Nuclear EMP Weapons: Facts, Myths, Unknowns and Speculation

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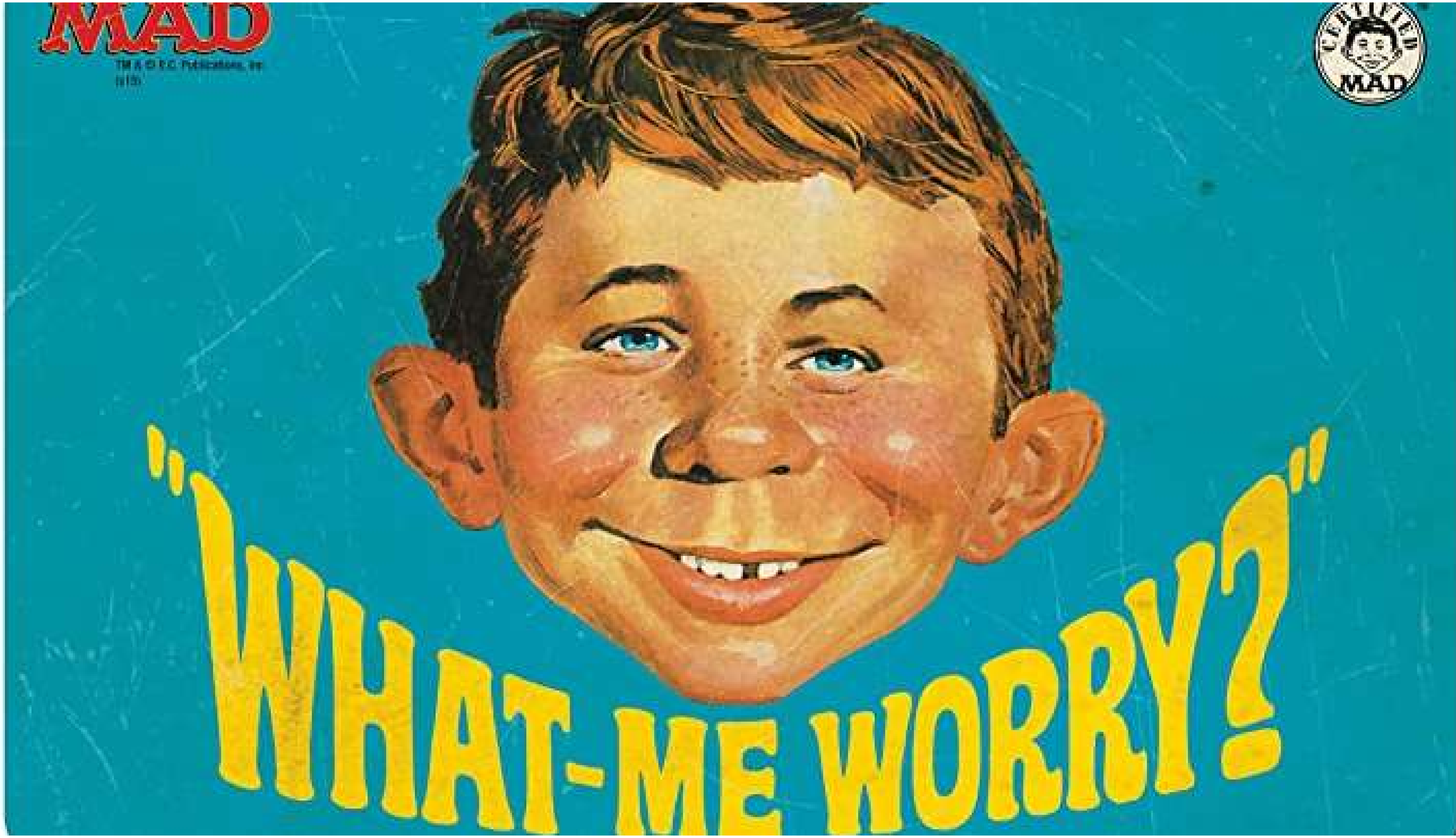
Flathead Valley Amateur Radio Club


MAD
CERTIFIED MAD
"WHAT-ME WORRY?"

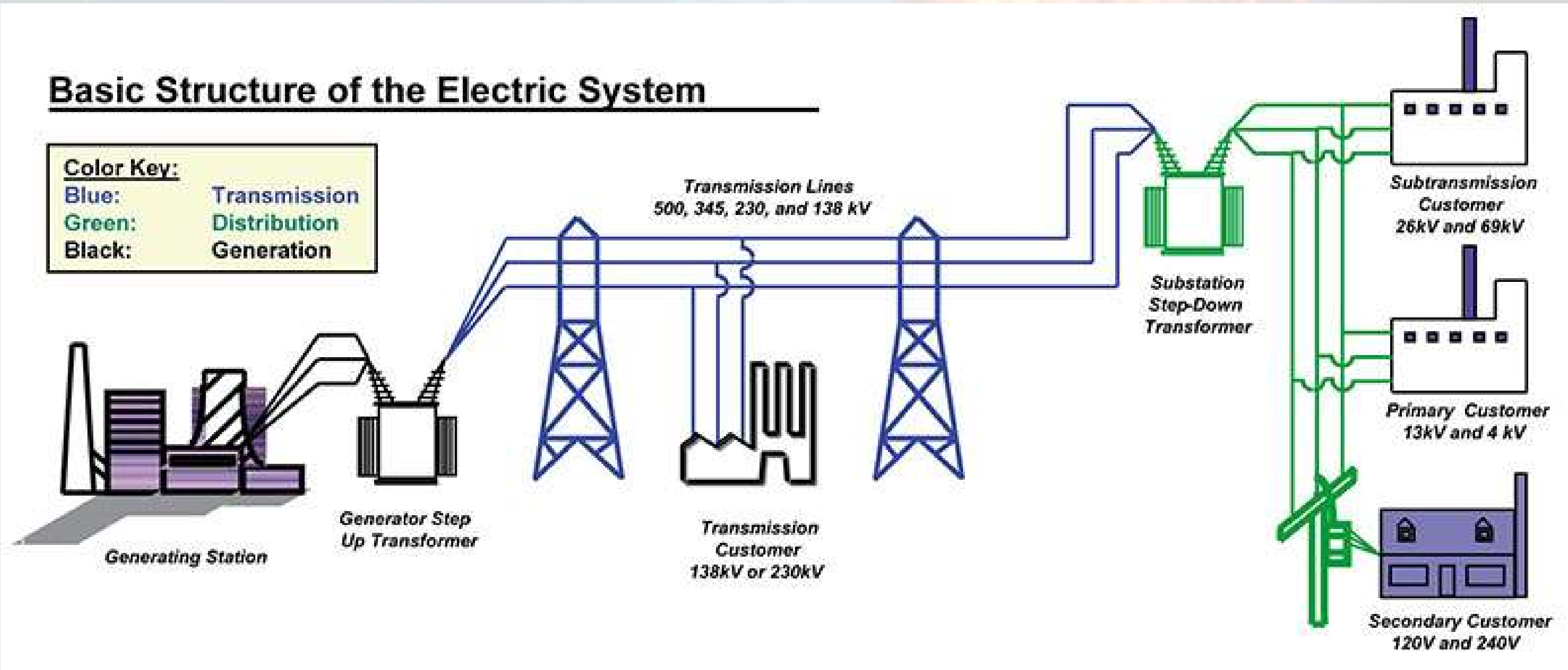
Introduction

- I'll be glossing over some details to keep this presentation short
  - A PDF copy will be sent out to everyone, as well as uploaded to the "Files" section of the club's website
- While a good grasp of nuclear physics is essential to fully understanding how a nuclear weapon generates ElectroMagnetic Pulses (EMP), those pulses can be thought of as essentially very high energy RF fields
- Only a cursory level description of the nuclear physics involved in the generation of EMP will be presented
- Some say a high-altitude EMP will be the death of most of us and others say it would be "no big deal"
  - Since no one has detonated a high altitude nuclear EMP device over modern infrastructure, no one really knows what will happen
  - The truth most likely can be found somewhere in between those extremes

