NPS CHDS 10th Anniversary Homeland Defense & Security Education Summit

Effects of and Responses to Electromagnetic Pulses (EMP)

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SPEAKER

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Lane conducted chemical security research as a NASA Fellow at the Stennis Space Center and as a National Science Foundation Fellow.

SPEAKER

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INTRODUCTION

An electromagnetic pulse (EMP) is an intense burst of electromagnetic energy caused by rapid acceleration of charged particles that can destroy or damage electronic systems by overloading circuits.

EMPs are caused by geomagnetic disturbances (GMD) in the Sun and by atmospheric detonation of nuclear weapons.

INTRODUCTION

Direct exposure to EMPs is harmless to people; however, EMPs can affect critical infrastructure and key resources (CI/KR), such as the power grid, communications, and transportation. The U.S. is vulnerable to an EMP attack.

INTRODUCTION

Nuclear EMPs are characterized by a range of spectrum of frequencies, pulse waveform shape, duration, and amplitude.

A nuclear weapon detonated between 40 and 400 kilometers can generate an EMP that could affect up to 70% of the U.S. electric power grid, depending upon intensity.

INTRODUCTION

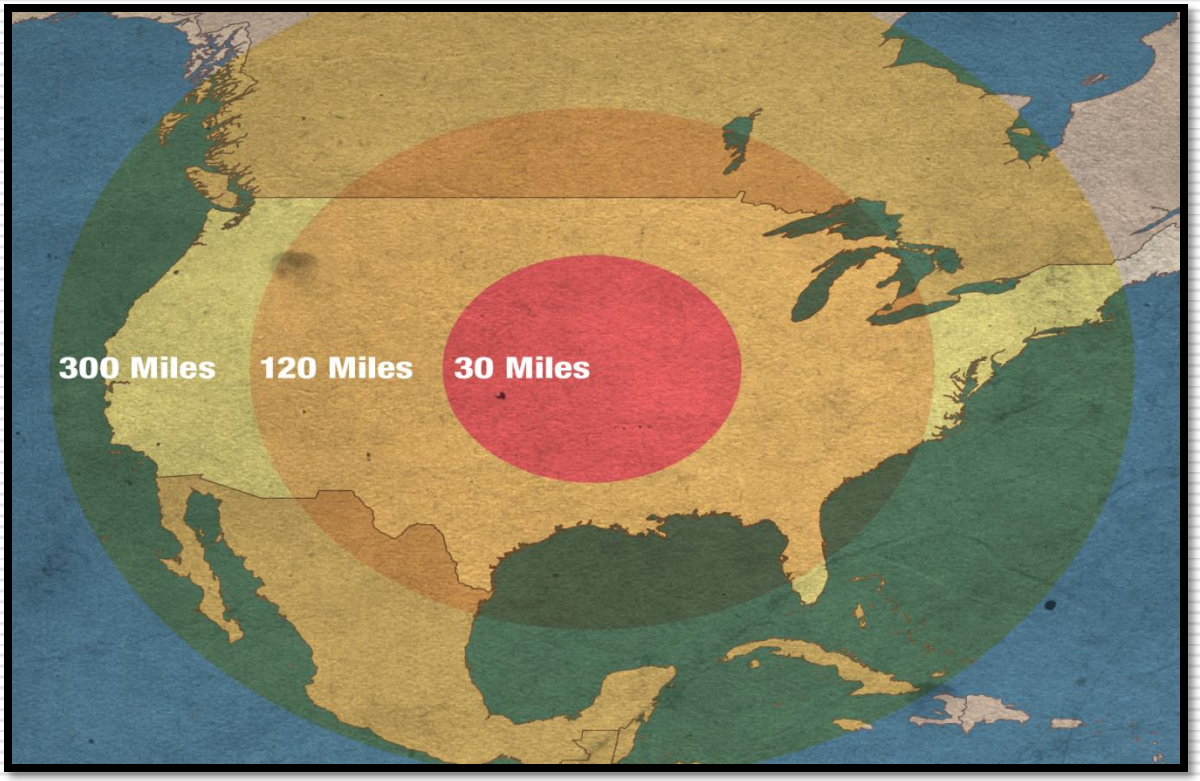

Fig. 1: EMP affected areas by height of burst (NASA)

INTRODUCTION

The Sun generates EMPs in solar flares that can cause GMDs. Solar coronal holes and coronal mass ejections (CMEs) produce magnetic disturbances.

A solar CME consists of low-frequency charged energetic particles that can reach Earth in from fifteen hours to four days and can energize long power lines.

