infrastructure
- Risk metric is product of average scores $R_i = \overline{V}_i \times \overline{C}_i$

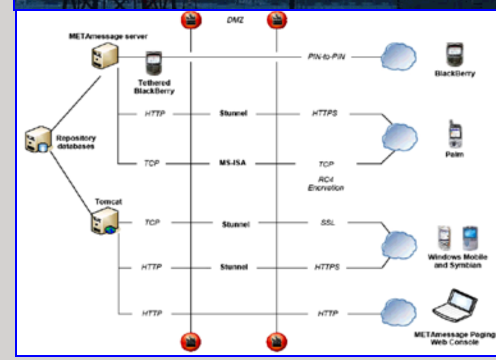


	Water Utility	Agriculture and Food	Public Health	Electric Power/Energy	Transportation	Banking and Finance	Chemical Industry and Hazardous Materials	Emergency Services	Information and Communication	Postal and Shipping	Gov't Services	Defense Industrial Base
Electromagnetic Vulnerability Factors												
Dependency on Long Lines	2	2	2	3	3	3	2	3	3	3	3	3
Dependency on digital electronic control systems	2	1	3	3	2	3	3	2	3	2	2	3
Lack of alternative survivable backup systems	1	1	2	3	1	2	1	2	3	1	2	2
Time delays to repair, reconstitute system	1	1	1	3	1	2	2	1	3	1	1	2
Lack of manual work-around regimens	2	1	2	3	1	2	2	2	3	1	2	2
VULNERABILITY SCORE	1.6	1.2	2	3	1.6	2.4	2	2	3	1.6	2	2.4
Individual Infrastructure Criticality Factors												
Number of other infrastructures affected	3	3	2	3	3	3	2	2	3	2	2	
Immediacy of effects	2	2	2	3	2	3	2	3	3	2	2	2
Economic impact	2	3	2	3	3	3	3	1	3	2	2	2
Human casualties	3	3	3	3	1	1	2	3	3	1	2	2
Infrastructure necessary to enable repair/recovery of other infrastructures?	3	3	2	3	3	3	3	3	3	2	3	2
CRITICALITY SCORE	2.6	2.8	2.2	3	2.4	2.6	2.4	2.4	3	1.8	2.2	2
RELATIVE RISK = V * C	4.16	3.36	4.4	9	3.84	6.24	4.8	4.8	9	2.88	4.4	4.8

Priority Infrastructures

- Debilitation of the electric power and information/communications infrastructures arguably pose the highest risks to society in an EMP scenario
  - Most vulnerable to EMP due to 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 and Internet particularly critical in the aftermath of an EMP attack





Preparedness/Protection → Event → Response → Recovery

Time Line

EMP Economic Impact Dominated by Electric Power/Communications Infrastructures[1]

Washington-Baltimore-Richmond Economic Impact

Infrastructure	Percent of capacity damaged			Midpoint of replacement times (months)		
	Low case	Mid case	High case	Low case	Mid case	High case
Electric grid						
Transformers	10%	40%	70%	2.5	13.5	33.0
Other	30%	40%	50%	1.5	5.0	10.0
Communications systems						
Large	10%	20%	50%	4.0	18.0	27.0
Small	5%	20%	50%	2.0	12.0	17.0
SCADA						
All types	5%	20%	50%	1.5	5.0	10.0
Electronics						
Large	20%	45%	70%	4.0	12.0	17.0
Small	1%	2%	3%	1.5	5.0	10.0

	Low case	*Middle case*	*High case*
Months for full recovery	4	18	33
Total lost value of economic activity (billions)	$34	$212	$771
Total lost value as share of annual regional gross domestic product	6.5%	40%	147%
Total lost value as share of annual national gross domestic product	0.3%	1.9%	7.0%