What We'll Be Covering

- Focus on the power grid (telecommunications and other systems won't be discussed)
- ElectroMagnetic Pulses (EMP) from a high altitude nuclear detonation (HEMP)
  - Are proposed nuclear EMP scenarios realistic?
  - E1, E2, E3
  - Effects of altitude and yield
  - Effects of ground (rock) conductivity and surface impedance
  - Unknowns
  - Speculation
- Methods of delivery
- Potential bad actors
- Personal Defensive measures
  - We will lightly cover measures which could be taken to protect the grid, something which is the responsibility of government and grid operators
  - We won't be doing a deep-dive into "prepper" considerations, focusing instead on how to protect key electronic devices and provide your own power during an outage
    - Countless websites and YouTube videos already cover the other preparations one should make to prepare for economic and social chaos
- The real threat
- References

Power Grid Representation*:



*While not shown, 765 kV lines are also used

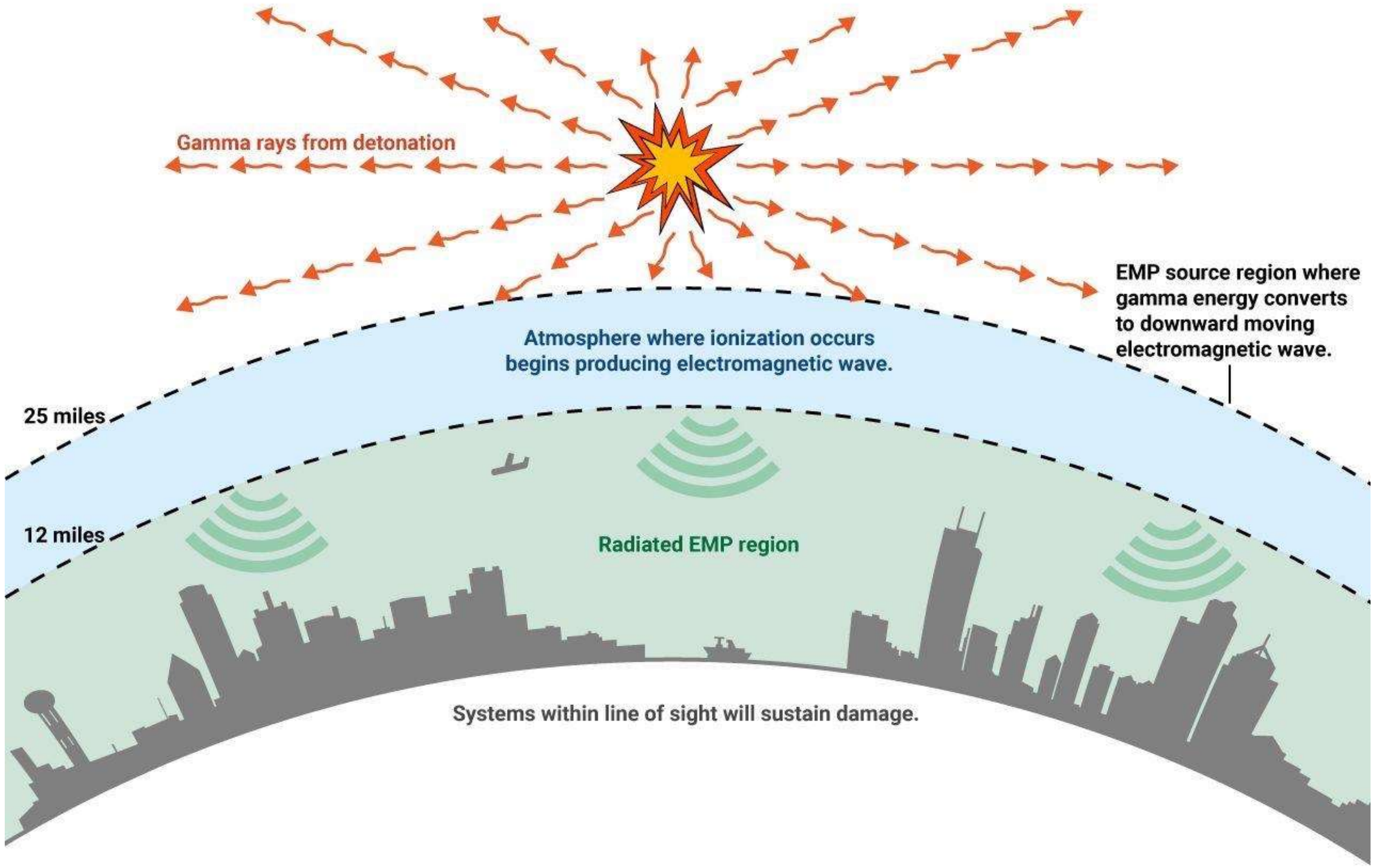
Description of Nuclear Electromagnetic Forces

- There are 3 types of pulses produced
  - E1 – Prompt, ultra fast rise time, high energy pulse, immediately followed by lower amplitude and longer lasting E2 and E3 pulses
    - Overvoltage surges
    - Cannot couple with Extra High Voltage (EHV) transmission lines
    - While producing RF from DC to 10 GHz, most energy is below 150 MHz
  - E2 - Fast but also can't couple with EHV transmission lines
  - E3 – Slow and long lasting
    - Couples well to long EHV transmission lines
    - Similar to EMP from solar storms
- Understanding the characteristics of these pulses is essential to understanding what effects they might have on electric power systems
  - While high altitude nuclear EMP can be destructive to satellites, that's a topic for another time

Generation of EMP By Nuclear Weapons

- Gamma rays are produced by nuclear fission and by inelastic scattering of neutrons in the material of the device
  - Most are absorbed by the material of the device
  - Typically, just 0.1-0.5% of the total bomb yield is radiated as “prompt” (nearly instantaneous) gamma rays
    - Fission bombs emit at the higher end of this range, while thermonuclear devices emit at the lower end of this range
    - Prompt gamma rays are emitted in a spherical shell only a few meters thick
      - Its radius expands at the speed of light
- When detonated at an altitude of 25-250 miles, downward-directed gamma rays collide with electrons in air molecules, transferring their energy to them (Compton process)
  - These highly energized electrons are ejected from their parent molecules at high energies, colliding with other electrons
    - A cascade of roughly 30,000 electrons for every original gamma ray
  - These electrons spiral in the earth’s magnetic field, producing coherent synchrotron radiation
    - Coherent electromagnetic pulses are the result

HIGH-ALTITUDE EMP DETONATION



Source: Congressional Commission to Assess the Threat of Electromagnetic Pulse to the United States of America

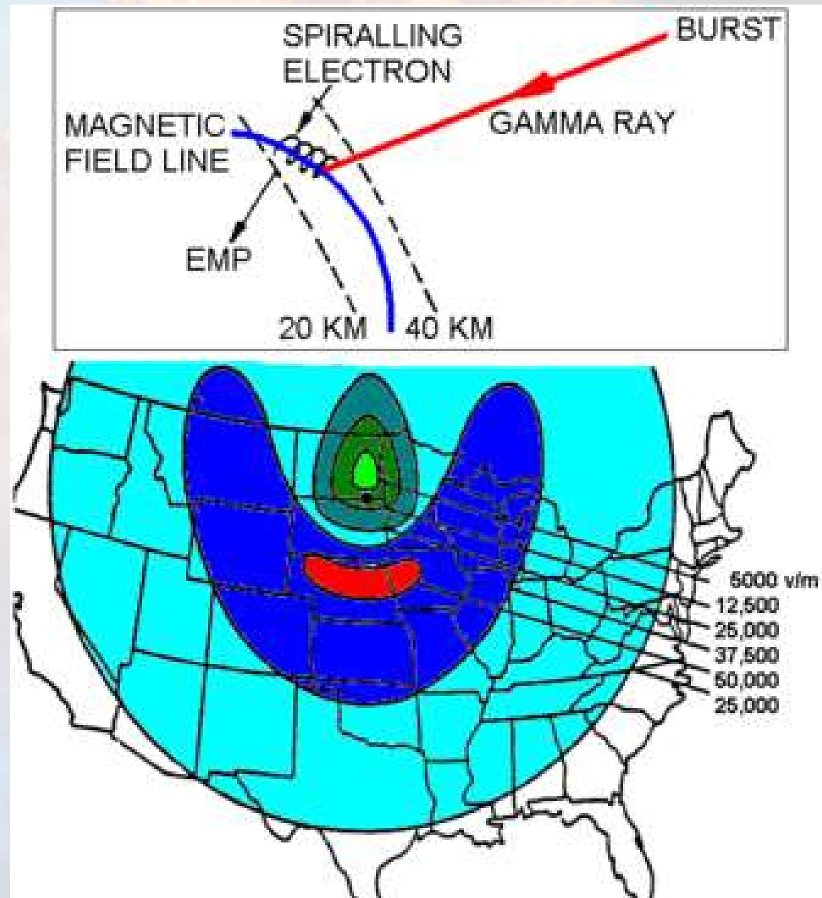
Graphic redesign by Geopolitical Futures

Generation of EMP By Nuclear Weapons (cont.)