INTRODUCTION

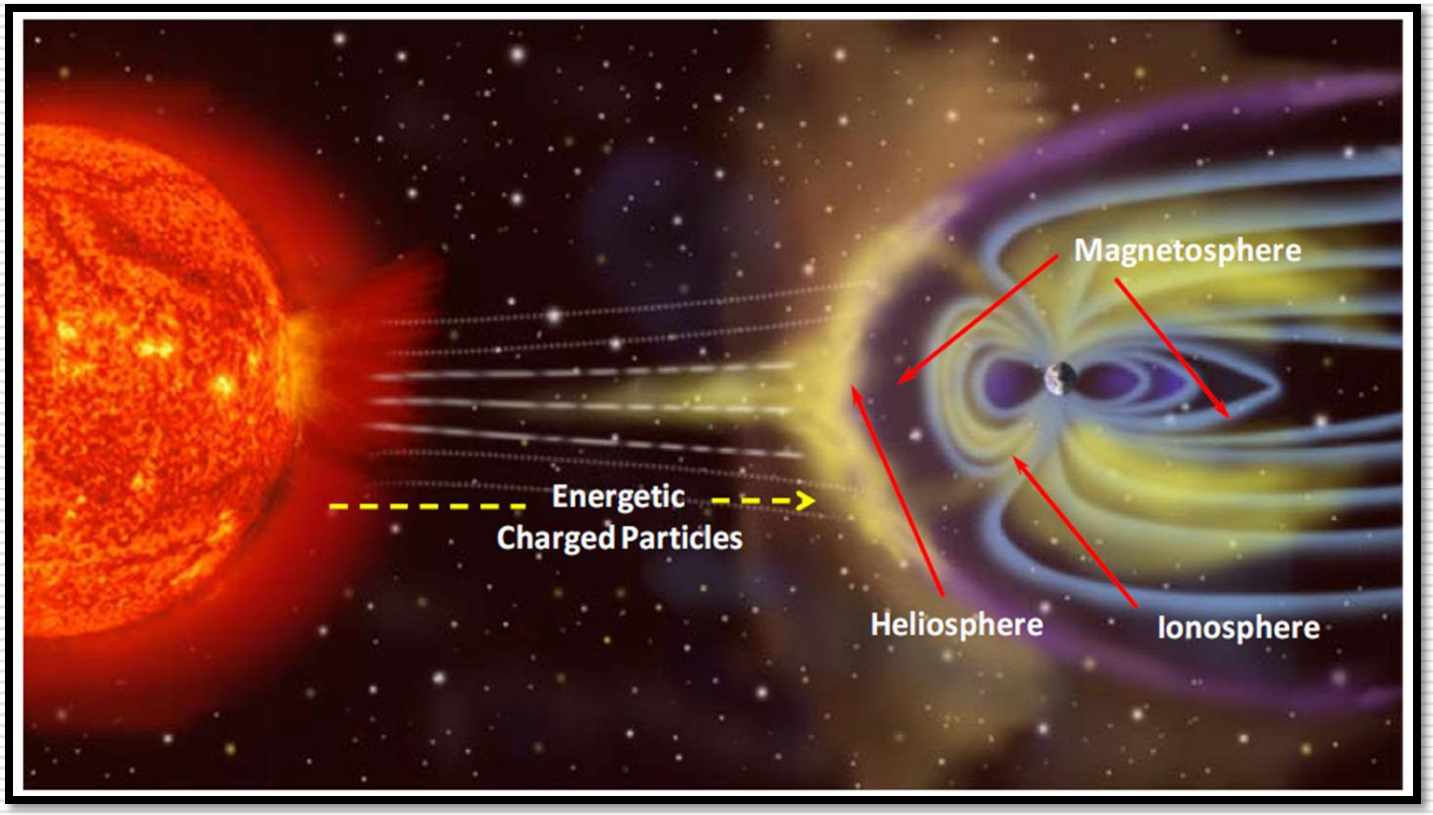

Fig. 2: Coronal mass ejection (CME) (NASA)

HISTORY OF EMPS

The Solar Storm of 1859, known as the "*Carrington Event*", was a powerful geomagnetic solar storm that caused a solar CME that struck Earth's magnetosphere on September 1, 1859 and induced one of the largest geomagnetic storms on record.

HISTORY OF EMPS

In 1859 while astronomer Richard Carrington was capturing images of sunspots, two brilliant white lights suddenly appeared over the sunspots and rapidly intensified.

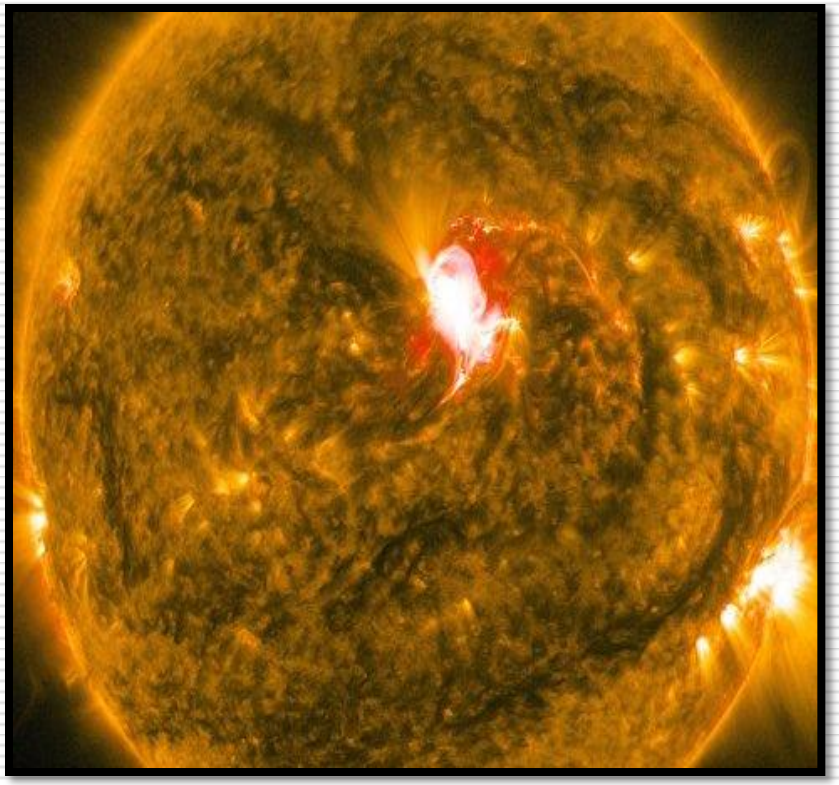

Fig. 3: Sunspots with white lights

HISTORY OF EMPS

Before dawn the next day, skies all over Earth erupted in red, green, and purple auroras so brilliant that newspapers could be read at night in Cuba, the Bahamas, Jamaica, El Salvador, and Hawaii.

Even when telegraphers disconnected the batteries, aurora-induced electric currents in the wires still transmitted messages.

HISTORY OF EMPS

On March 13, 1989, solar activity created a GMD that caused a nine-hour outage of Hydro-Québec in Canada's power grid.

The storm began with extremely intense auroras at the poles, and could be seen as far south as Texas and Florida.

Because this occurred during the Cold War, many people worried that a nuclear first strike might be occurring.

