Severe Space Weather Threats

National Electrical Grid and Impacts to Critical Infrastructures

A Roundtable Exercise
Hosted by National Defense University
In Conjunction with the US Congressional EMP Caucus

AFTER ACTION REPORT

October 3, 2011

Produced by:
The Energy & Environmental Security Policy Program
at National Defense University *and* **CRA, Inc.**

For more information, consult the following points of contact (POCs):

At NDU:
Dr. Richard Andres
Energy & Environmental Security Policy Chair, NDU
Professor of National Security Strategy, National War College
National War College
300 D Street SW
Washington, DC 20319-5078
(202) 685-4427
AndresR2@ndu.edu

Dr. Alenka Brown
Energy & Environmental Security Policy Associate Chair, NDU
Human Interoperability Lead, Center for Technology and National Security Policy
NORAD and US NORTHCOM Chair, NDU
National Defense University
300 5th Avenue SW
Washington, DC 20319-5066
(202) 685-6344
BrownVanHoozerS@ndu.edu

At CRA:
Dave Hunt
Director, Planning and Technical Assistance Services
CRA, Inc.
4401 Ford Avenue, Suite 600
Alexandria, VA 22302
(703) 519-4510
dhunt@cra-usa.net

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Executive Summary

On Monday, October 3, 2011, the National Defense University (NDU) hosted a roundtable exercise on the topic of severe space weather threats posed to the US electrical grid and other related impacts to critical infrastructures. This event was held in conjunction with the US Congressional Electromagnetic Pulse (EMP) Caucus. Selected subject-matter experts provided an overview on the nature of the threat. Participants included representatives from the Federal, State, and Local government sectors in addition to private industry representatives. The day's events closed with an address by Congressman Roscoe Bartlett, co-chair of the EMP Caucus.

Primary Areas of Strength

The participants accomplished the following actions:

- Discussed the direct and cascading impacts of a catastrophic geomagnetic (GM) storm.
- Confirmed that leadership from government agencies and the private sector are aware of this threat and working to identify real solutions. There are several accredited scientific studies published on the topic that can serve as valuable resources. Interest in the topic is growing rapidly and new constituency groups (i.e. Infragard) are becoming involved.
- Acknowledged that expanding technological advances and systems related to the electric grid are assets but that each new system means another interdependency that must be factored into modern emergency management preparedness.

Primary Areas for Improvement

The participants identified the following areas for improvement:

- Discussed the need to increase public awareness and messaging about the threat of a catastrophic GM storm without triggering public panic. This need includes improved warning systems and further discussion of options to prevent damage to infrastructure.
- Discussed the need to harden the grid, including which technologies could be implemented.
- Defined the Federal government's role, including the Department of Defense, in assisting communities' recovery from a catastrophic GM storm.
- Identified numerous gaps in planning such as ensuring employees, especially police and emergency response personnel, can and will report to work.
- Discussed the need for continued research and development efforts (i.e. modeling) to further identify risks and planning needs.

Section 1: Exercise Overview

Exercise Details

Exercise Name
Severe Space Weather Threats: National Electrical Grid and Impacts to Critical Infrastructures

Exercise Type
Discussion – Roundtable Exercise

Location
Lincoln Hall, Room 1105
National Defense University
Fort Lesley J. McNair
300 5th Avenue SW
Washington, DC 20319-5066

Exercise Planning Team

- Dr. Richard Andres, National Defense University
- Dr. Alenka Brown, National Defense University
- Micah Loudermilk, National Defense University
- Chuck Manto, Instant Access Networks, LLC
- Tony Shaffer, Center for Advanced Defense Studies
- Sallie Taylor, Congressman Roscoe Bartlett's Office
- Drew Nishiyama, Congressman Trent Franks' Office

Exercise Support Team

- Dave Hunt, CRA, Inc.
- Maari Hanson, CRA, Inc.
- Boglarka Freije, CRA, Inc.