- With both the gamma rays and the coherent synchrotron radiation traveling at the speed of light, the EMP field piles up like the air associated with a sonic boom
  - The EMP fields form at different distances from the blast
  - The source region is located in a 6-mile-thick region of the atmosphere, roughly between 16 and 22 miles altitude
    - Above 22 miles, the air density is too low to produce this high energy electron cloud
  - Pulse (E1) has a rise time of nanoseconds and usually decays within a microsecond or so
    - Within this time frame it can induce fields of 100 to 50,000 V/m at ground level
    - Ionization in the source region will tend to “short out” the EMP
      - High energy X-rays, left out of many EMP calculations and also produced by the nuclear blast, will increase the ionization in the EMP source region, significantly lowering realized peak EMP fields
    - Pre-ionization effect of a two-stage thermonuclear device also helps to “short out” the E1 pulse
- Exact electric field strength is determined by bomb yield, its design, detonation altitude, local geomagnetic field strength and the geographic latitude of the detonation
  - Higher geomagnetic field strengths at higher northerly latitudes will produce stronger EMP fields, everything else being equal

Generation of EMP By Nuclear Weapons (cont.)

- Radiation is produced by electrons' motion transverse to the Earth's magnetic field
  - Peak field region occurs in a broad arc positioned south of burst "ground zero"
  - A region of near zero field strength exists just north of "ground zero"
- E1 pulse rise and decay time depends upon location relative to burst "ground zero"
  - As a general rule, the further away one is from the peak field region (shown in red), the pulse will have a slower rise and decay time
- Lower amplitude but longer lasting E2 and E3 pulses immediately follow



Source: Nuclear Environment Survivability, U. S. Army, report AD-A278230 (1994)

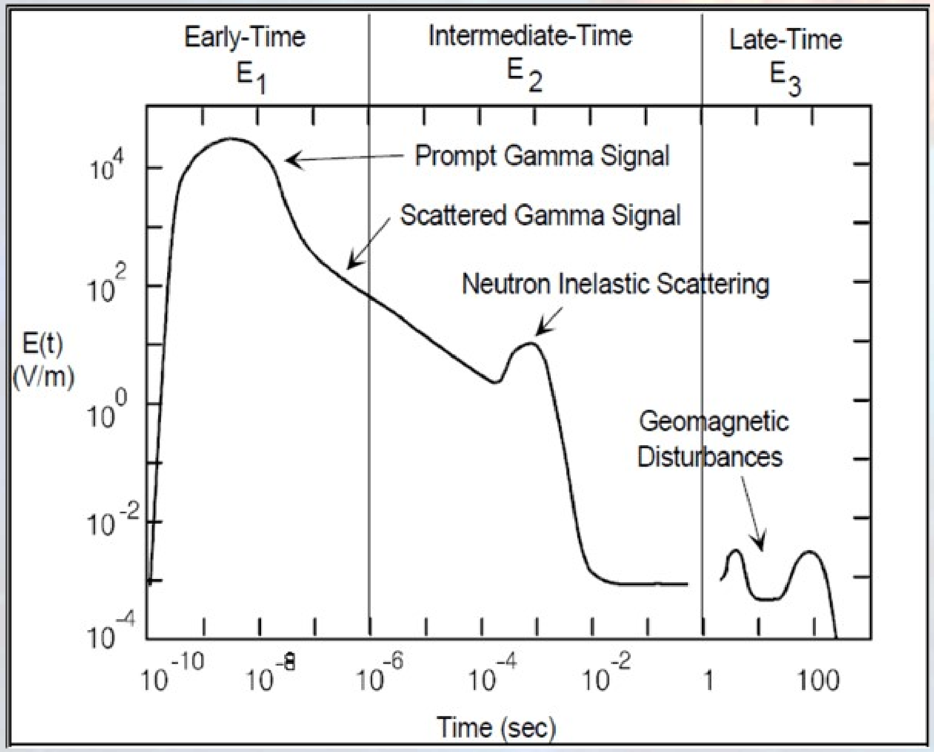
Generation of E2 Pulse

- Arises from previously scattered ambient gammas, in combination with inelastic scattering of bomb-produced neutrons from the nuclei of atmospheric molecules, a process which also produces copious gamma radiation
  - The sum of these gammas produces an impulsive Compton electron current
- E2 energies are lower in magnitude than E1
  - Covers roughly the same geographic area as the E1 pulse
- E2 pulse has a duration of up to a second
- Lightning shares many of the characteristics of E2
  - Lightning's electric fields can be an order of magnitude greater than the highest peak E1 fields from the largest nuclear devices

Generation of E3 Pulse

- Even lower amplitude
- The result of the ionized explosive fireball expanding and "expelling" the earth's magnetic field (due to the fact that it is an electrically-conductive region), in a "heaving" action
  - Known as the Magneto-hydrodynamic (MHD) pulse
- E3 pulse has a duration of up to 1,000 seconds or longer, with a frequency of less than 1 Hz
- Directly under the burst, a temporary area of ionized air, created by the X-rays produced by the weapon, shields most of that region from the early portion of the MHD-EMP pulse
  - This air rises and begins to move across the Earth's geomagnetic field lines, producing large atmospheric currents
    - These ionospheric currents are believed to account for the second phase (> 10 secs) of the MHD-EMP pulse
- Auroral motion of charged particles results in a final VLF EMP
  - Typically around 0.01 Hz
- E3 most closely resembles EMP from a natural geomagnetic storm
- Unlike E1 and E2, E3 can penetrate the ground (Ground Induced Currents (GIC))
  - Can induce substantial currents in very long (60 miles or more in length) buried cables

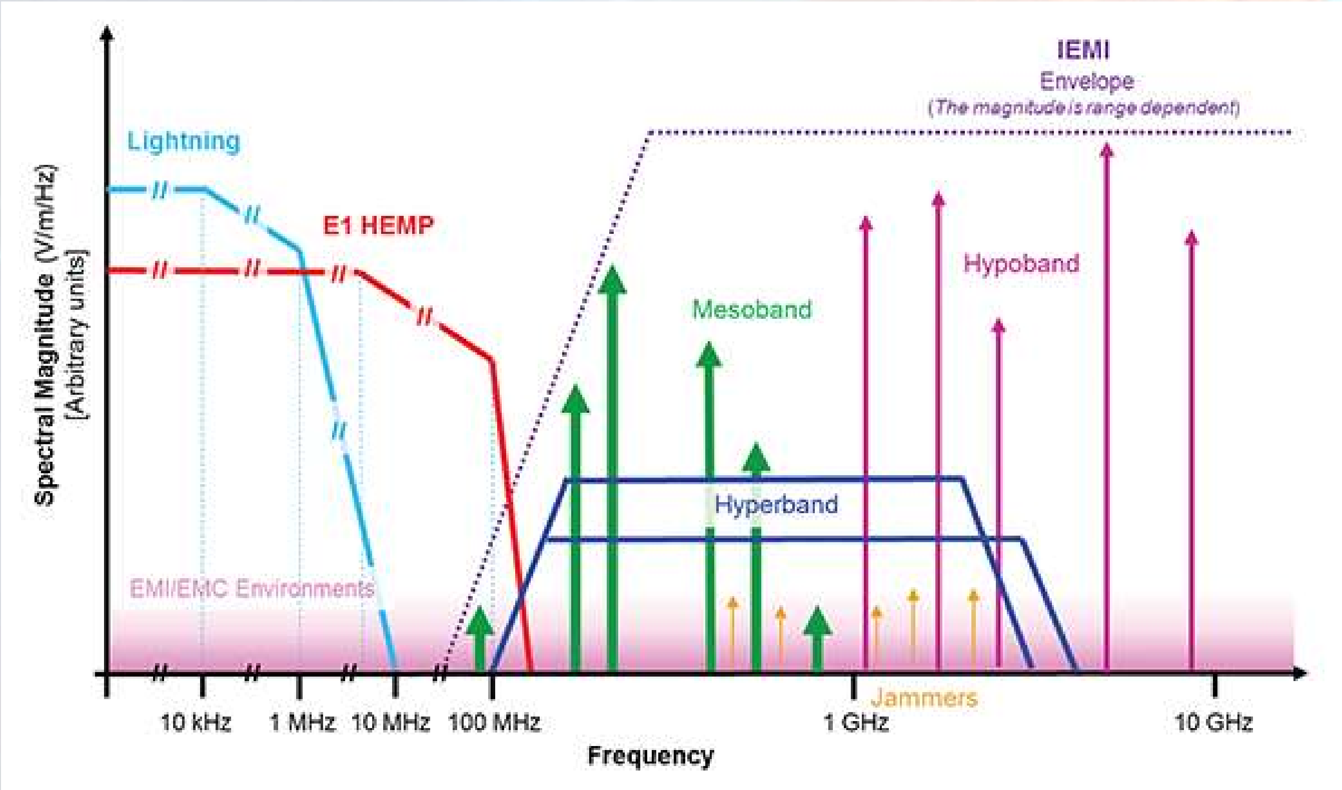
Summary of E1, E2 and E3 EMP Pulses



Russian military documents claim they have a "super EMP" device which can generate 200 kV/m

