S. Hrg. 116–78

PERSPECTIVES ON PROTECTING THE ELECTRIC GRID FROM AN ELECTROMAGNETIC PULSE OR GEOMAGNETIC DISTURBANCE

ROUNDTABLE

BEFORE THE

COMMITTEE ON HOMELAND SECURITY AND GOVERNMENTAL AFFAIRS UNITED STATES SENATE

ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

FEBRUARY 27, 2019

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ROUNDTABLE PERSPECTIVES ON PROTECTING THE ELECTRIC GRID FROM AN ELECTROMAGNETIC PULSE OR GEOMAGNETIC DISTURBANCE

WEDNESDAY, FEBRUARY 27, 2019

U.S. SENATE,
COMMITTEE ON HOMELAND SECURITY
AND GOVERNMENTAL AFFAIRS,
Washington, DC.

The Committee met, pursuant to notice, at 2:31 p.m., in room SD–106, Dirksen Senate Office Building, Hon. Ron Johnson, Chairman of the Committee, presiding.

Present: Senators Johnson, Peters, Hassan, Harris, and Rosen.

Also present: Senator Toomey.

OPENING STATEMENT OF CHAIRMAN JOHNSON

Chairman JOHNSON. Good afternoon. I guess I will gavel in the roundtable.

First of all, thank you all for taking the time to come to participate in this roundtable, for your thoughtful testimony. I have read all of it. I have read some of it a couple of times.

I reached out to a couple of you, as well, trying to do some summaries.

Because we have so many participants—normally, we would offer about 5 minutes' worth of opening statements, but what I think we want to do is keep it to 2 minutes. So be thinking right now about the top priorities of the points you wanted to make in this roundtable, and then I told my staff to keep my time open. I know one participant is going to have to catch a flight, but I am going to sit here until my questions are answered, until my curiosity is satiated.

I would ask that my written statement be entered in the record.[1]

The only point I want to make is I have been working on this issue now for probably 6 years, and the level of frustration is hard to describe.

The threats I believe this Nation faces with any kind of high-altitude nuclear explosion causing electromagnetic pulse (EMP) or a high-intensity solar storm in terms of geomagnetic disturbances (GMD) and the threat that poses to our infrastructure and literally our very way of life, it is just hard to overstate.

[1] The prepared statement of Senator Johnson appears in the Appendix on page 45.

I think, certainly, before I really started delving into this, I was like most Americans, either largely unaware or I heard about this and go, oh, it is just science fiction. That would never happen. We are not going to see Mad Max and Thunderdome, OK?

The frustration is there is such a broad spectrum of opinion here. I am not an electrical engineer. I am not a technical expert on this. I am an accountant. I am a business guy, but I have had that process of solving problems, which is gathering information, doing root-cause analysis, properly defining the problem, trying to establish achievable goals. What drives me nuts about this is nobody agrees on the information. You have really smart people, and there is a broad spectrum.

So what I find interesting about this roundtable is I think we have some really good testimony. I think we can zero in on some action items so that we can hopefully establish some achievable goals.

By the way, I am talking about actionable achievable goals. We have for far too long talked about developing a strategy, to develop a strategy, to develop a plan. "Let us do more research," and then we just elongate the time period before we actually start doing something concrete to start mitigating what could be a horrific catastrophe. I never want to be sitting here in the dark saying, "I told you so." I want to start taking action as quickly as possible.

I want to thank Senator Peters and Senator Rosen for showing up; I thank Senator Toomey, not on our Committee. I want to thank Senator Murkowski. Most of the law that we would have to write would probably come under her jurisdiction, so I hope her staff is here.

We have to work together collaboratively on this thing. We have to find the areas of agreement to address what again would just be a cataclysmic-type event, either space weather or the growing threats from some of these rogue States that have probably the capability of detonating something that could cause a lot of harm.

So, with that, I will turn it over to Senator Peters before we let all of you go through, and we will just go around the table, ask you to state your name, what is the organization that you are representing, and then just kind of hit your high points. Then it is going to be a free-for-all. We are not going to do this normally, where it is 7 minutes or whatever, because otherwise it becomes too disjointed. I want to be able to follow a line of questioning, the points being made in somewhat logical order.

With that, Senator Peters.

OPENING STATEMENT OF SENATOR PETERS[1]

Senator PETERS. Well, thank you, Chairman Johnson. I will be brief as well so we can get to hearing the testimony here.