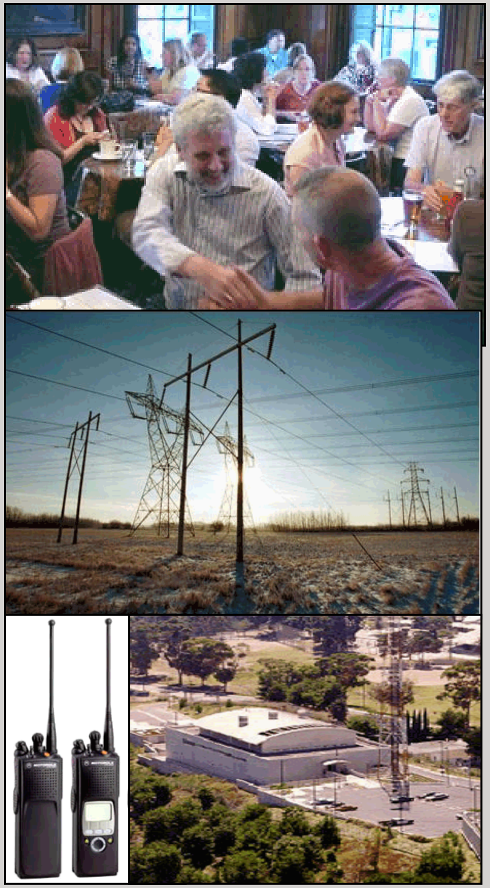
- Losses due to electric grid and communications systems failure predominate
- Restoration of other infrastructures dominated by availability of electric grid and communications systems

Based on IMPLAN Economic Model

[1]Source: Charles Manto, Instant Access Networks, Sept 2007

Proposed Way Forward

- Public Awareness/Education
  - National Homeland Security Agencies
  - Regional Hazards Consortia
  - Local Emergency Organizations
  - Citizen groups
- Pursue initial "demonstration programs" to protect selected high-risk infrastructures
  - Electric Power:
  - Communications
- Successful demonstration programs will
  - Pave the way for broader application of EMP protection
  - Establish feasibility
  - Enable improved cost analysis
  - Enable improved technical implementation guidance documents
- Programs will require coordination through
  - Public-private partnerships
  - Infrastructure Sector Coordinating Councils



Importance of Public Awareness

"I know of no safe depository of the ultimate powers of the society but the people themselves; and if we think them not enlightened enough to exercise their control with a wholesome discretion, the remedy is not to take it from them but to inform their discretion."