- Source: Congressional Research Service, "High Altitude Electromagnetic Pulse (HEMP)", Clay Wilson, 2008

RF Spectrum of E1 Pulse



Coupling of EMP Components to Ground Systems

- EMP affects electrical systems and electronics by “coupling” to them
  - Electrical/electronic devices and attachments act like antennas which pick up the EMP signal
- E1 couples well to local antennas, short (3-35 ft) cable runs, equipment in buildings and can damage or disrupt IC-based electronics
  - Sensors, communications systems, control systems and computers
  - Protection involves electromagnetic shielding, filters and surge arrestors
- E2 couples well to longer conductive cables, vertical antenna towers and aircraft trailing wire antennas
  - Similar to lightning in key characteristics, it is generally not considered a threat to critical infrastructure which already has protection in place
    - Risk is synergistic, since E1 may damage some of the lightning protective devices
- E3 couples well to long (60 mi +) power and communications lines, including undersea cables
  - It’s low frequencies make shielding and isolation difficult
  - E3 varies so slowly that quasi-DC analysis models are used to estimate the effects on power systems, especially components at the end of long power lines (e.g., HV, EHV transformers)

Possible/Probable Effects of EMP on the Grid

- Malfunction and damage to solid-state relays in substations (E1)
- Malfunction and damage to computer controls in power generation facilities, substations and control centers (E1)
  - Our nuclear EMP “Achilles heel”
  - Disorderly shutdown of facilities and power generating stations could cause massive damage and lengthy time-to-repair
- Malfunction and damage to power system communications (E1)
- Flashover and damage to distribution class insulators (E1)
- Voltage collapse of the power grid due to transformer saturation (E3)
- Damage to HV and EHV transformers due to internal heating (E3)
- E1, E2 and E3 scale differently with weapon yield and design
  - Question becomes what strength E1 and E3 pulses might be expected over what parts of the country, from what types of devices and who the likely actors might be who would carry out such an attack

Peak E for E1 and E3 (Source: EMP Commisson)