HISTORY OF EMPS

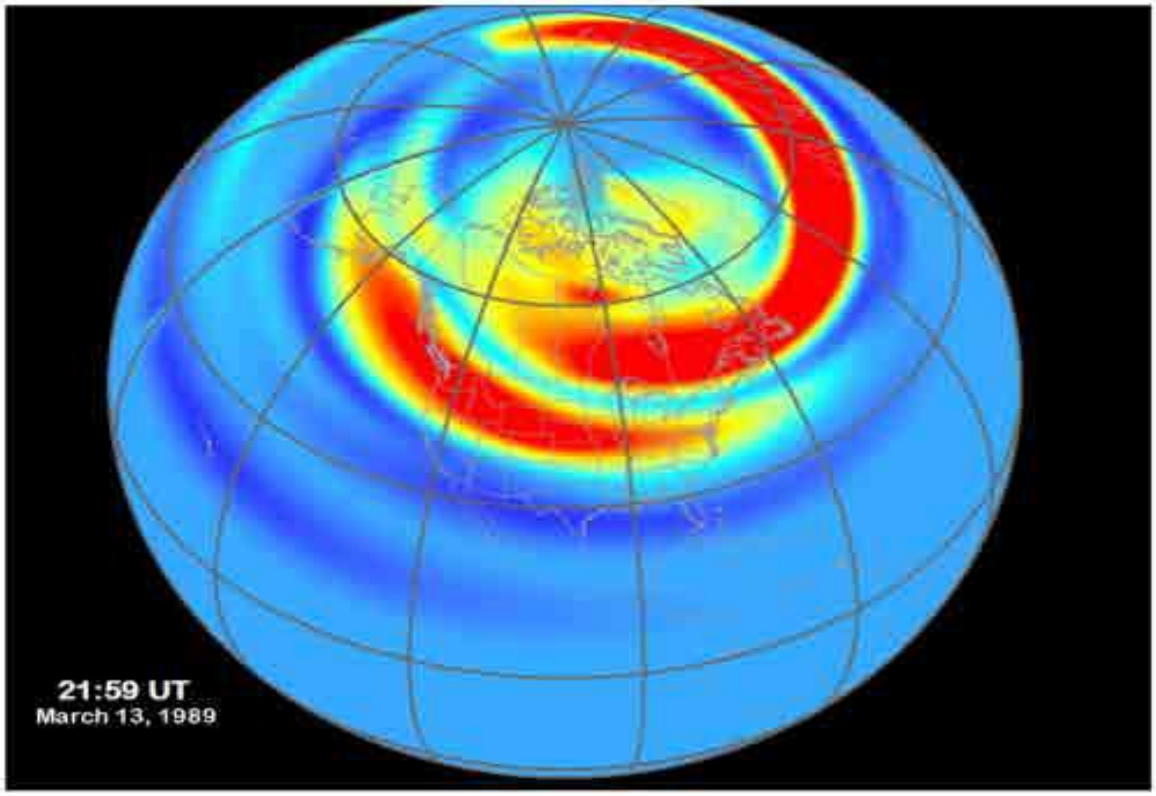

Fig. 4: Extent of 1989 Geomagnetic Storm

HISTORY OF EMPS

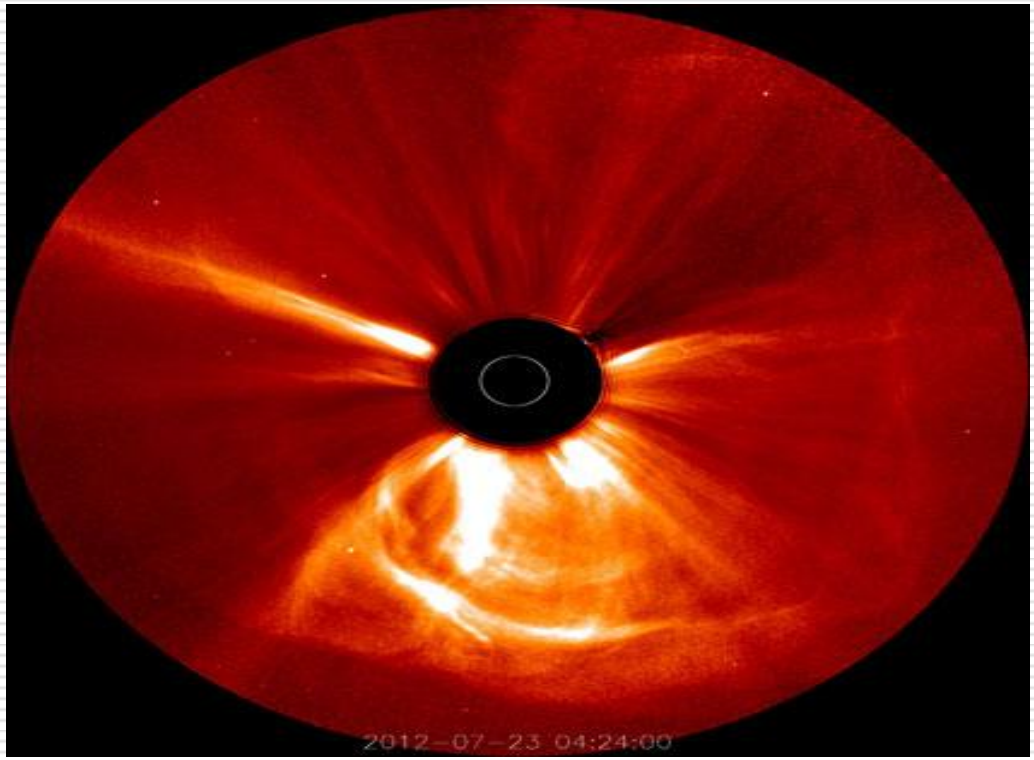

Fig. 5: Satellites tracked this CME as it barely missed Earth in 2012 (NASA)

HISTORY OF EMPS

EMPs were known to be produced since the earliest days of nuclear weapons testing; however, the magnitude and significance of the EMP and its effects were not realized.

EMPs affect electrical systems by "*coupling*", acting as antennas that pick up EMP signals.