Participating Organizations

- Advanced Fusion Systems, LLC
- American Radio Relay League
- Center for Advanced Defense Studies
- CenterPoint Energy
- City of Chicago Police Department
- Congressional Research Service
- CRA, Inc.
- EMPact America
- Emprimus
- Federal Bureau of Investigation (FBI)
- First Energy Corp.
- FriiPwr USA, Ltd.

- Illinois Emergency Management Agency
- InfraGard
- James Madison University
- Maryland Fire Chiefs Association
- National Aeronautics and Space Administration (NASA)
- National Defense University (NDU)
- National Governors Association
- Stored Energy Systems (SENS)
- Storm Analysis Consultants
- The Clarion Fund
- ThoughtQuest, LLC
- University of Maryland
- U.S. Army War College
- U.S. House of Representatives

Section 2: Exercise Design Summary

Exercise Purpose and Design

The Exercise Planning Team created the NDU Roundtable Exercise to provide a forum to discuss the impact a geomagnetic storm similar in intensity to the 1859 Carrington Event would have on the US power grid and modern critical infrastructures.

The Exercise Support Team created documentation that focused on the: 1) national grid; 2) impacts on critical infrastructures and the inter-relationships between various systems at the Local, State, and Federal levels; 3) social impacts; and 4) policies that exist today to mitigate or minimize damage.

The Exercise Planning Team selected subject-matter experts to provide background information briefs to ensure all participants possessed an understanding of the threat environment.

The discussion at the Roundtable focused on the cascading and catastrophic failures via a massive E3 electromagnetic pulse (EMP) event caused by a severe solar storm. Based on the catastrophic impacts, the Roundtable discussed implications of the nation's ability to respond to such events involving utilities, industries, national policy, extended recovery time, and related resiliency steps that can be implemented by individuals as well as Local, State, and Federal government agencies.

Exercise Objectives

1. Identify implications of long-term infrastructure outages with the goal of discovering ways to mitigate and improve recovery time from such events.

2. Promote public-private resiliency efforts to protect the electrical grid and critical infrastructure that can be implemented on the Federal, State, Local, and individual levels.

3. Discuss the recovery timeframe from a catastrophic GM storm.

4. Discuss policies that exist today to assist in recovery time.

5. Identify processes and plans in place to improve recovery time.

Scenario Summary

This roundtable exercise featured two modules. Module One depicted a severe geomagnetic storm causing a near complete collapse of the nation's bulk power grid and failure of many extra high voltage transformers. Module Two presented preparedness mitigation of cascading and catastrophic failures of a severe space weather EMP event similar to the magnitude of Module One. In Module Two, the power supplies for the nation's 100 most critical military installations, as well as the population centers located in proximity to those installations, are protected from total failure due to a severe space weather event.

An overview of Module One and Two is provided below.

Module One

On September 26-27, 2011, an extremely large and complex sunspot cluster emerges on the sun. Several major solar flares erupt from this sunspot group from September 27-30, 2011. On October 2, 2011, the National Oceanic and Atmospheric Association (NOAA) Space Weather Prediction Center (SWPC) in Boulder, Colorado detects another massive sunspot cluster. Shortly thereafter, a large solar flare is observed with an associated coronal mass ejection (CME) whose plasma, gas, and magnetic fields appear to be directed at the Earth.

Within minutes, the Earth experiences a strong R5 radio blackout from X-rays emitted by the storm, affecting satellites, GPS transmissions, and most radio and television signals around the world. SWPC scientists begin modeling the effects of this CME, trying to predict when the other components of the geomagnetic storm will hit the Earth, and what potential they may have to damage the power grid.

As further information comes in, the SWPC model indicates the CME is moving directly toward the Earth at a high rate of speed and is estimated to hit the Earth in 20 hours. NOAA issues a G5 Geomagnetic Storm Warning, indicating that the storm has the potential to disrupt the bulk power grid, inducing high voltages that can cause protective system problems, damage extra high voltage transformers (voltages above 345 kilovolts), and sensitive control circuitry within various critical and non-critical systems. A NOAA spokesperson compares this event to the 1859 Carrington Event in scope, calling it a "Space Weather Katrina."