Megaton yield nuclear device detonated at an altitude of 125 miles

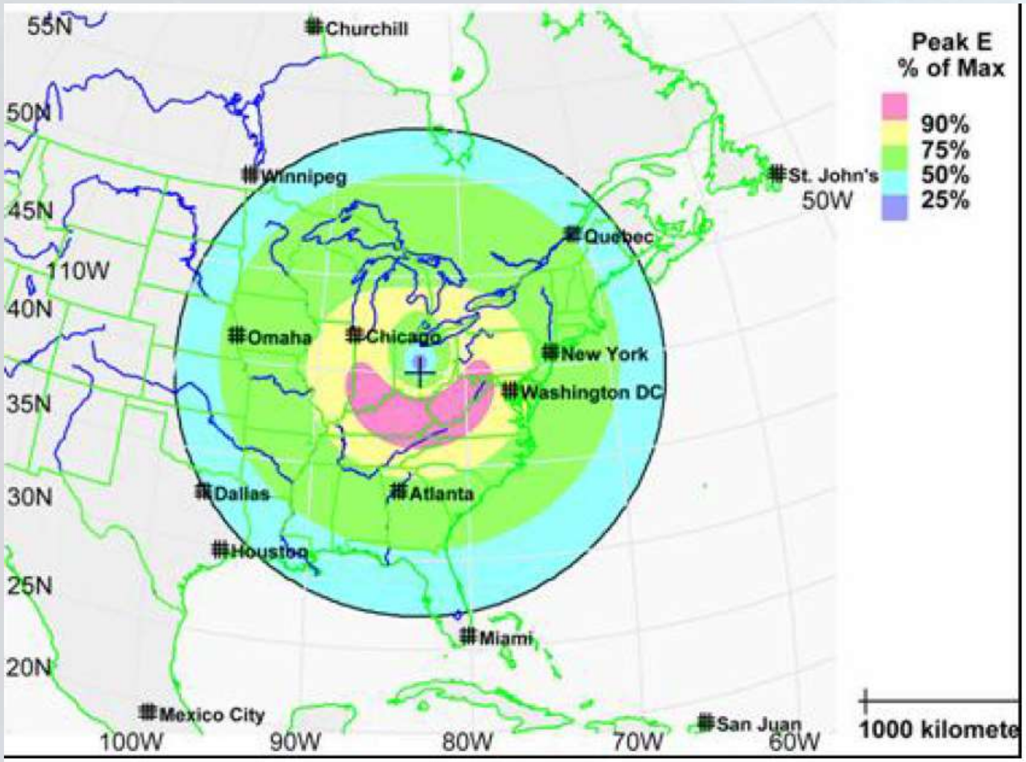


Figure 2. Illustrative EMP Effects – Fast Pulse

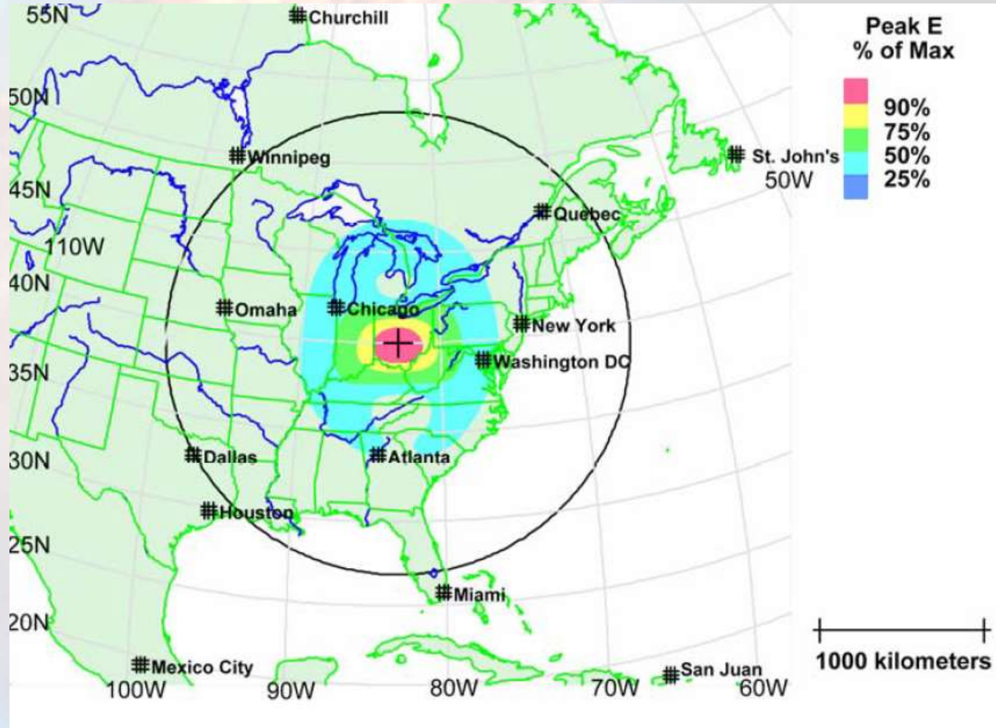
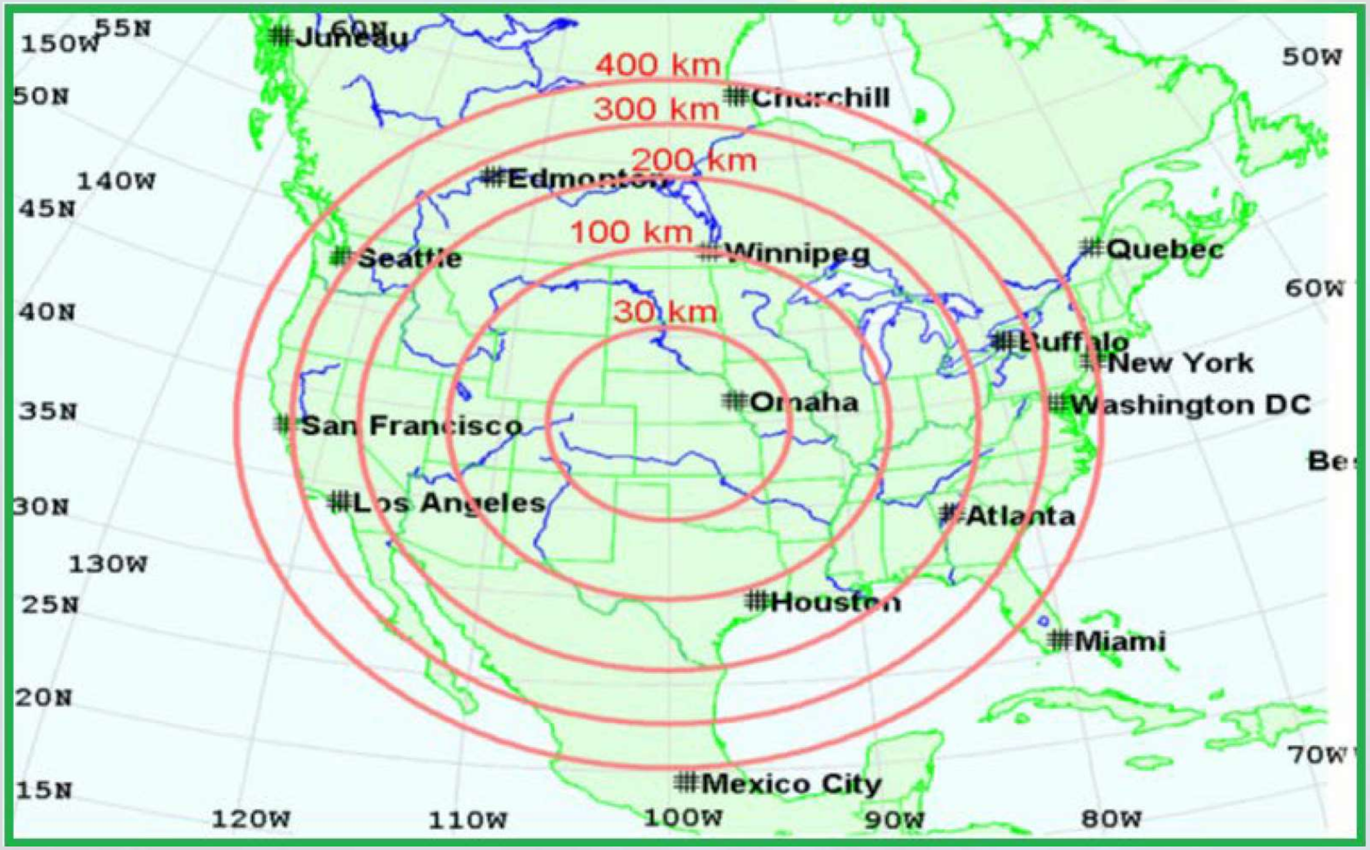


Figure 3. Illustrative EMP Effects – Slow Pulse Protection and Recovery of Civilian Infrastructures

70% of the total U.S. electrical power load is covered within these circles of EMP

Peak E1 at different Burst Heights (megaton yield)



SOURCE: Oak Ridge National Lab, supercomputer physics simulations

Real World Experience (Cold War)

- Roughly 13 U.S. tests and 7 Soviet tests between 1955 and 1962
  - Some of the data remains classified
  - Many were powerful megaton-range devices
    - Effects can't be interpolated to lower yield weapons such as those which nuclear proliferator states might possess
  - Tests were done before the infrastructure included so many sensitive electronic devices and control systems
    - ICs, especially VLSI chips, are about a million times more vulnerable to E1 than the electronic devices of the 60's, most of which used vacuum tubes
  - Many were done in more southerly latitudes and in weaker geomagnetic regions
    - E1 would not be as intense
- Starfish (July 9, 1962) – Produced the largest fields of the high altitude nuclear tests

Starfish (July 9, 1962)

- Produced the largest fields of the high altitude nuclear tests
    - 1.4 megaton thermonuclear warhead
- Detonated about 900 miles west-southwest of Hawaii at an altitude of 250 miles
    - Explosion was about 10^{o} above the horizon, as seen from Hawaii
- Effects seen in Hawaii
    - Outages of series-connected street lights on Oahu
    - Failure of a microwave repeating station
    - Failure on input stages to ionospheric sounders
    - Damage to rectifiers in communication receivers
        - Probably caused by power line transients
    - No apparent increase in repairs to radios and TVs
    - No reported problems with the phone system
    - NOTE: Line-runs in Hawaii are considerably shorter than in the continental U.S.

Widespread red air glow (6300 å) amid dark clouds, caused mostly by x-ray-excited atomic oxygen (i.e., oxygen by photoelectrons liberated by Starfish X-rays)

Prevention and Recovery from Nuclear EMP Damage

- Instead of one or two ‘insults’ to the power grid, EMP will cause a large number of ‘insults’, along with disabling of protective devices and cascading failures
  - E1 may have largely disabled monitoring systems and the ability to see the problems, their nature and location
    - There’s much disagreement as to how bad the damage would be to these components
    - Hardening every component would be an overwhelming task and expense
- Coal-fired generation plants account for 40% of power generated and are older, with more electromechanical controls
  - Usually also have several days to a month’s fuel on-site
- Nuclear power plants have more redundant safety systems
- Hydroelectric power is generally robust to EMP
- Solar power plants would likely suffer damage
  - ‘Solar cell upset’ – cells reverse polarity and output drops substantially
  - Catastrophic cell breakdown may occur
  - Localized inverters and control electronics likely vulnerable to E1
- No research found for wind farms
- Operators need to be trained to recognize failures caused by EMP
  - Recovery plans, training per those plans and key component spares are essential

E1 Early Pulse Impact

- No direct impact to major power equipment
- Insulation breakdown in electric/electronic circuitry
- Computers and microprocessor-based devices will “latch up” or be damaged
- Control centers (SCADA, EMS,DMS, PLC) will experience various failures
- Local distribution lines and transformers might be damaged
- NOTE: No large scale testing has ever been done regarding HEMP
  - These are predictions based upon computer modeling and not all models agree with each other

E1 Early Pulse Mitigation

- Hardening added to new or refurbished hardware as it's merged into the existing utility system
- Full duplication of key Control Centers
- Joint Electromagnetic Pulse Resilience Strategy (July 2016)
  - Joint effort by DoE and Electric Power Research Institute (EPRI)
  - Improve and share understanding of EMP
    - Threat
    - Effects
    - Impacts
  - Identify priority infrastructure
  - Test and promote mitigation and hardening approaches
  - Enhance response and recovery capabilities
  - Share best practices across government and industry
    - Nationally and internationally

E3 Mitigation (GIC)

- 2016 research by ARPA-E (Advanced Research Projects Agency – Energy) identified two key concerns from a big storm or HEMP:
  - Large scale blackouts due to voltage collapse
  - Permanent HV and EHV transformer damage due to overheating
- Quasi-DC nature of GIC currents, up to 2 kA, is hard on the grid's AC system design
  - Saturation and overload of magnetic circuits of major power transformers and shunt reactors
  - Large spectrum of harmonics
- Capacitor/resistor/surge-arrestor GIC-blocking of DC currents
- E1 surge can be easily sensed and used to quickly disconnect/protect key power components from the coming E3

Rebuttal From Electric Power Research Institute

- More than 60 utilities, the Defense Threat Reduction Agency, DoE, 3 national laboratories and the Electricity Subsector Coordinating Council contributed
  - Report from 3-year EPRI study: "High-Altitude Electromagnetic Pulse (EMP) and the Bulk Power System – Potential Impacts and Mitigation Strategies"
    - Assessed risks and made mitigation proposals
      - E1 Focus was on Digital Protective Relays (DPRs)
        - Most critical electronics-based asset in a substation which detects voltage anomalies and trips a breaker to protect other system components
        - 60 different DPRs were tested
        - Performance of potential surge protection devices was also tested
    - Laboratory testing concluded that the U.S. electric transmission system would largely survive a kiloton yield HEMP attack at 30 km altitude
    - Modeling was done for HEMP at other altitudes with devices of varying yields:

	Yield (kTon)	Height of Burst (km)	Peak Field (kV/m)
Benchmark #1	25	100	11.4
Benchmark #2	25	400	1.7
Benchmark #3	125	100	19.6
Benchmark #4	125	400	5.6
Benchmark #5	1000	200	24.9

Rebuttal From Electric Power Research Institute (cont.)