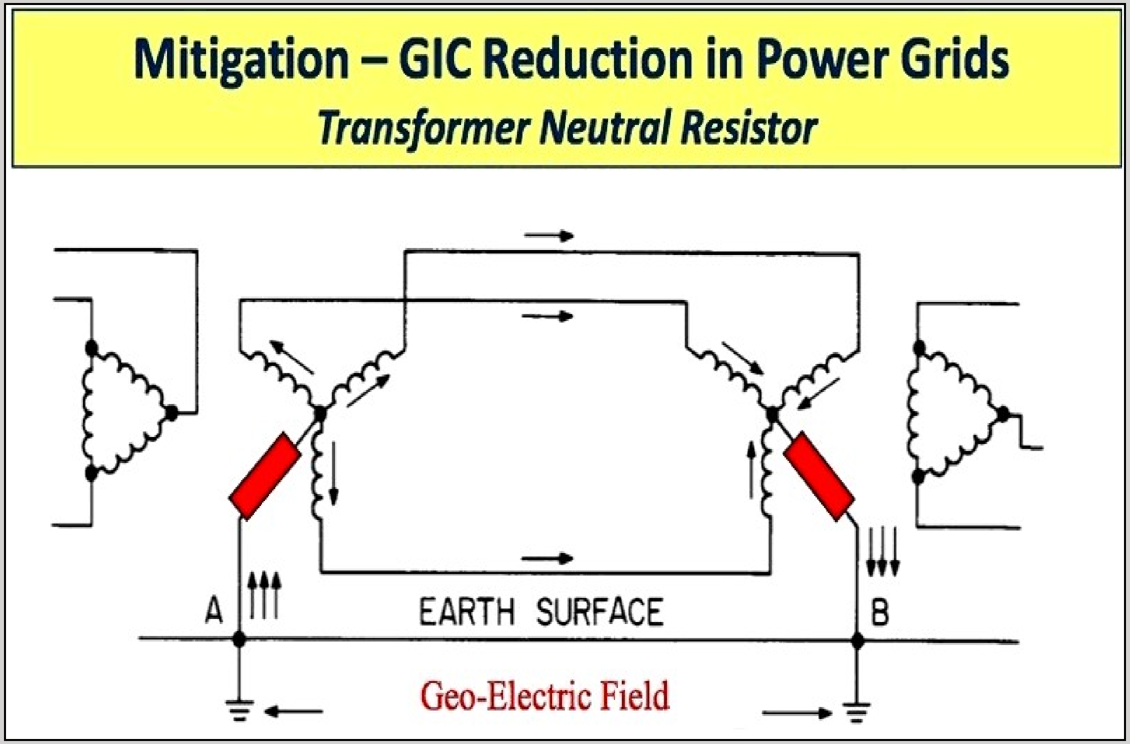
…Thomas Jefferson

Where to Start? – Electric Power Emergency Generators

- Recognizing that significant parts of the grid are likely to fail in an EMP 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 have emergency generators
- Additional requirements should apply to:
  - Water supply systems
  - Gas stations
  - Food stores
  - Pharmacies
- Emergency generators relatively easy to protect and certify via test

EMP Protection Approach – Electric Transmission System[1]

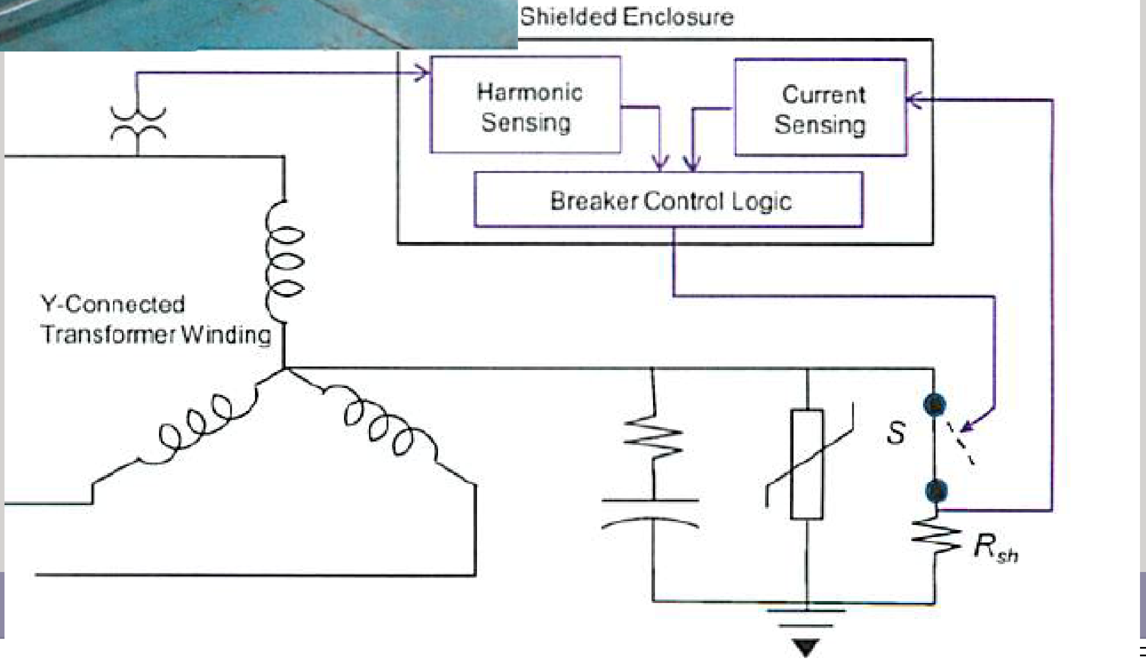
- Transformers form the "backbone" of the electric power grid, enabling long-distance power transmission
- HV transformers typically take between 18 and 36 months to be manufactured and delivered and cost in the range $1-5M
- Current blocking devices in large transformer neutral ground connection significantly reduces E3-induced currents and solar storm currents