HISTORY OF EMPS

During the first U.S. nuclear test on July 16, 1945, "*Trinity*", electronics were shielded because Dr. Enrico Fermi, awarded the 1938 Nobel Prize for Physics in induced radioactivity, anticipated an EMP. However, electronics were still damaged.

Instrumentation failures during British nuclear testing in 1952 revealed "*radioflash*," the British term for an EMP.

"*Operation Hardtack*"

The first openly-reported high-altitude EMP data came from "*Operation Hardtack*" in 1958 in "*Yucca*", the code name of the first high altitude test of a nuclear device carried by a balloon.

Fig. 6: "*Operation Hardtack*" (Los Alamos Laboratory)

"*Operation Hardtack*"

The final report of "*Yucca*" in "*Operation Hardtack*" provided the first data confirming that high-altitude EMPs could be more than 1,000 times as intense as low-altitude EMPs.

The ground acts as a radiation absorber and an electrical conductor at the surface of the earth, reducing the effect of EMPs.

"*Operation Hardtack*"

Many had argued that multi-megaton weapons were required to produce an EMP.

However, in "*Operation Hardtack*", an EMP was generated using a weapon with a yield of only 1.7 kilotons launched by a balloon.

By comparison, Trinity had a yield of approximately 15 kilotons.

Artificial radiation belt

There was an EMP effect that had not been predicted, the production of an artificial radiation belt.

An artificial radiation belt is a "*torus*", a surface formed by rotating a closed curve, containing energetic electrons or protons that encircles the Earth, threatening satellites.

Artificial radiation belt

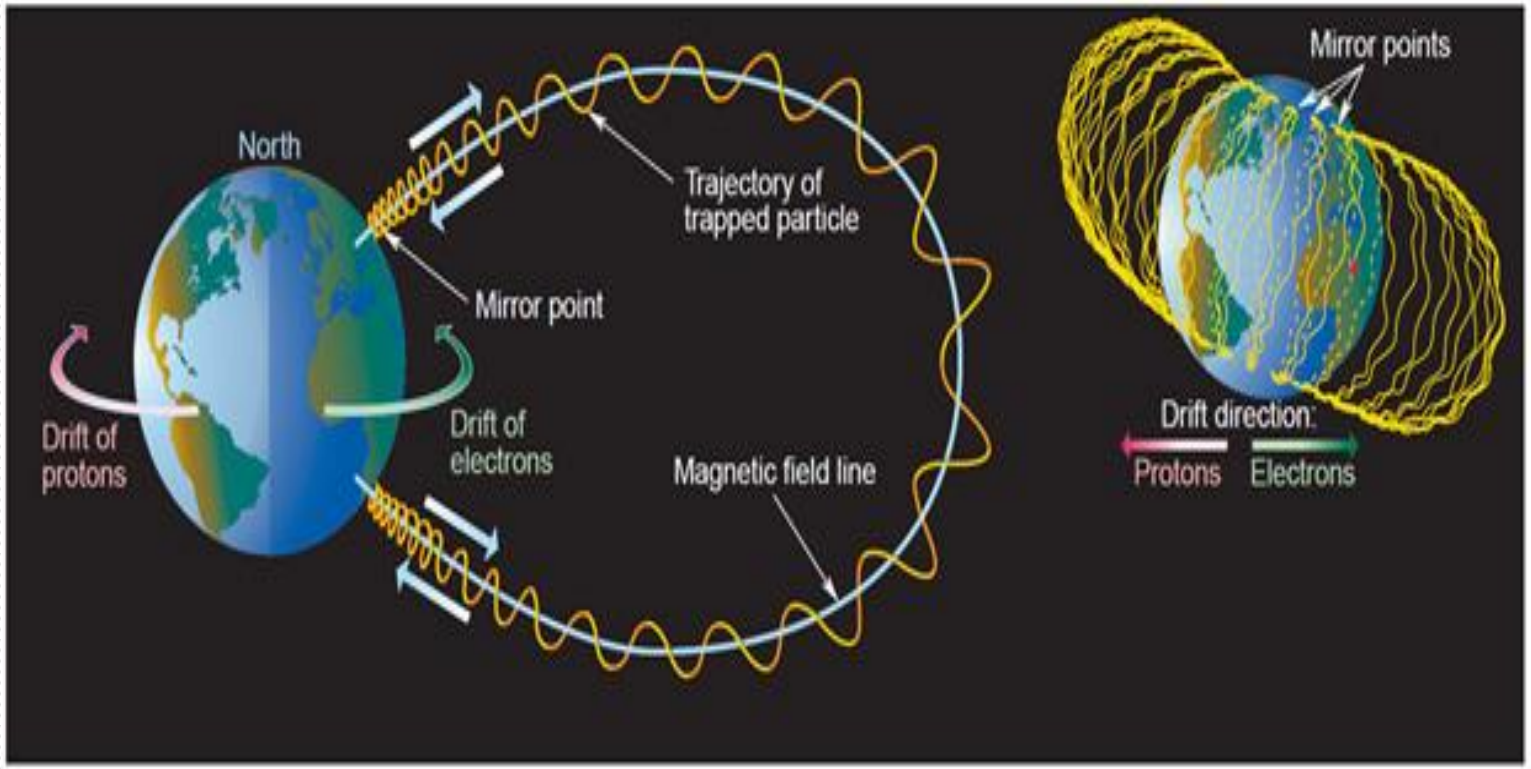

Fig. 7: Electrons and protons drift in Earth's magnetic field (NASA)

Artificial radiation belt

Many of the electrons generated by the blast did not fall down into the Earth's atmosphere, but instead lingered in space for months, trapped by Earth's magnetic field.

When a high-speed electron hits a satellite, it can generate a miniature EMP that can damage satellites' electronics.

"*Starfish Prime*"

An artificial radiation belt was created by the "*Starfish Prime*" 1.44 megaton nuclear test 400 kilometers over Johnston Island in the Pacific Ocean on July 9, 1962.

"*Starfish Prime*" demonstrated that the magnitude of high altitude nuclear explosions generated EMPs were much larger than had been previously calculated.