Within 24 hours of the storm, there are outages across large portions of the U.S. Over 300 high-voltage transformers are out of service. Not every area of the U.S. is affected equally however, and some regions, especially in the Texas Interconnect, escape severe damage, but over 70% of the nation has lost power. Generators provide backup power to critical facilities for at least 72 hours, though many vital utilities, including water and telecommunications, are down.

One week after the storm, a small number of high-voltage transformers are in service nationwide and utilities have managed to repair some units. Most backup generators have failed due to lack of fuel and local governments are rationing remaining stocks to critical facilities such as hospitals and government communications. Some jurisdictions are still supplying police, fire, and ambulance services, though many are beginning to encounter fuel, food, and supplies issues for the crews. Some micro-grid communities and families are generating their own power.

30 days after the storm, power systems are slowly coming back online. Estimates are that the Western Interconnect has 10% of power online, the Eastern Interconnect has 25%, and the Texas Interconnect is 70% operational. Sparse food distribution and shortages of fuel have made it difficult for people to get to work, even those working in critical industries.

Over the next few months, the country realizes that based on the shortage of replacement transformers, full restoration of the grid will be measured in years, not months. This complicates the mission to keep fuel and food flowing and to sustain the economy. Partial restoration in areas of the country may be possible. Some islands of power exist, and some renewable sources not connected to the grid are generating limited localized supplies. Many have died and complete recovery will take years.

Module Two

Recent 2011 legislation has established new standards and measures to prepare the United States for an EMP event resulting from geomagnetic storms, nuclear blasts, or radiofrequency weapons. One hundred select military installations have been hardened with features that protect their infrastructure from EMP damage. Additionally, the electric grid that serves these 100 bases has been hardened to assure that consistent electrical supply can be maintained at these locations. This effort means that over 250 EHV transformers of the national bulk power system have been protected. The metropolitan areas located near these selected bases and major transformers have some protection given their proximity and shared electrical infrastructure.

Independently, several cities and private institutions across the nation have also started building EMP-hardened, renewable energy sources that are locally produced and managed. Of the dozen locations that have made these upgrades, most believe that 15% of their energy sources would be available following a severe solar event.

From April 12-14, 2012, NASA and NOAA alert the national authorities of a significant increase in solar activity. Some government leaders see the potential threat as an opportunity to test their protected electrical equipment, but others deem the predictions a serious threat and begin to disseminate public notifications for citizens to stock up on critical supplies such as medications and fuel. These mixed messages lead to rampant speculation by the public and supplies fly off the shelves as people prepare for the worst. The stock market plunges in response to public perception and emergency services prepare for increased activity.

On Wednesday, April 18, 2012, an intense geomagnetic storm begins and lasts over 24 hours. A massive power fluctuation affects the transmission grid; however, the electric grid surrounding the 100 bases does not collapse and the protected transformers remain operational. Despite these remaining resources, other significant portions of the national grid are damaged due to transformer failures. The hardened resources of the selected areas have caused the massive GIC to affect non-protected areas more severely.

Large portions of the population attempt to relocate to areas where electric power is available.

Areas exist in all three Interconnections, with the most prominent states being California, Nevada, Washington, Virginia, New York, Texas and Florida. The mass exodus to these locations causes gridlock and overburdening of services around protected bases. Major national and international long-haul communication network trunks have become inoperable due to failure of fiber-optic repeaters impeding telephone and internet access. Millions of Americans try to get in contact with loved ones. Public officials and emergency managers are struggling to find ways to communicate information to the public. Industries including banking, finance, and commerce have severely limited capabilities. Isolated instances of riots and looting in major cities break out. The Army and National Guard are able to provide resources on the ground to control the situation.