- Extensive testing of substation components was done by injecting voltage surges with the characteristics and timing of those expected to be coupled by an actual HEMP
  - E1 impacts on individual substations
  - E1 impacts on all substations within an interconnection
  - E3 impacts on individual substations
  - E3 impacts on an interconnection
  - Potential impacts from unintended consequences of mitigation and hardening strategies were also explored
- Modeling did not include field strengths above 25 kV/m
  - A multi-megaton device could easily produce field strengths in excess of 50 kV/m
  - Russia claims to have a 200 kV/m device
    - At least theoretically possible
- Their conclusions are rosier than everyone else's and still depend heavily on computer modeling
  - But how accurate are their models versus those used by other 'experts'?

Results of EPRI E1 Testing

- DPRs were susceptible to conducted transients but mostly resilient to free field illumination by E1 EMP
  - Disruption/damage was moderate at field strengths of 25 kV/m at near ground level and baseline soil conditions
    - Approximately 5% of transmission line terminals within an interconnection would have a damaged/disrupted DPR
  - Extrapolated damage at 50 kV/m was concerning
    - Approximately 15% of DPRs would be negatively impacted
- They believe that E1 induced immediate voltage instability or blackout was unlikely within an interconnection
  - This is a ‘guesstimate’ since it’s unknown how damaged DPRs might respond during an actual event
    - Study did not include possibly damaged generator controls and automatic generator controls
    - Study did not try to assess stress-induced damage which might show up later

Results of E1 Mitigation Device Testing

- Low-voltage surge protection devices (SPDs)
  - MOV and hybrid (TVS diode + MOV or TVS diode + gas discharge tube) SPDs performed well
    - Hybrids performed best
- Not tested but recommended when used with SPDs
  - Shielded control/signal cables with proper grounding
  - Fiber optic-based communications and protection and control systems
  - Enhanced electromagnetic shielding in substation control houses
  - Grounding/bonding enhancements
  - Sparing of critical assets such as DPRs, SCADA and communications equipment to shorten recovery times

Results of EPRI E3 Testing and Recommendations

- Interconnection-scale assessments were made for transformer thermal and voltage stability
  - Immediate widespread transformer damage due to hotspot heating from part-cycle saturation was not expected to occur
  - No attempt was made to estimate service life reductions
- Results showed that E3 EMP could result in a regional blackout encompassing multiple states
- Recommendations for mitigation/recovery:
  - Make protection systems resilient to harmonics and system imbalance
  - Block or reduce the flow of GICs
  - Automatic removal of some shunt reactive power compensation devices or employment of under-voltage load shedding (UVLS)
  - Sparing of large power transformers and HV circuit breakers

Are Proposed Nuclear EMP Scenarios Realistic?

- Scenario #1: A megaton yield nuclear weapon, carried by an ICBM, explodes 25-250 miles above the Earth (Commission to Assess the Threat to the U.S. from EMP Attack)
  - While too high up for the blast and heat to reach the ground, the EMP causes significant damage to critical infrastructure and 90% of the population dies within a year
  - The greater the altitude, the greater the radius of the EMP
  - Precise effects of a nuclear EMP are difficult to predict as they depend on many factors
    - Yield of the weapon
    - Detonation altitude
    - Geographic latitude
    - Local geomagnetic field
    - Ground conductivity
- Knowing the type of adversary who might attack allows us to narrow down the type of weapons and how they might be deployed
  - This is essential to assessing the true risk of such an attack
  - Only Russia and China have the capability to launch such an attack
    - With incoming ICBM(s), do you not launch your own (MAD)?

Are Proposed Nuclear EMP Scenarios Realistic?

- Scenario #2: A rogue nation uses a kiloton yield nuclear weapon, carried by a medium-range missile, which explodes at 25 miles above the Earth
  - Pentagon believes that North Korea now possesses this capability
  - This altitude will maximize the EMP produced
  - Lower gamma ray yield produces weaker E-fields
  - Distant pulse will have a wider, therefore less threatening, pulse time profile
  - A reasonable estimate of the extent of the destructive E1 field is about 10 times the altitude, or approximately a 250-mile radius
  - A much smaller E3 component due to its much smaller electrically-charged fireball compared to a thermonuclear device
    - Long-lasting power outages would be unlikely
    - Longer-lasting outages would likely be limited to a state-sized region
- These missiles are easy targets for our missile defense systems
- One suggested scenario is launch from a container ship out at sea
- Launch signature will tell us point of origin and launch vehicle country of origin

Are Proposed Nuclear EMP Scenarios Realistic?

- Scenario #3: A terrorist attack using a kiloton yield nuclear weapon, carried by a balloon, short-range missile or drone explodes at 65,000 feet above the Earth
  - Such a low altitude detonation would produce a small EMP
  - E1 might have a destructive radius of 80-100 miles
  - E3 would be inconsequential
  - Terrorists would get more impressive results from detonating that device in a major urban area
- Delivery vehicles are easily shot down
- Could be difficult to determine country/group responsible
- Rogue terrorist nations/groups might be able to build one device, but will it work?
  - Why waste it on an unimpressive EMP demonstration?

The Real Threat: Geomagnetic Storms

- Virtually guaranteed that a powerful geomagnetic storm capable of knocking out sections of the U.S. electrical grid will happen sometime
  - Such storms are E3-like: low intensity but long-lasting with low frequency coupling to long lines
- First recorded instance in 1847, when currents were noted on telegraph wires
- In 1849, there were major failures of telegraph systems in New England and Europe caused by a large solar flare called the “Carrington Event”
  - Named after astronomer Richard Carrington who witnessed the flare
- The modern era wakeup call came in March, 1989, when a moderate intensity storm shut down the entire Hydro-Quebec grid
- Geomagnetically-induced currents (GICs) in long-line power delivery systems are caused by rate-of-change of the geomagnetic field, much like that in an E3 pulse
  - Severity is measured in nanotesla per minute (nT/min)
  - The Hydro-Quebec collapse was triggered by a modest ≈480 nT/min
  - Other solar storms have produced disturbances of ≈2000 nT/min
  - Disturbances of ≈2800 nT/min have been observed at “latitudes of interest”

Effects of a GIC on the Power Grid

- August 2003 Northeast Blackout
  - NOT GIC-induced, but had a similar impact on the grid which a GIC might have
  - Purportedly caused by high voltage power lines coming into contact with "overgrown trees"
  - Affected the Northeast U.S. and parts of Canada
    - 55 million people affected
    - More than 200 power plants, some nuclear, were shut down as a result of the power disruption
    - Secondary effects included loss of water pressure, transportation disruptions, gridlock, sewage treatment plant contamination, idled refineries, gas stations forced offline, TV and radio stations off the air and phone service disruptions due to high call volumes
  - The estimated cost of the 1-day blackout in spoiled food, lost production, overtime wages and other related expenses: $7-10 billion
  - Our power grid has only become more vulnerable as it now operates closer to design margins