"*Starfish Prime*"

"*Starfish Prime*" generated an EMP that;

- **Created an artificial aurora seen in Hawaii 900 miles away;**
- **Affected the power grid in Hawaii; and**
- **Knocked out one Soviet and six U.S. satellites, including Telstar I, the first communications satellite.**

"*Starfish Prime*"

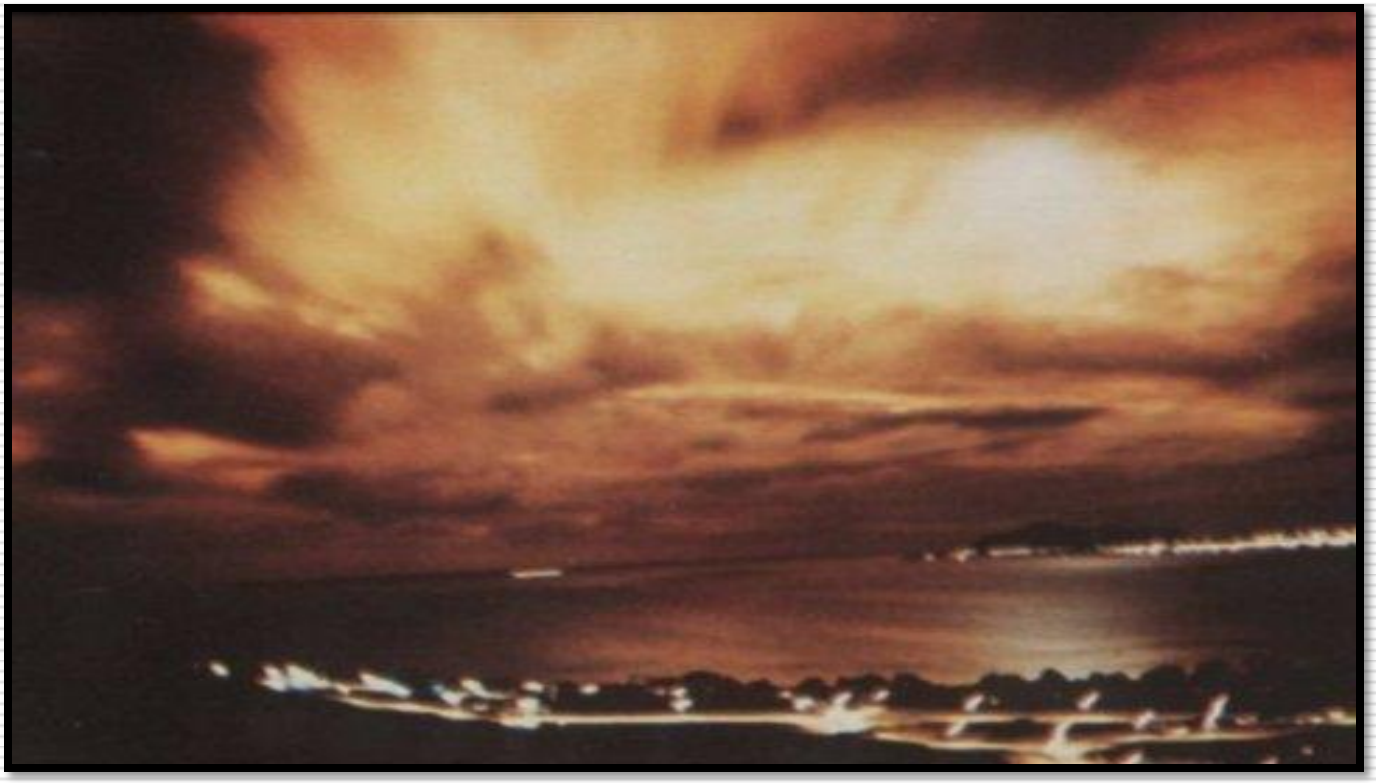

Fig. 8: Artificial aurora caused by "*Starfish Prime*" seen in Hawaii through heavy overcast (NASA)

"*Starfish Prime*"

If "*Starfish Prime*" had been detonated over the northern continental U.S., the EMP would have been much larger because the Earth's magnetic field is twice the strength there.

Earth's magnetic field doubles in intensity from the equator to the poles.

Consequently, the effect of an EMP or GMD increases proportionately at higher latitudes.

"*The K Project*"

In 1962 the Soviet Union performed nuclear tests in space that produced EMPs in the "*K Project*" over Kazakhstan.

Although these weapons were much smaller than those used in "*Starfish Prime*", 300 kilotons, they were detonated over a populated area and at a location where the Earth's magnetic field was greater.

"*The K Project*"

Fig. 9: Missile flight path over Kazakhstan in blue

"*The K Project*"

The missiles were launched from the east of Volgograd, formerly Stalingrad, creating an EMP much greater than in "*Starfish Prime*".

The geomagnetic storm-like EMP induced an electric current surge in long underground power lines, causing a fire in a power plant in Kazakhstan.

EMP THREAT

The increasing reliance on EMP-sensitive microelectronics heightened awareness that the EMP threat is a very significant problem.

The general community became aware of the significance of the EMP problem in 1981 when Dr. William Broad published articles about nuclear EMPs in "*Science*".

EMP THREAT

In 2010 the Defense Threat Reduction Agency issued "*Collateral Damage to Satellites from an EMP Attack*", detailing the effects of high-altitude nuclear blasts on satellites.