I could not agree more with Chairman Johnson that this is a topic that we need to explore.

I have been focused on one aspect of that, which are the GMDs, which if you look at whether or not we have an EMP or a GMD event, the one thing about GMD, I think it is not a question of if. It is just when. We know that they have occurred. We know that

[1] The prepared statement of Senator Peters appears in the Appendix on page 47.

they have been significant in the past. They existed before we were all interconnected in the Internet and with elaborate grids.

If we have another event like Carrington in the 1850s, it will be much different today than it was back then. I know Dr. Kasper will be talking about that. I have worked with Dr. Kasper on this issue for a while, and my friends at the University of Michigan in the Heliophysics Department and others have been big advocates for doing something and actually having action. That we cannot just sit back and not look at this. This is something that will come eventually, and it could be absolutely catastrophic if we are not prepared for that.

In order for us to move forward, though, we have to get everybody on the same page. We have to make sure we all agree on what the facts are and we all agree on the risks associated with GMD events or other events, and that we can write some meaningful legislation.

I did write legislation in the past, the Space Weather Research and Forecasting Act. That has now passed the Senate twice, which is great. It has not passed the House, unfortunately. In this place, you need to have both, and we are hoping that what we get out of this hearing will give us some further momentum to get that Act first. Certainly, that bill is not the end-all, but it gets us on a track where we can start coordinating activities between all of the various government agencies and making sure that data is being provided to those who need to see the data as a result of solar activity.

It is a meaningful step forward, but we have to do a whole lot more. But in order to get there, the opinions and the facts and the counsel that we get from all of you here is going to be absolutely critical.

Thank you for being here today. I look forward to a good discussion.

Chairman JOHNSON. We will start with Karen Evans. She currently serves as the Assistant Secretary for the Office of Cybersecurity, Energy Security, and Emergency Response (CESER) at the U.S. Department of Energy (DOE).

We have a little 2-minute timer and just trying——

Ms. EVANS. I am ready.

Chairman JOHNSON. Pardon? You are ready, OK. I have the gavel.

TESTIMONY OF HON. KAREN EVANS,[1] ASSISTANT SECRETARY, CYBERSECURITY, ENERGY SECURITY, AND EMERGENCY RESPONSE, U.S. DEPARTMENT OF ENERGY

Ms. EVANS. OK. Thank you, Chairman and Ranking Member Peters, and Members of the Committee. I appreciate the opportunity to discuss the risks posed.

DOE's role in addressing energy sector risks and energy sector security is well established. From the Department's role in nuclear security through the National Nuclear Security Administration (NNSA) to the ground-breaking grid modernization research at our National Laboratories, DOE has the expertise and the relationships

[1] The prepared statement of Ms. Evans appears in the Appendix on page 50.

to support the energy sector and to help protect its critical infrastructure in coordination with the Department.

I would like to highlight just a few of our ongoing projects in this area, which include improving unclassified E3 waveforms, code and databases, to be able to share EMP effects with our partners; enhancing the Nation's EMP and GMD capabilities through the Center for EMP and GMD Simulation, Modeling, Analysis, Research, and Testing (CE–SMART); implementing a pilot project to field deploy and evaluate technologies to mitigate the effects of GMD and the E3 from the EMP on the electric grid.

We also plan to develop a hardening and resilience road map this year, specifying what we can and should be doing, working with our industry partners with available resources to deploy technologies to protect critical components, equipment, and systems on the electric grid from EMP and GMD effects and impacts.

DOE is fully committed to help forging the grid of the future that will be more resilient to all hazards, including EMP and GMD. Continued progress in the grid modernization is vital to help us protect the grid from these impacts.

I appreciate the opportunity to be here with the Committee to discuss the effects of this and participate in the roundtable, and I applaud your leadership in this area.

Chairman JOHNSON. Thank you, Ms. Evans. You have set a good example for everybody else. [Laughter.]

The next witness is Brian Harrell. He currently serves as the Assistant Director of the Infrastructure Security Division at the U.S. Department of Homeland Security (DHS). Mr. Harrell.