Section 3: Analysis of Capabilities

This section of the report summarizes the areas of strength and areas for improvement that were identified during the course of the roundtable exercise. The analysis includes related observations and recommendations.

Areas of Strength

Area of Strength: The participants discussed the direct and cascading impacts of a catastrophic geomagnetic (GM) storm.

Analysis: The participants were presented with information from several subject-matter experts. The speakers included Dr. George Baker, who served as a senior staff member on the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP Commission) and John Kappenman, who served as a principal investigator for the EMP Commission. Mr. Kappenman and his research were featured prominently in the 2008 U.S. National Academy of Sciences Report on Severe Space Weather Events—Understanding Societal and Economic Impacts. From these presentations, the group was able to discuss the known and unknown impacts of catastrophic space weather. The most important items of discussion included noting that Carrington-scale solar flares happen on a regular occurrence; they are not rare events. However, it is rare for them to have all the necessary features to severely affect the Earth's magnetic field.

Recommendations:

1. Continue to introduce multijurisdictional groups to the expert knowledge and research of subject-matter experts regarding catastrophic GM storms.

Area of Strength: The participants confirmed that leaders in government agencies and private industry are aware of the threat and are working to identify real solutions. There are several accredited scientific studies published on the topic that can serve as valuable resources. More interest in the topic is being generated every day and new constituency groups (i.e. InfraGard) are becoming engaged.

Analysis: As referenced in the above analysis, there is a wealth of expertise on the subject of catastrophic space weather threats. This roundtable exercise was held in conjunction with the Maryland Emergency Management Agency (MEMA) EMP Planning Workshop on October 4, 2011. As more jurisdictions, agencies, and special interest groups take the time to seriously discuss the threat, more interest will be generated and better emergency management planning measures can be identified and implemented.

Recommendations:

1. Overall, it was apparent from the roundtable exercise discussion that planning is essential for preparedness, and this type of hazard needs to be incorporated into the

all-hazards approach. It is recommended that this threat be featured in future exercise and training scenarios.

Area of Strength: The participants acknowledged that expanding technological advances and systems are an asset but that each new system can mean another interdependency that must be factored into modern emergency management preparedness.

Analysis: The participants discussed how the world of today is one of technology, reliant on electronic systems. If a catastrophic space weather event knocks out the electric grid or satellite and GPS communications, numerous critical infrastructures will be compromised. Each connection between systems could become a self-reinforcing failure. For example, if there is no power, then communication systems (i.e., phones, high-frequency transmissions, and the internet) would eventually be compromised. The participants identified the following key questions: How will jurisdictions communicate their needs to FEMA if all systems are down? How will the public be notified about what happened, why there is no power, what to expect next, and where to go?

Recommendations:

1. When new technologies are added to systems, their interdependencies need to be tested and vulnerabilities identified.

Areas for Improvement

Area for Improvement: The participants discussed the need to increase public awareness and messaging about the threat of a catastrophic GM storm without triggering public panic. This need includes improved warning systems and further discussion of options to prevent damage to infrastructure.

Analysis: From the discussion, it is apparent that the public needs to be educated on this threat and the current alert system/classifications. NOAA's SWPC releases alerts on impending space weather and they do a very good job of monitoring and analyzing the threats. There are occurrences of severe phenomenon on a regular basis. In most cases, these early forecasts/warnings are non-threatening (i.e. flares are not heading straight to Earth or have little to no impact), which raises the issue of how to recognize when emergency managers should take action. The reality is that there will be a number of false alarms. However, these early warnings can be viewed as opportunities to practice response operations for when a catastrophic space weather event actually occurs.

Recommendations:

1. Continue the conversation between emergency managers and space weather experts (NOAA's SWPC) to promote a better understanding of the warnings, the appropriate response to the warnings, and public education.
2. Any new policy regarding space weather should contain guidance on providing public

education about the threat.