[1]John Kappenman, Metatech Corporation, 2008

EMPRIMUS Transformer Neutral Blocking Device

- Blocks GIC and EMP-E3 currents
- All grid harmonics are stopped
- Ferro resonance protection included
- No transformer half-cycle saturation
- Transformer neutral always tied to ground
- Continuous operation through ground faults
- System operator control and override
- Factory assembled. Ready for installation
- Add surge arresters for EMP E1/E2 protection



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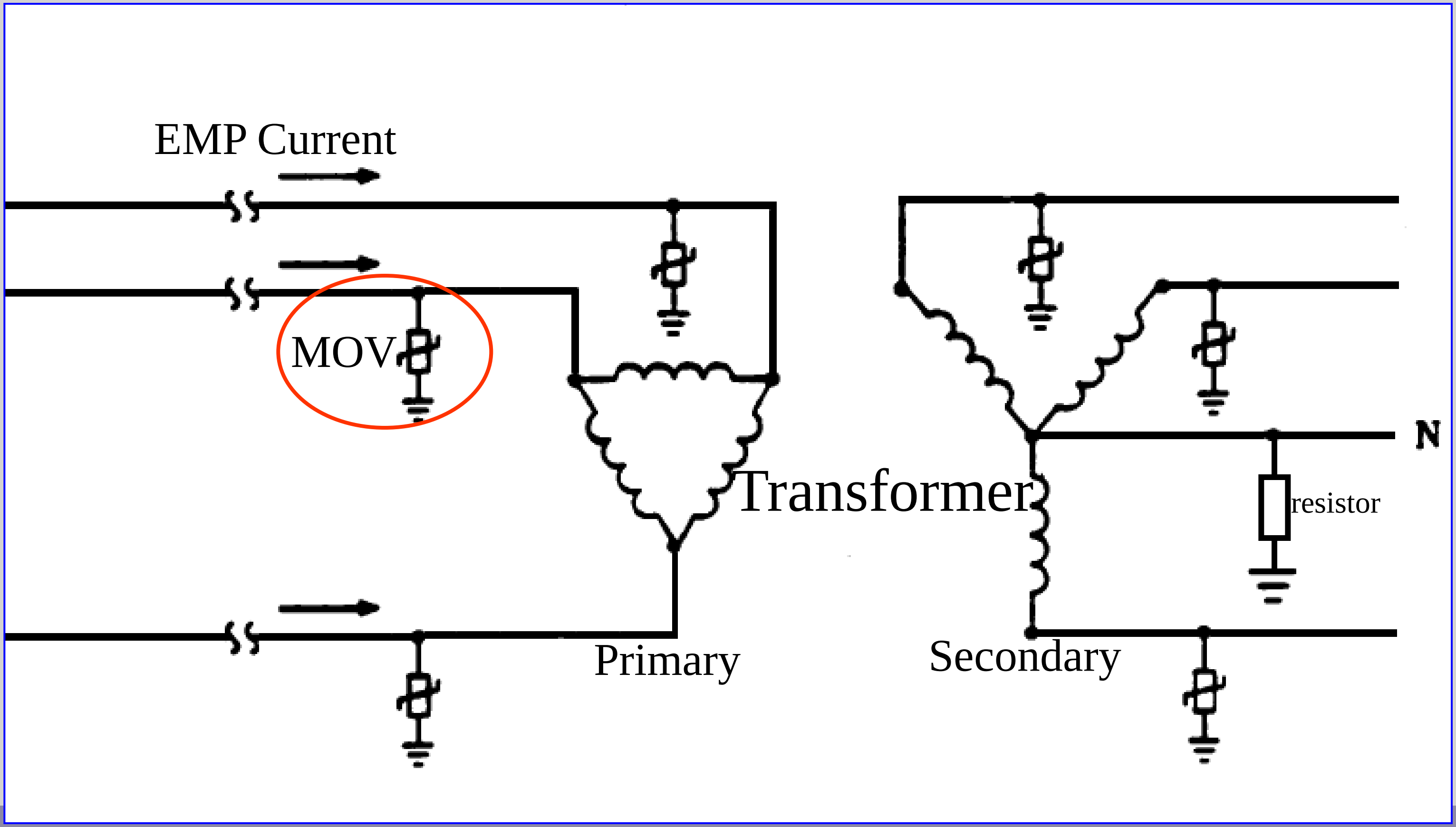
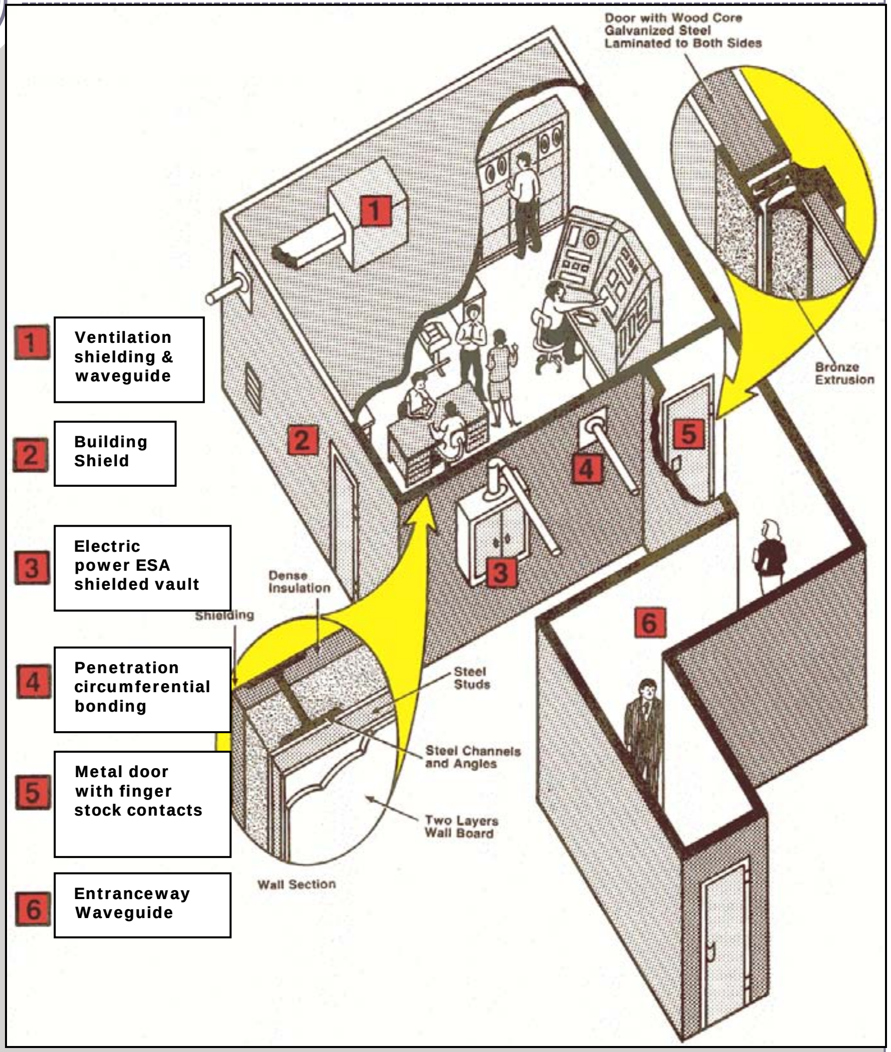
Transformer Protection, cont'd