TESTIMONY OF BRIAN HARRELL,[1] ASSISTANT DIRECTOR, INFRASTRUCTURE SECURITY DIVISION, U.S. DEPARTMENT OF HOMELAND SECURITY

Mr. HARRELL. Chairman Johnson, Ranking Member Peters, and Members of the Committee, good afternoon, and thank you for the opportunity to discuss the Department of Homeland Security's ongoing efforts to secure our Nation's critical infrastructure against threats from electromagnetic pulse and geomagnetic disturbances.

As a short introduction, I am the Assistant Director for Infrastructure Security within the Cybersecurity and Infrastructure Agency within DHS.

I want to thank you all for your leadership in passing the Cybersecurity and Infrastructure Security Agency (CISA) Act of 2018.

I appreciate the interest of this Committee on getting to the facts regarding threats from EMP and GMD.

While I am new to my current role, I previously served as the Managing Director of Enterprise Security at Duke Energy. I am also the former Director of Critical Infrastructure Protection at the North American Electric Reliability Corporation. I am very familiar with the risk management conversation we are discussing today.

The effects of nuclear EMP and GMD on critical infrastructure are related, but the threat space is very different and should be discussed separately.

[1] The prepared statement of Mr. Harrell appears in the Appendix on page 55.

Regarding the threat landscape for nuclear EMP, work completed by the intelligence community (IC) and the nuclear weapons community provides specific and period assessment of the nuclear weapons capabilities of foreign countries, including the capabilities to generate an EMP.

The intelligence community currently has no specific, credible information indicating that there is an imminent threat to critical infrastructure from an EMP attack. However, the consequences of a successful nuclear EMP attack using a nuclear weapon detonated at high altitude are potentially severe and may include long-term damage to significant portions of the Nation's power grid and communications infrastructure.

Under the joint DHS–DOE funding, the United States nuclear weapons laboratories have completed a preliminary nuclear EMP impacts assessment on the Nation's electric power system. This study developed a spectrum of EMP attack scenarios and estimates of impacts. Although additional work is required, this study provides the basis for more advanced risk assessments in the electric sector and a framework for risk assessments in other sectors.

DHS, in collaboration with interagency partners, is working to provide owners and operators of critical infrastructure with the resulting information and frameworks to help them manage risks from electromagnetic events.

Regarding the threats landscape from GMD——

Chairman JOHNSON. Again, I have to discipline this. We have your written testimony. We can read that. I want to move on. You do not have to necessarily read these things, off the top of your head the subject matter. Give us the primary points of what you are coming here to testify about.

Our next participant will be Nathan Anderson. He is the Acting Director of the Homeland Security and Justice Team at the U.S. Government Accountability Office (GAO). Mr. Anderson.

TESTIMONY OF NATHAN ANDERSON,[1] ACTING DIRECTOR, HOMELAND SECURITY AND JUSTICE TEAM, U.S. GOVERNMENT ACCOUNTABILITY OFFICE

Mr. ANDERSON. Thank you, Chairman Johnson, Ranking Member Peters, Members of the Committee.

Since 2016, we have issued several reports reviewing Federal agency actions to address electromagnetic risks.

First, we found in 2016 that DHS, DOE, and the Federal Energy Regulatory Commission (FERC) had taken actions, such as establishing industry standards and Federal guidelines and completing EMP-related research. We found that their actions aligned with the some of the EMP Commission recommendations.

We also found that opportunities existed to enhance Federal efforts to coordinate and address electromagnetic risks to the grid and made several recommendations, most of which have been implemented.

Second, we reported that electricity suppliers had identified information on GMD and high-altitude electromagnetic pulse

[1] The prepared statement of Mr. Anderson appears in the Appendix on page 58.

(HEMP) effects on the grid, and most suppliers we interviewed had taken some steps to protect against GMD effects.

U.S. and Canadian suppliers have identified information on the potential effects of a severe GMD resulting from a solar storm, but have identified less information about the potential effects of HEMP events.

Suppliers we interviewed also described the range of costs incurred to protect against GMD and HEMP, which can range from minimal costs to 20 percent of such projects' costs.

We also reported on technologies that are available or in development that could help prevent or mitigate the effects of GMDs on the grid. They hold promise but are not ready for widespread operational deployment.

Finally, we found that efforts are under way to address the likelihood of a large-scale GMD, the risks such storms pose and potential mitigation measures, which will help inform whether additional actions are needed to prevent or mitigate the effects of GMDs on the grid.

Regarding EMP events, we found more research is needed to fully investigate and evaluate how an electric utility could protect itself from or mitigate the effects of EMP on its system.