Area for Improvement: The participants discussed the need to harden the grid, including which technologies could be implemented.

Analysis: Some participants conjectured that 50-70% of the grid could be fully operational within days after a GM storm, depending on the extent of transformer damage. If part of the grid is operational, then power can be redistributed to local systems. Once that redistribution occurs, customers can be prioritized. Given sufficient warning, some participants suggested that the necessary resources/procedures could be implemented before irreversible damage is done to the grid. Others believe it would be a mistake to depend on islands of power to restore the grid to full operational capacity (or serve the entire country's needs). Either way, there are considerable issues of planning and cost that remain to be resolved.

Recommendations:

1. The key parties need to reach an agreement on how to best protect the grid. Experts agree that any protective measures that can be taken should be taken because the threat is significant.

Area for Improvement: The participants identified the need to define the Federal government's role, including the Department of Defense, in assisting communities' recovery from a catastrophic geomagnetic storm.

Analysis: Throughout the day, participants spoke of the need to have clearly defined roles for Federal agencies during a catastrophic GM storm. Some participants agreed that the Department of Defense may be the best equipped agency to lead the country in a national action plan. In particular, DOD may have the best assets/capabilities to develop and test plans and procedures for responding to national, regional, and localized disasters due to a worst-case space weather scenario. Many participants agreed that the DOD procurement system is superior to the DHS system and that this could be an advantage in advancing this cause. DOD is certainly aware of the threat and is working to resolve its specific role and responsibilities during a catastrophic GM storm.

Recommendations:

1. Encourage collaboration among private and public partners to identify clear roles and responsibilities of the Federal government, including the Department of Defense.

Area for Improvement: The participants identified numerous gaps in planning, such as ensuring employees can and will report to work.

Analysis: One participant asked if under this scenario it is assumed that emergency response teams and other personnel are able to get to posts to work critical functions. The speakers confirmed that yes, it is an assumption but unfortunately there is no modeling on how to get personnel to their work stations in the event of a GM storm (considering that

traffic lights and public transit would be experiencing disruptions, among other problems). Beyond getting people to work, how do they stay sustained? What about their basic needs of food and water? What about their concerns for family members? The group believed that it is probable that civil servants (police, fire, EMS) may not be available as they would prioritize the safety of their family and loved ones before reporting to work stations and in many cases live well outside the jurisdictions they serve, and may not be able to even reach work.

Recommendations:

1. Continue to work with multi-disciplinary groups to identify these gaps and propose solutions. Extensive personal and public/corporate preparedness efforts and public education may help to relieve some of these challenges. If the public is aware of the nature of geomagnetic storms, they will be better able to prepare for an event.

Area for Improvement: **The participants discussed the need for continued research and development efforts (i.e. modeling) to further identify risks and planning needs.**

Analysis: The participants had questions for each of the subject-matter experts present at the exercise and most questions were answered in full. However, there are some factors that are still unknown. Continued research and development of solutions (either documenting best practices for individuals/communities or developing the infrastructure to harden vulnerable assets) is a necessary next step. This includes robust models for 2nd & 3rd order effects on societal interactions. Beyond that, more time, energy, and funding should be devoted to the matters of policy. As discussed, this will be an all-of-nation challenge and requires collaborative solutions. Concern was expressed by some participants that a call for more research would likely delay implementation of potential grid protection measures.

Recommendations:

1. Promote funding for research and development studies into emergency planning and critical infrastructure protection relating to GM storms.

Appendix A: Participant Feedback Summary

Following the conduct of the NDU Roundtable Exercise, participants were asked to complete a participant feedback form. This form was designed to assess participants' experiences and attitudes about various aspects of the exercise. A blank copy of the form is provided on the following pages.

"Part I" of the feedback form presented three statements which asked participants to list top issues, their respective action steps and priorities, and any policies, plans or procedures that should be reviewed.