CHARACTERISTICS OF EMPs

A nuclear EMP is a complex multi-phase pulse, usually described in three components defined by the International Electrotechnical Commission as;

E1: Early time;
E2: Intermediate time; and
E3: Late time

CHARACTERISTICS OF EMPs

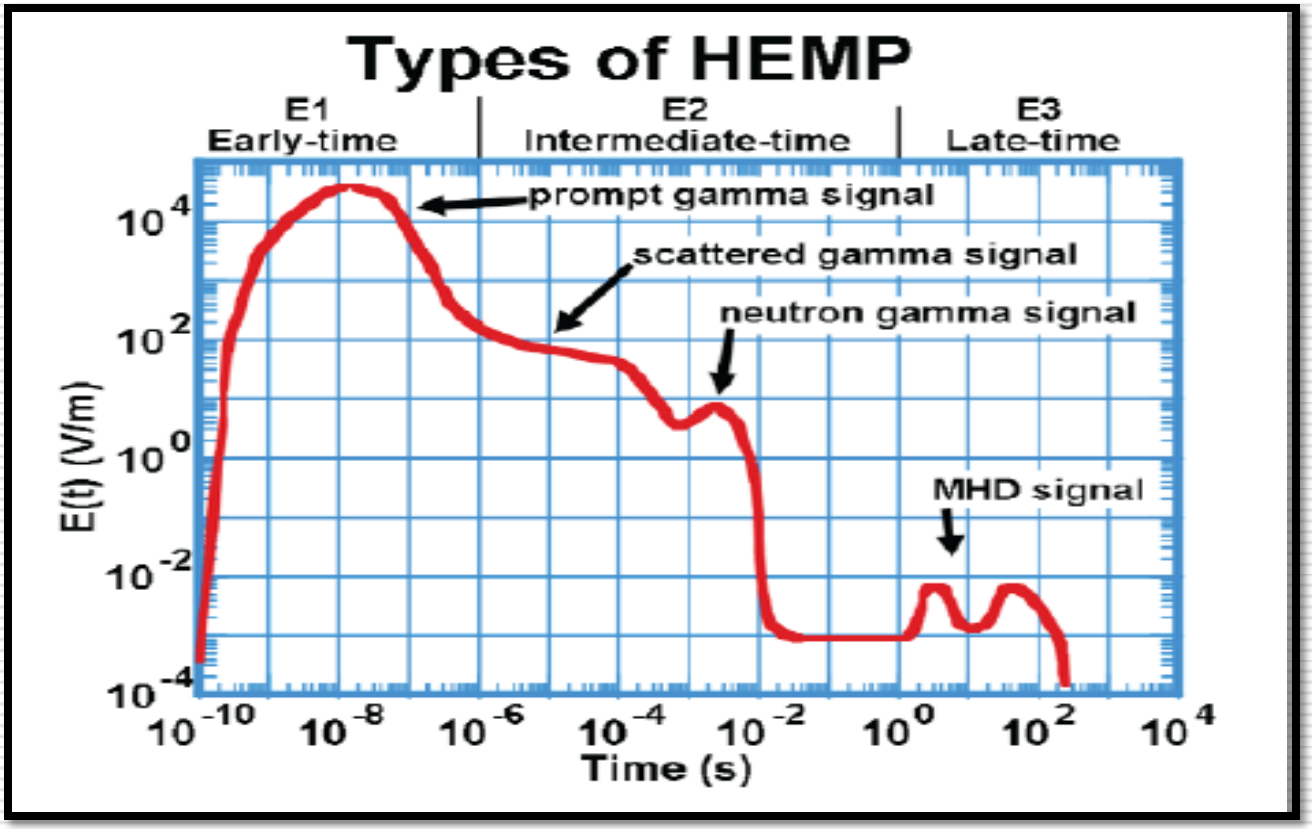

Fig. 10: Three parts of the EMP waveform

E1: EARLY TIME

The E1 pulse is the fast component of nuclear EMPs, a brief but intense electromagnetic field that can quickly induce very high voltages in electrical conductors and transformers in the power grid within line of sight of detonation.

E1: EARLY TIME

The E1 is too fast for standard lightning surge protection and is produced when gamma radiation knocks electrons out of the atoms in the upper atmosphere.

The electrical disturbance in "*Starfish Prime*" was due to the "*Compton effect*", theorized by physicist Dr. Arthur Compton in 1925.

E1: EARLY TIME

Compton said photons could remove electrons from atoms with low atomic numbers.

Photons from intense gamma radiation in a nuclear explosion produce a large number of electrons from Oxygen and Nitrogen atoms present in the atmosphere.

E1: EARLY TIME

These electrons interact with the Earth's magnetic field to create a fluctuating electric current, inducing a powerful magnetic field and an EMP.

The strength of the E1 pulse is dependent upon the intensity of the gamma rays and altitude of the nuclear detonation.

E2: INTERMEDIATE TIME

The E2 component is generated by scattered gamma rays and inelastic gammas produced by neutrons in the intermediate time pulse from 1 microsecond to 1 second.

Because of the similarities to lightning-caused pulses, the E2 pulse is considered to be easier to protect against than E1.

E2: INTERMEDIATE TIME

According to the EMP Commission in 2004;

"*The most significant risk (of an E1 followed by an E2) is synergism, because the E2 component follows a small fraction of a second after the first component's insult, which has the ability to impair or destroy many protective and control features*."

E3: LATE TIME

The E3 pulse is generated by the fireball of a nuclear explosion, which expands and collapses, causing the Earth's magnetic field to oscillate.

The E3 pulse is not a freely propagating wave like E1 and E2, but rather similar to natural GMDs and can last minutes.

E3: LATE TIME

The E3 pulse is a low frequency pulse which, unlike the high frequency E1 and E2 pulses, can penetrate the ground where it can induce geomagnetically-induced electric currents in long buried cables.

Although the E3 pulse contains little unit energy, this energy is multiplied by power lines, typically miles long, building up currents that can melt transformers.

Vulnerability of transformers

The sequence in an EMP is important to the vulnerability of transformers.

A nuclear-generated EMP occurring at from about 40 to 400 kilometers generates an E1.

The secondary E2 component covers the same geographic area as the E1, but is more widespread and lower in strength.

Vulnerability of transformers

An E1 alone may not cripple a transformer, but an E2 immediately following the E1 can provide the required collective energy.

An E3 low frequency, longer duration pulse creates disruptive currents in long underground electrical transmission lines.

Vulnerability of solar panels

Solar panels are vulnerable to the E1 and E2 pulses of an EMP because of their low individual operating voltages.

However, if solar panels are not plugged into the grid, the E3 pulse cannot affect them.