This concludes my statement.

Chairman JOHNSON. Thank you, Mr. Anderson.

Our next participant is Joseph McClelland, who is the Director of the Office of Energy Infrastructure Security at the Federal Energy Regulatory Commission. Mr. McClelland.

TESTIMONY OF JOSEPH H. MCCLELLAND,[1] DIRECTOR, OFFICE OF ENERGY INFRASTRUCTURE SECURITY, FEDERAL ENERGY REGULATORY COMMISSION

Mr. MCCLELLAND. Thank you, Chairman Johnson and Ranking Member Peters, for your leadership and interest in this subject and with the invitation to this roundtable discussion today.

I am here today as a member of the Commission staff, and my remarks do not necessarily represent the views of the Commission or any individual Commissioners.

The Commission's authority to oversee the development of mandatory standards to protect the reliability of the bulk power system fall under the Federal Power Act. Under this authority, FERC cannot author or modify reliability standards but must depend upon an Electric Reliability Organization (ERO) to perform this task.

The Commission certified the North American Electric Reliability Corporation (NERC), as the ERO. The ERO develops and proposes new reliability standards or modifications to existing standards with industry for the Commission's review, which it can either approve or remand.

However, the consequences of a severe, naturally occurring event, or national security threat by entities intent on attacking the United States by exploiting its vulnerabilities in its electric grid or using physical or cyber means stands in stark contrast to major reliability events that have caused regional blackouts and reliability failures in the past.

[1] The prepared statement of Mr. McClelland appears in the Appendix on page 65.

Widespread disruption of electric service can undermine the security of the U.S. Government, its military, the economy, as well as endanger the health and safety of its citizens.

Given the national security dimension to this thread, it is imperative that action be taken quickly and effectively to protect America's infrastructure.

For these reasons, the Commission uses a dualfold approach, employing both mandatory standards to establish foundational practices, while also working collaboratively with industry, the States, and Federal agencies to identify from best practices to mitigate advanced threats.

Because EMP and GMD events pose a serious threat to the electric grid and its supporting infrastructure that serve our Nation, the Commission has found it necessary to use both standards and a collaborative approach to address these threats, as is detailed in my written testimony.

Thank you, and I look forward to our discussion.

Chairman JOHNSON. Thank you.

By the way, we do not have to restate the fact that this could be catastrophic. We have both said it twice. So focus in on new information, particularly your agency or the people you are representing, what are the main points.

Our next participant is Dr. George Baker. Dr. Baker is currently a professor emeritus at James Madison University. He previously served as the Senior Advisor to the former Commission to Assess the Threat to the United States from Eelectromagnetic Pulse Attack, which is normally called the EMP Commission. Dr. Baker.

TESTIMONY OF GEORGE BAKER, PH.D,[1] PROFESSOR EMERITUS, JAMES MADISON UNIVERSITY

Mr. BAKER. Again, thanks for this opportunity and for holding this roundtable. I think it is very important.

My watch word is "defense conservative." We need to be defense conservative in everything we do, and the problem I see, that is not happening.

I have a long list of recommended actions. I will go down these, and stop me in midcourse, if you want.

I have top-down recommendations, things that need to happen from the Federal level down and then bottom-up from the local, State level up.

I would say the most important recommendation of the Congressional EMP Commission was that we need an office of EMP coordination within the National Security Council (NSC), and I am told that is actually part of the Executive Order (EO) that should come out soon.

The FERC GMD standard, No. TPL–007–2, though its specified environments and systems thresholds are not defense conservative, it has at least brought industry attention to GMD. This standard, even if rigorously enforced, will leave the grid dangerously vulnerable to GMD and needs to be revised.

Without a corresponding FERC EMP directive, the private sector is not doing much of anything on the EMP front.

[1] The prepared statement of Dr. Baker appears in the Appendix on page 73.

New legislation is needed to empower FERC, specifically to be able to write and enforce grid protection standards and, second, to identify mechanisms, including cost recovery measures to incentivize the private sector.

A national EMP protection standard is needed. DHS is to be commended for issuing a coordination version of a protection standard, but that needs to become official and expanded to address not just communication centers, but the electric grid itself.

For more than half a century, the Department of Defense (DOD) has protected high-priority military command-and-control communication computer assets for nuclear deterrence. DHS and DOE programs need to emulate what DOD is doing, their methods.