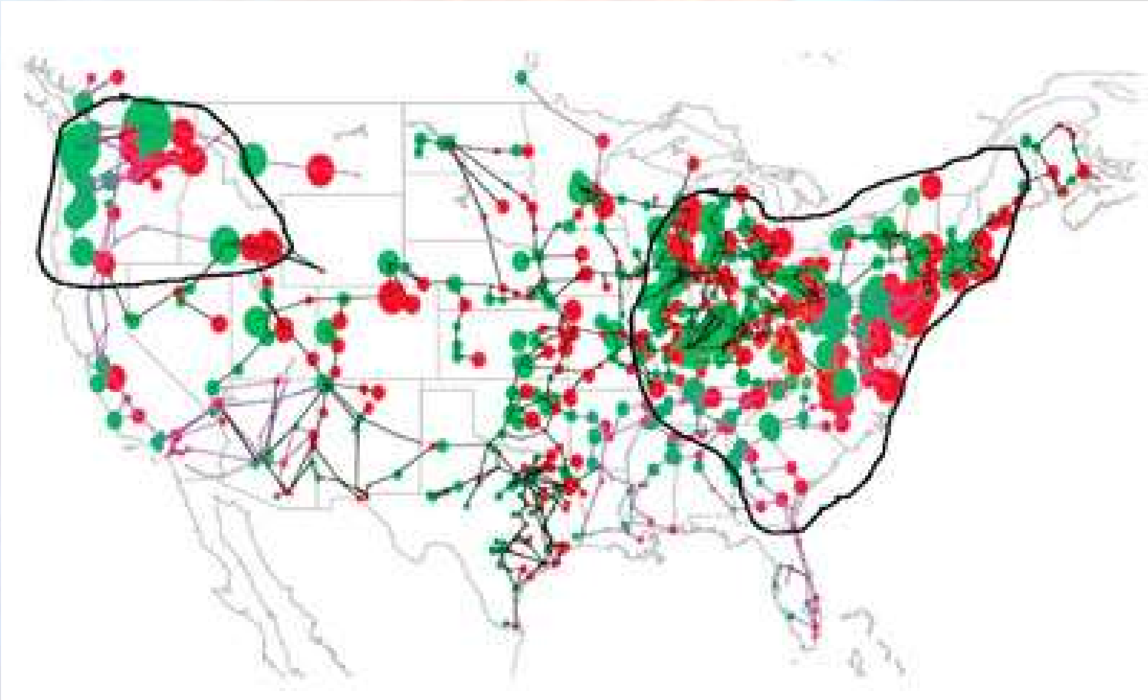
Great Magnetic Storm of May 13-15, 1921

- Also known as the “New York Railroad Storm”
  - Induced electrical currents caused a fire near Grand Central Terminal
- Caused by the impact of a powerful Coronal Mass Ejection (CME) on the Earth’s magnetosphere
  - Occurred within Solar Cycle 15
  - Scientists estimate the size of sunspot AR1842, which began on May 10th and ultimately caused the storm at roughly 94,000 miles by 21,000 miles in size
- With little interconnection between local electrical systems and little dependence upon power compared to today, its effect was limited
- Telegraph service slowed, then stopped at about midnight, May 14
  - Fuses were blown and station equipment was damaged
- Estimated GIC: ≈5000 nT/min
- Ground currents have been estimated at ten times that which caused the March 1989 Hydro-Quebec blackout

What a 4800 nT/min Event Might Look Like Today

- Scenario showing effects of a 4800 nT/min geomagnetic field disturbance at 50° geomagnetic latitude scenario. The regions outlined are susceptible to system collapse due to the effects of the GIC disturbance; the impacts would be of unprecedented scale and involve populations in excess of 130 million.

- SOURCE: J. Kappenman, Metatech Corp., "The Future: Solutions or Vulnerabilities?," presentation to the NAS space weather workshop, May 23, 2008.



Power Grid Vulnerabilities

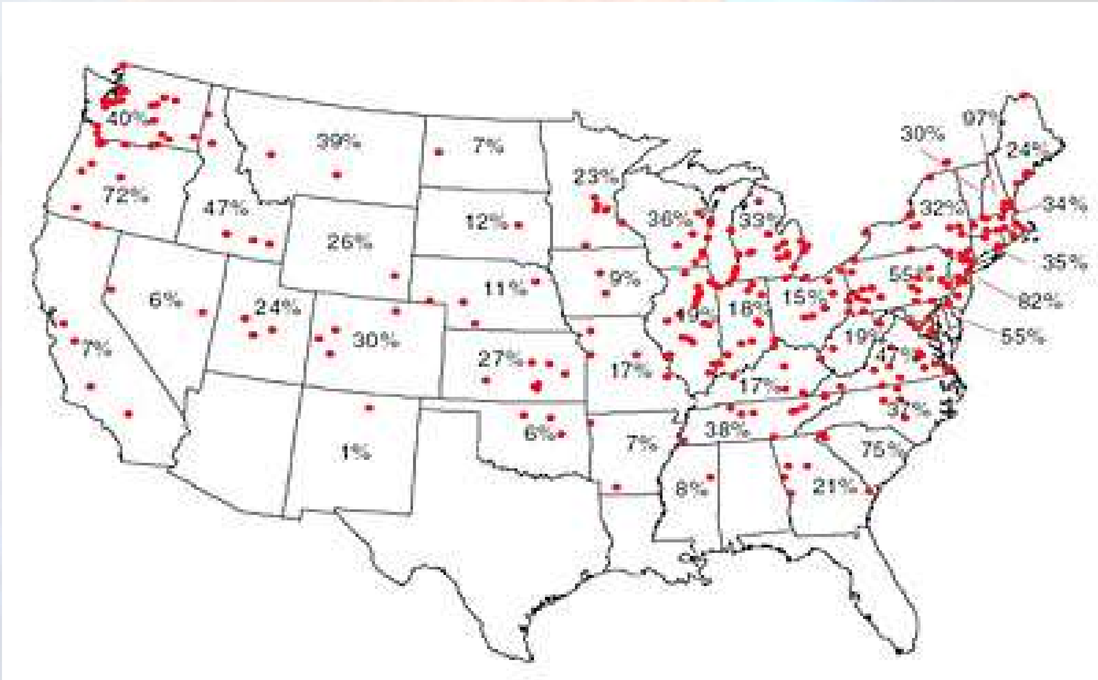
- The most serious outcome of such a power delivery failure would be damage to transformers
  - Transformers would experience excessive internal heating from the GICs causing their magnetic core to saturate
    - Extra-High Voltage transformers especially at risk
  - Melting and burn-through of large amperage copper windings and leads would occur
  - Insulation would also be damaged
  - Most of these transformers cannot be repaired in the field and would require replacement
    - Lead times are typically 12 months or more
    - We get many of these from China (anyone see a potential problem here?)
- Other critical systems on the grid would also be at some risk

Large Transformer Fire

This particular event was at a substation located north of the Angeles National Forest, near Palmdale, CA. The transformers were about 30 years old

Extra-High Voltage Transformer Vulnerabilities

- A map showing the at-risk transformer capacity (estimated at ~365 large transformers) by state for a 4800 nT/min geomagnetic field disturbance at 50° geomagnetic latitude.
- Regions with high percentages of at-risk capacity could experience long-duration outages that could extend multiple years.
- SOURCE: J. Kappenman, Metatech Corp., "The Future: Solutions or Vulnerabilities?," presentation to the NAS space weather workshop, May 23, 2008.
- Grid operational procedures generally don't reduce GIC flows and are unlikely to be adequate for historically large disturbance events
    - Such storms could cause transformer damage of unprecedented proportions, leading to lengthy blackouts, as well as chronic shortages for multiple years



Recommendations

- 2008 NAS study and the EMP Commission made recommendations for addressing these vulnerabilities which fall into three categories:
  - Space Weather Monitoring
    - Essential but still under-resourced
  - Hardening
    - Substantial investment is needed in making the grid resistant to E3 disturbances
  - Response
    - National asset-backed EMP response plan is also essential

Space Weather Monitoring

- NASA’s Advanced Composition Explorer (ACE) satellite
  - Launched in 1997 and has operated far beyond its expected lifetime
  - Positioned roughly 930,000 miles sunward of Earth
  - Collects and analyzes particles of solar, interplanetary, interstellar and galactic origins
  - One-third of major storms still arrive unannounced
  - One-quarter of all warnings are false alarms
- While critical to providing advanced warning of space weather events, there’s no announced plan to send up new satellites with enhanced and more accurate monitoring capabilities

Grid Hardening

- The likelihood of a geomagnetic storm FAR exceeds that of an incapacitating multi-megaton EMP strike
  - Prudence demands investing in hardening the grid against E3 rather than focusing on E1 from a nuclear EMP
    - "With respect to the entire grid, remedial measures to reduce GIC levels are needed and are cost-effective. The installation of supplemental transformer neutral ground resistors to reduce GIC flows is relatively inexpensive, has low engineering trade-offs, and can produce 60-70 percent reductions of GIC levels for storms of all sizes." - 2008 NAS Study
    - Improved education and training of grid operators in their roles in protecting the grid during solar events using new tools
    - New design codes are needed which would help to reduce GIC flows in the power grid
- Emphasis on making the grid "smarter", particularly as part of our effort to incorporate more 'renewable' energy sources, often works at cross-purposes with efforts to harden the grid
  - Measures need to be taken to make Smart Grid technology resistant to E3 and even E1
    - Improved cabling, transient voltage suppressors and other protective devices designed to protect against faster pulses