Common recommendations from Part I included determining the extent of the threat, determining the effects of the threat, and determining appropriate actions, including consideration of the potential downside effects of proposed remedial measures/actions.

"Part II" of the feedback form was comprised of statements about which participants were asked to rate their agreement on a scale of **1** to **5**, in which **1** indicated "Strongly Disagree," **3** indicated "Neutral," and **5** indicated "Strongly Agree."

As evident from Table 1, the participants were pleased with the exercise organization, scenario, and materials. In continuing this conversation, the next step could be to provide a different type of exercise with different range of invited participants.

Table A.1: *Average Ratings from Participant Feedback Forms*

a. The exercise was organized.	5
b. The exercise scenario was plausible and realistic.	4
c. The controller(s) was knowledgeable about the material, kept the exercise on target, and was sensitive to group dynamics.	5
d. The documentation used during the exercise was a valuable tool throughout the exercise.	4.7
e. Participation in the exercise was appropriate for someone in my position.	5
f. The participants included the right people in terms of level and mix of disciplines.	3.7
g. After this discussion, I believe my agency/jurisdiction is better prepared to deal successfully with the scenario that was exercised.	3.7

PARTICIPANT FEEDBACK FORM

Participant Name: _____ **Title:** _____

Agency: _____ **Role:** ____ Participant ____ Observer

Part I – Recommendations and Action Steps

1. **Based on discussions today and the tasks identified, list the top 3 issues and/or areas that need improvement.**

_____
_____
_____
_____

2. **Identify the action steps that should be taken to address the issues identified above. For each action step, indicate if it is a high, medium, or low priority.**

_____
_____
_____
_____

3. **List the policies, plans, and procedures that should be reviewed, revised, or developed. Indicate the priority level for each.**

_____
_____
_____
_____

Additional Comments:

_____
_____
_____
_____
_____

Part II – Discussion Design and Conduct

1. What is your assessment of the discussion design and conduct?

*Please rate, on a scale of 1 to 5, your overall assessment of the exercise relative to the statements provided below, with **1** indicating **strong disagreement** with the statement and **5** indicating **strong agreement.***

		Rating of Satisfaction with Exercise				
	Assessment Factor	*Strongly Disagree*				*Strongly Agree*
a.	The event was well structured and organized.	1	2	3	4	5

	Assessment Factor	Rating of Satisfaction with Exercise *Strongly Disagree*				*Strongly Agree*
b.	The scenario was plausible and realistic.	1	2	3	4	5
c.	The facilitator(s) was knowledgeable about the material, kept the exercise on target, and was sensitive to group dynamics.	1	2	3	4	5
d.	The documentation provided to assist in preparing for and participating in the exercise was useful.	1	2	3	4	5
e.	Participation in the event was appropriate for someone in my position.	1	2	3	4	5
f.	This exercise allowed my agency/jurisdiction to practice and improve priority capabilities.	1	2	3	4	5
g.	After this discussion, I believe my agency/jurisdiction is better prepared to deal successfully with the scenario that was exercised.	1	2	3	4	5

2. Further Questions/Discussion.

Please provide any follow up questions or comments that you have after participating in this discussion.

Appendix B: Acronyms

Table B.1: *Acronyms*

Acronym	Definition
AAR	After Action Report
CME	Coronal Mass Ejection
DHS	U.S. Department of Homeland Security
DOD	U.S. Department of Defense
EMP	Electromagnetic Pulse
EMS	Emergency Medical Services
EOC	Emergency Operations Center
EOP	Emergency Operations Plans
FBI	Federal Bureau of Investigation
FEMA	Federal Emergency Management Agency
GIC	Geomagnetically-Induced Current
GM	Geomagnetic
GPS	Global Positioning System
NASA	National Aeronautics and Space Administration
NDU	National Defense University
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Association
POC	Point of Contact
SENS	Stored Energy Systems
SITMAN	Situation Manual
SME	Subject Matter Expert
SWPC	Space Weather Prediction Center