- Transformers also need protection from E1
- Metal oxide varistors provide overvoltage protection



EMP Protection: Where to Start? Communication Systems

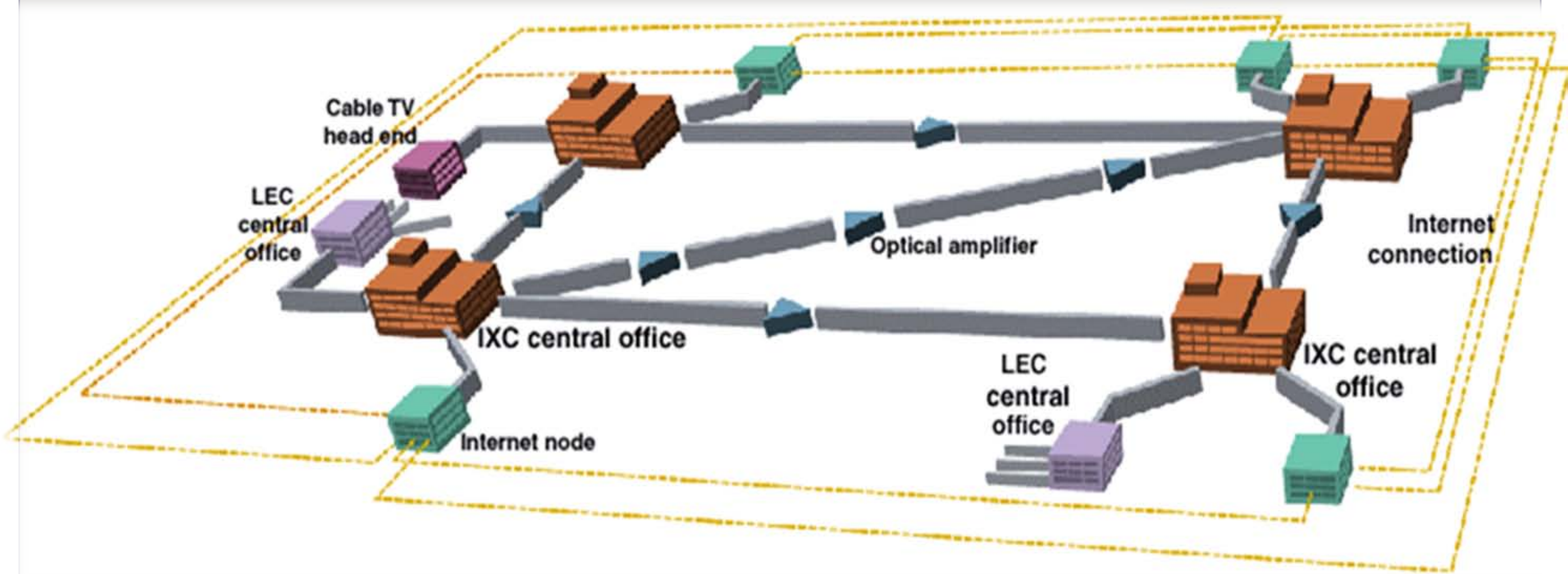
- EMP protection methods are understood and feasible
- Low-risk system and facility shielding approach
  - Shielded enclosures
  - Limit and protect cable and doorway penetrations
  - Backup power systems
  - Good grounding techniques
- The military has developed experience in successful implementation since 1960s



Where to Start? Communication Systems

- Emergency communication facilities protection is effective place to start.
  - Include facility EMP protection guidance in fire code standards [e.g. NFPA 1221 - National Fire Protection Association (NFPA) Standard for Public Emergency Services Communications Systems, NFPA 1600- Disaster Emergency Management & Business Continuity of Operations (COOP)]
  - Include EMP protection in interoperable radio communication system procurements
- Assess and protect long-haul communication lines
  - Terrestrial and undersea
  - Particular attention to ensuring Internet connectivity
- Benefits for electric power grid control (SCADA) facility protection and grid reconstitution