Response

- EMP Commission recommends stockpiling of large transformers in a way which would make it easy to move them into place in an emergency
  - EHVs (≥ 66 kV) are massive and can weigh hundreds of tons
    - Typically special rail cars are used and they're in short supply
    - Average age of installed EHVs is about 39 years, exceeding their design lifetime (≈30-40 years), increasing their vulnerability
    - Relatively easy targets for direct attack by terrorists
    - Only a limited number of spares are maintained
    - In Europe, two equally-sized full-load capable EHVs split the load
  - U.S. has over 80,000 miles of EHV transmission lines
    - Over 90% of consumed power passes through an EHV transformer at some point
  - EMP Commission estimates that enough transformers could be stockpiled in a few years if ordered in bulk
  - Establishment of a domestic supplier is essential
    - 82% of EHV transformers are imported at this time
      - We compete with other nations for these limited resources
    - Lead times on domestically-produced EHVs is roughly 38 months
    - Increase domestic production and standardize on the DHS Science and Technology Directorate's RecX design

The Recovery Transformer (RecX)

- Due to the size of this video, a link to the video by the DHS Science and Technology Directorate is being provided instead:
  - https://www.youtube.com/watch?v=xIpLwp2YuDk

Politics and Regulation of the Grid

- There are no federal laws that require the power industy to protect the grid from threats such as nuclear EMP, space weather and cyberattacks
  - Under rate constraints from PUCs, electric companies have minimal budgets for maintenance, let alone preventative measures for these threats
- The North American Electric Reliability Corp (NERC), a not-for-profit corporation, acts as a self-regulating body "whose mission is to assure the reliability of the Bulk Power System (BPS) in North America."
  - The BPS, comprised of over 1,000 public and private companies, does not include distribution to end-users which is regulated by state PUCs
- The Federal Electric Regulatory Commission (FERC) is an independent federal agency overseeing "the reliability of the BPS."
- Grid regulation between FERC and NERC is complex
  - NERC provides most regulatory functions and is overseen by FERC
  - The Energy Policy Act of 2005 allowed FERC to certify an organization as an "Electric Reliability Organization" (ERO), which would develop the reliability standards , subject to FERC approval
  - On the 20th of July, 2006, FERC certified NERC as the ERO
- Found a sea of dead links to scientific literature and academic papers which suggests the government has been engaging in fearmongering about nuclear EMP while ignoring the real threat of GIC from solar storms
  - Government directed Censorship?

Funding and Controlling NERC

- NERC's funding is provided by assessments on the entities which it regulates
  - Those assessments also fund industry groups like the Electric Power Research Institute (EPRI) and the Edison Electric Institute (EEI)
- NERC has 12 voting members, 9 of which are required to be part of the industry being regulated
  - This leaves only 3 positions for consumers and government
  - While FERC 'oversees' NERC, it can't easily tell it what to do
- NERC, EPRI, and EEI have spent tens of millions of dollars each year, lobbying against laws designed to protect the grid from a massive failure
  - When you pay your electric bill, you're paying to help keep the grid unprotected from catastrophic failure
  - The Center for Responsive Politics published these figures for 2018:
    - $122,281,276 on lobbying
    - $24,413,992 in PAC contributions
    - $12,059,457 in political contributions to members of the House
    - $3,731,572 in political contributions to members of the Senate

Summary

- Vulnerability of parts of the grid to nuclear EMP is real, but is being overblown
- A much greater threat to the grid is GICs from a once-in-a-century type solar storm
  - E3 from a large solar storm can vastly exceed E3 energy levels from a nuclear EMP
    - Addressing that threat will also eliminate much of the existing vulnerability to nuclear EMP
    - This should take precedence over E1 type pulses
- We have to demand federal action
  - Regional/local storage of RecX EHV transformers
    - Sparing of other critical assests (e.g., DPRs, SCADA, communications)
  - E3 hardening must be mandated

HEMP Myths

- Starfish (1962) caused minor HEMP effects in Hawaii, so we have nothing to worry about
  - That was a world without our solid state, chip-based electronics and control systems
  - The burst was far away from Hawaii, so the incident E1 which hit Hawaii was greatly reduced
  - The Island is small, without the long transmission and phone lines of the continental U.S.
- All vehicles in operation will come to a halt and all modern vehicles will be damaged
  - Some vehicles probably will be affected, especially those with mostly nonmetallic bodies
    - As vehicles use lighter materials to meet tougher CAFE requirements, this advantage may disappear
  - Cars don't have long wires to act as antennas, coupling the EMP energy into their systems
- Electronic watches, FitBits, etc. will die
  - These are far too small to be affected by HEMP

HEMP Myths (cont.)

- Turning equipment off will protect it
  - Some truth to this, if you could predict the coming EMP
  - Equipment is more vulnerable if operating at the time of the EMP
  - Damage can still happen from energy coupled through cables/coax connected to the idled equipment
- Equipment will be OK if all connected conductors are less than a certain length
  - Shorter lengths are generally better, but there is no ‘magically’ safe length
    - Resonant lengths would be a big exception
- Stay away from metal (assuming there was a warning)
  - Metal can collect E1 energy and generate high voltages, but the “skin effect” will prevent current flow from penetrating into the body
  - The consensus of opinion is that E1 is harmless to human bodies

Protecting Your Electronics/Appliances

- Two avenues of attack
  - Directly to the devices
    - Small handheld devices might survive
    - Tube-based devices have a better chance of surviving than solid state devices, especially those with small junction size VLSI ICs
  - Via the power grid
    - Damage from energy coupled into the grid
    - Can the devices be powered/charged without power?
    - Backup power – solar cells might survive with some damage/reduced output
      - Solar inverters/chargers will likely suffer some damage
    - Emergency disconnect switch
      - Required outside the house, usually at the main panel where the power drop comes in
      - Optional second switch with a larger air gap for higher induced voltages
      - Useless unless you know the attack is about to happen

Surge Protectors

- Whole house
  - Installed at main electrical panel
  - Downstream house wiring can still couple some E1 and E2 energy
    - Use additional quality surge protectors ahead of key appliances and electronic devices powered by house AC
    - Surge protector strips/wall outlets
    - UPS with surge protection
      - True sine wave inverter type are the best

- Surge protector ratings (UL 1449)
  - Voltage Protection Rating (VPR) – maximum voltage the device will pass through to connected devices
    - The lower the better
  - Suppressed Voltage Rating (SVR) – pass-through voltage based on a test current of 500 A
    - The lower the better (330 V is the lowest possible)
  - Joule Rating (J) – measure of the energy it can absorb before it fails
    - Higher is better (look for a minimum of at least 600 Joule)
  - Response Time – measured in nanoseconds (look for 1 ns or less)
  - Clamping Voltage – voltage level at which the surge protector will attenuate the voltage surge
    - The lower the better (400V is typical for better surge protectors)
  - If a surge protector claims to be “EMP rated”, it must meet MIL-STD-2169 stress ratings

Electromagnetic Shielding (Faraday Cage)

- Bags for small or larger devices
  - Military requires at least 80 dB attenuation of E1 spectrum (10 Mhz-1.5 GHz)
    - Protects against 99.999999% of EMP energy
  - Inexpensive Faraday bags often have only 30-50 dB of attenuation
    - Nest 2 or 3 bags
  - Look for MIL-STD 188-125 and/or IEEE 299-2006 compliance
  - Larger bags should be used to protect portable solar power panels and controllers
- Aluminum foil – wrap 5 layers around device
  - 3 layers if using heavy duty foil
- Galvanized steel trash can with tight-fitting lid
  - Good electrical contact between lid and can is essential
- EMP 'conductive concrete' structure with tight steel door/hatch
  - EMSS-Electromagnetic Shielding Shotcrete (ABC Group, Inc.)
- DIY Faraday Cage or Kits
  - 60 dB attenuation shields contents from 99.9999% of EMP
- Myths:
  - Mylar bags – normally not thick enough
  - Microwave oven – most have RF leaks outside of 2.4 GHz range

Other Considerations

- Unplug and remove power cords, data lines (phone, Internet, LAN), coax and other wires from spare equipment
  - Do the same for other equipment if you know an EMP is coming
- Turn off equipment that cannot be unplugged and is not being used
- Have a backup generator, preferably whole-house capable
  - Ensure it is EMP-hardened
  - Minimum supply of 2 weeks of fuel
- Maintain charged amateur HF/VHF/UHF radios
  - While not in use, keep disconnected from antennas (remove HT antennas)
  - Winlink for global radio-based email
- Store at least 2 weeks of food, water and other essentials
- Battery/solar/hand-cranked AM/FM/NOAA emergency radio

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Q & A