Vulnerability of solar panels

A Faraday cage can shield solar panels against E1 and E2 in nuclear EMPs.

However, they are only protected while inside the cage.

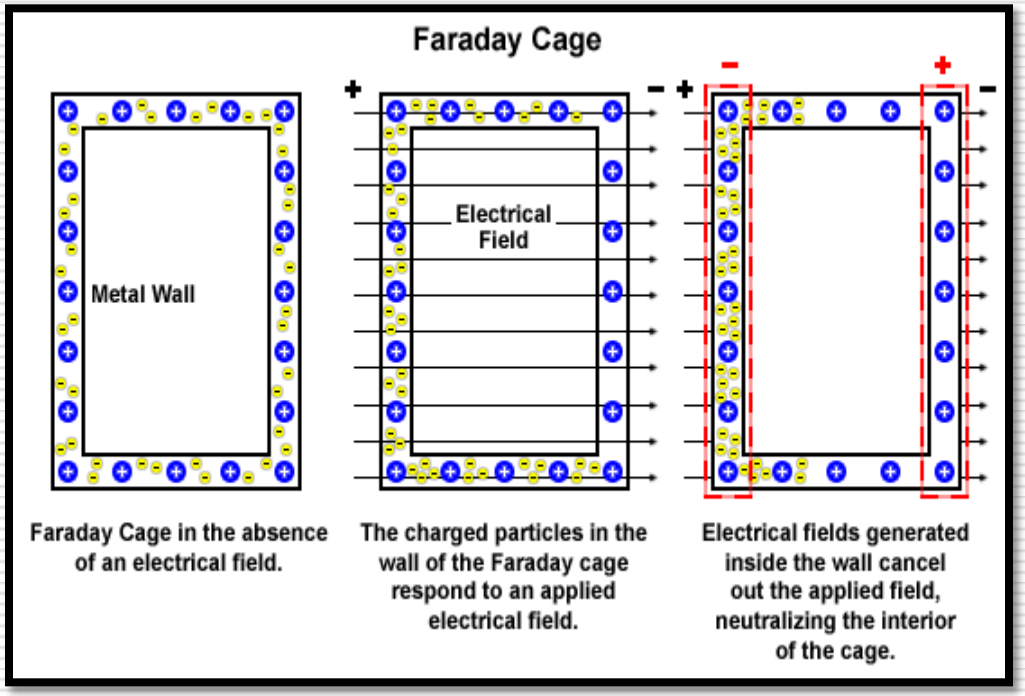

Fig. 11: Faraday cage

Vulnerability of cell phones

The E3 EMP pulse would not directly harm cell phones unless connected to the power grid, such as recharger cords.

However cell phone towers with long power lines are vulnerable to E3 pulses as well as E1 and E2.

Vulnerability of cell phones

Because microwave ovens are shielded to keep energy within their walls with a viewing port, they act as Faraday cages, and can keep cell phones safe in ovens during an EMP.

Fig. 12: Microwave oven

Effects of Hurricane Katrina as example of EMP threat

On August 29, 2005, Hurricane Katrina struck New Orleans, providing a model for studying the effects of an EMP attack.

EMPs would have limited effect on individual vehicle microprocessors because cars are made of metal and act as a natural Faraday cage. That means that the electronics within cars are protected from EMPs.

Effects of Hurricane Katrina as example of EMP threat

However mass transit utilizing long metal tracks, such as street cars in New Orleans and subways in other urban areas, would be severely affected by the E3 component, disabling mass transportation.

MITIGATION AGAINST THE EMP THREAT

The vulnerability of the U.S. electrical power grid to EMPs is a national security issue.

It is urgent that Congress, the executive branch, and especially DHS protect the U.S. power grid and implement and enforce uniform effective national safety regulations.

MITIGATION AGAINST THE EMP THREAT

The nation's electric power grid must be made resilient to EMP attack.

Emergency services and essential agencies can retain power after an attack by using a "*microgrid*", a small-scale version of the power grid that can run independently and be activated during times of peak usage.

State legislation to protect grids

12 states protect their power grids from EMPs from a solar flare or nuclear detonation.

In 2013 Maine was the first in the nation to mandate a study of power grid threats from both solar storms and man-made EMP.

Legislation requires that the state examine the vulnerabilities of Maine's power grid to the impacts of EMPs.

Federal developments to protect grids from EMPs

On May 15, 2013, the Federal Energy Regulatory Commission directed the North American Electric Reliability Corporation (NERC) to submit proposed reliability standards to address the impact of GMDs on the operation of the Bulk Power System.

Federal developments to protect grids from EMPs

On November 7, 2013, NERC approved a standard "*to mitigate the effects of GMD events by implementing operating plans, processes and procedures*."

This report assesses the impacts of GMD/EMP-E3 events (considered equivalent) as well as EMP E1 and E2 events on power transmission systems.

Federal developments to protect grids from EMPs

The U.S. Department of Energy has developed the "*Smart Grid Investment Grant Program*" to fund EMP protection projects throughout the United States.

Federal developments to protect grids from EMPs

An experiment is being conducted in New Jersey with Sandia National Laboratory in which Public Service Electric & Gas Company is developing its own "*microgrid*,", taking strain off the larger electric power grid.

Federal developments to protect grids from EMPs

On February 14, 2017 Congress passed the "*Critical Infrastructure Protection Act*" (CIPA), which directs DHS to include EMPs in "*National Planning Frameworks*" to develop;

***"national standards for uniform grid security protection and education of operators of critical infrastructure and emergency planners and responders of the EMP threat"*.**

SUMMARY

The U.S. is currently vulnerable to an EMP event from a man-made nuclear weapon or naturally occurring solar storms.

A determined adversary can achieve an EMP attack without a high level of sophistication.

SUMMARY

An EMP attack poses minimal initial threat to public health; however, if power grids are disabled by EMPs, cascading consequences to CI/KR can threaten public health, especially in developed urban areas.

CONCLUSIONS

DHS EMP "*National Planning Scenarios*" should provide protection to the national power grid from the EMP threat by including methodologies already developed by states, DOE, and national laboratories.