Long-Haul Communication Vulnerabilities



Fiber Optic Lines

Copper Land-lines

Recent Developments

- National Research Council Study – 2009 Report
  - "Severe Space Weather Events – Societal and Economic Impacts"
  - Explains phenomena and seriousness of effects
- NERC Report: High-Impact, Low-Frequency Event Risk to the North American Bulk Power System – June 2010
  - Identifies a class of high-impact, low-frequency risks shown to have the potential to significantly affect the reliability of the North American bulk power system.
  - Concludes that the extremes of the geomagnetic threat environment may be much greater than previously anticipated.
- Introduction of "Shield Act" in U.S. House of Representatives (HR 668)
  - Amends the Federal Power Act to "protect the bulk-power system and electric infrastructure critical to the defense and well-being of the United States against natural and manmade electromagnetic pulse (''EMP'') threats and vulnerabilities"
  - Would enable FERC to
    - Issue and enforce emergency procedures applying to bulk electric power suppliers in the event of an electromagnetic threat.
    - Order a reliability standard and develop rules requiring suppliers to address known electromagnetic vulnerabilities
    - Enables suppliers to recover costs associated with implementation of electromagnetic protection

Recent Developments

October 2011 – First National Table-Top Exercise on Wide-Area EM Effects at NDU/JHU-APL – themes

- Grave effects on society
- Long-term outage (LTO) of electric power likely cascading to most other critical infrastructures
- Overstress on first responders, reconstitution organizations
- Effects modeling improvements needed to treat interdependency complexity and stochastic nature of EM effects.
- Programs to address limited set of high risk infrastructure greatly lessen societal impact
- Multi-level awareness and education essential

Recent Developments

- February 2012 North American Electric Reliability Corporation (NERC) GMD Task Force Report
- Conclusions favor the electric industry
  - Task Force membership largely electric power industry representatives
  - Conclusions avoid new federal regulations/standards requiring physical protection of the national electric grid from severe geomagnetic storms
  - Report co-opts the Congressional SHIELD Act (HR 668) now awaiting action.
  - Concludes that not even a rare geomagnetic "super storm" like the 1921 event could cause widespread damage to big transformers and catastrophic LTOs
- NERC GMD Task Force Report is contradicted by independent, science-based studies concluding that LTOs are real possibilities.

- U.S. Department of Energy ORNL
- Congressional EMP Commission
- President's NSTAC
- National Research Council W.G.
- National Defense University

Recent Developments

May 2012 – International Electric Infrastructure Survivability Summit at U.K. Parliament - themes

- Real and present dangers posed – Grave threats that will happen eventually – Solar Storm 6-12% chance per decade – Israel considers EMP likelihood is high
- Deterrence not enough – let's get started – protection takes time
- Hardware solutions preferred over operational fixes
- Needs to be coordinated, not piecemeal (FERC, MPs, Congressman Franks)
- Shield Act highly beneficial – FERC needs empowerment provided by Act
- Better technology needed: warning, validated models, increase transformer reserve
- Standards needed – design and certification
- Insurance Industry viewpoint – Can't afford NOT to invest in protection - Insurance industry resources only a drop in the bucket - Don't ensure outages caused by operation fixes.

Summary

- EMP and solar storm wide geographic coverage and ubiquitous system effects beg the question of “Where to begin?” with protection efforts
  - Must be clever in deciding where to invest limited resources
- Based on simple risk analysis, the electric power and communication infrastructures emerge as the highest priority for EMP protection
- Programs to address a limited set of highest risk infrastructure go a long way in lessoning societal impact
- Programs must be coordinated at the national level, implemented at local level
- Incorporate effects in emergency exercises
- Pilot programs to demonstrate wide-area EM protection engineering for highest risk infrastructures pave the way for protection of critical infrastructure systems in general
- Congressional, FERC initiatives essential to spur progress

References

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- EMPACT America Website -http://www.blogtalkradio.com/empact-radio
- FERC Docket AD12-13