CONCLUSIONS

EMP response should be within FEMA's National Incident Management System (NIMS) and Incident Command System (ICS), currently used by every state and federal agency in emergency response planning.

CONCLUSIONS

A risk-based approach should be used to assess the feasibility and cost of hardening CI/KR in an EMP attack using an alternative weapon delivery methodology.

EMP attack scenario utilizing a weather balloon

EMP attacks using missiles affecting all of the United States are possible.

However, smaller regional EMP attacks are also possible, using small nuclear devices delivered by high-altitude balloons, launched by terrorists under the guise of collecting weather from 3 miles off the coast, beyond legal jurisdiction.

EMP attack scenario utilizing a weather balloon

During "*Operation Hardtack*" in 1958, an EMP was generated using a weapon with a yield of only 1.7 kilotons launched by a balloon.

An EMP attack by balloon would affect a smaller area and have less intensity, but would still be very damaging to the power grid in urban areas containing critical CI/KR.

EMP attack scenario utilizing a weather balloon

"*Yucca*" in "*Operation Hardtack*" carried a 762 pound payload to 85,000 feet in one hour and 28 minutes using a balloon.

Fig. 13: Balloon used in Yucca

EMP attack scenario utilizing a weather balloon

Larger weather balloons could go much higher.

Terrorists with a crude nuclear weapon designed for EMP could reach 120,000 feet.

Fig. 14: High Altitude Balloon

CONCLUSIONS

It is difficult to detect launch by balloon at night and determine its purpose. A balloon launch vessel remaining 3 miles off the U.S. coast can avoid interdiction.

A balloon launched off the coast of New Jersey could cause an EMP that would damage the power grid from Washington, D.C. to New York City.

CONCLUSIONS

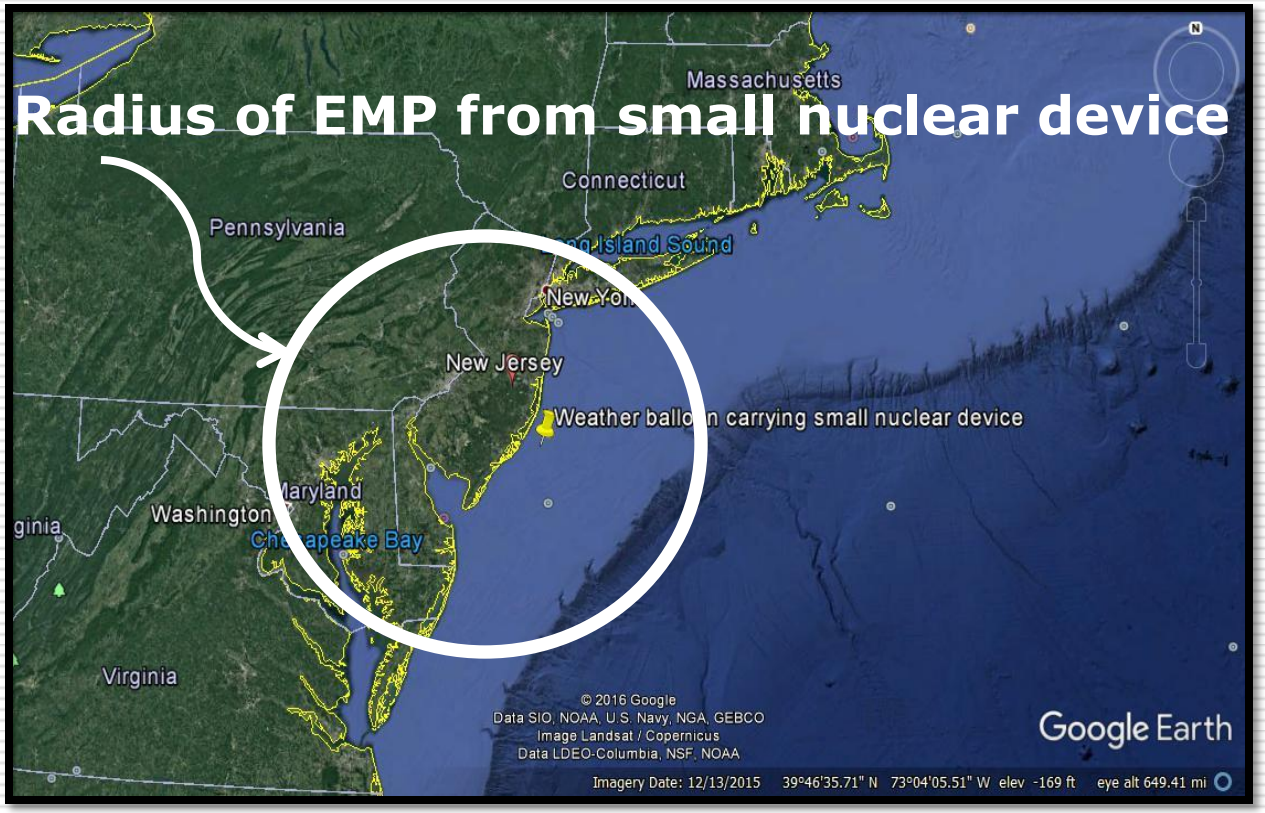

Fig. 15: EMP at 120,000 feet 3 miles off coast of New Jersey

CONCLUSIONS

The psychological effects of an EMP attack using a common weather balloon to deliver a nuclear device would be devastating and simultaneously damage CI/KR in the power grids of D.C. and New York City.

CONCLUSIONS

The "*9/11 Commission Report*" called the attacks on September 11, 2001 a "*failure of imagination*", a failure to imagine the use of airliners as weapons.

It would be another "*failure of imagination*" not to plan for the possibility of an EMP attack using balloons.

CONCLUSIONS

Questions, answers, and discussion

Lane, George; "*Effects of and Responses to Electromagnetic Pulses*", Homeland Security Affairs, Journal of the Naval Postgraduate School Center for Homeland Defense and Security, Spring 2017