We need to preclude the temptation to reinvent the wheel by giving DHS and DOE full access to the DOD standards and databases. There is no need to recalculate a standard EMP waveform.

Chairman JOHNSON. Listen, I understand that this is not easy to do, OK? I apologize for that, but I really wanted to get into the discussion phase as quickly as possible.

Mr. BAKER. OK.

Chairman JOHNSON. What I will say about Dr. Baker's testimony is that I did call him. Was it yesterday or 2 days ago? Because reading through his testimony, I saw what I have not seen in about 6 years of doing this—actual action items.

I asked him to prioritize that. He was going through that list. I would kind of like to use that list. You have all got the testimony, correct? OK. Do you have that priority list of Dr. Baker?

I would suggest as we continue this discussion—again, we will go through all the opening statements, but when we turn to questions, I would recommend to the Senators and I would also recommend to the panelists to take a look at that priority list because it is actual action items, the things that we should be doing from a top-down approach, what the Federal Government has to do, versus a bottom-up approach, local utilities, local governments, that type of thing.

Again, I thought it was just very well organized, and I think it is a good way for us to organize our discussion, around basically the action items that Dr. Baker put in his testimony.

Again, I apologize for cutting you off, but we will get to these lists and I think in good detail.

What I want to ferret out from this is, What do we agree on? Where is there a dispute? What maybe does not industry agree with versus what does government agree on? I want to get this out, fleshed out, so we can actually move forward with some real action items.

Having said that, our next participant is Scott Aaronson. He is Vice President for Security and Preparedness at Edison Electric Institute (EEI). Mr. Aaronson.

TESTIMONY OF SCOTT AARONSON,[1] VICE PRESIDENT FOR SECURITY AND PREPAREDNESS, EDISON ELECTRIC INSTITUTE

Mr. AARONSON. Thank you, Chairman Johnson, Ranking Member Peters, and Members of the Committee. As you said, my name is Scott Aaronson, Vice President for Security and Preparedness at EEI.

EEI represents all of the Nation's investor-owned electric companies, and members operate in all 50 States and the District of Columbia and serve more than 70 percent of all electricity customers in the United States.

EEI appreciates your leadership in convening this roundtable, and I look forward to discussing the electric power industry's work to protect against both electromagnetic pulses and geomagnetic disturbances.

My written testimony goes into further detail about industry's efforts to address threats posed by EMPs, but for the purpose of open comments, I want to address three important themes.

First, we take all threats to our infrastructure seriously. Whether preparing for natural hazards or malicious acts, EEI's members are committed to protecting the communities they served. Ensuring we provide a reliable product is our business. So we have every incentive to protect our systems.

Second, when it comes to issues of national security, the electric power industry recognizes its role in protecting the lives and safety of our customers. We also recognize that with intelligent adversaries and an evolving threat landscape, partnering with Federal, State, and local government is paramount.

In fact, the President's National Infrastructure Advisory Council (NIAC), called the Electricity Subsector Coordinating Council and the electric sector the "model for government-industry coordination." While we are exceedingly proud of that designation and working with our partners at DOE and DHS, we are also striving to improve the industry's preparedness against all hazards by leveraging both industry and government capabilities.

Finally, we agree that both EMP and GMD post threats to the reliability operation of the energy grid and therefore to the economic and national security of the Nation.

To the extent that policy changes are necessary, we look forward to working with all the committees of jurisdiction and our partners at DOE, DHS, DOD, FERC, and throughout the Federal Government.

But sound policy must be based on sound science, and it is for that reason that we appreciate the work of the Electric Power Research Institute (EPRI) and the North American Electric Reliability Corporation, which informs industry as we pursue the right investments and operating posture to appropriately protect the energy grid.

Thank you again for this opportunity. I look forward to the discussion.

Chairman JOHNSON. Thank you, Mr. Aaronson.

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[1] The prepared statement of Mr. Aaronson appears in the Appendix on page 85.

We will now turn to Randy Horton. He is the Senior Program Manager for Grid Operations and Planning at the Electric Power Research Industries. Mr. Horton.

TESTIMONY OF RANDY HORTON, PH.D.,[1] SENIOR PROGRAM MANAGER, GRID OPERATIONS AND PLANNING, ELECTRIC POWER RESEARCH INSTITUTE

Mr. HORTON. Chairman Johnson, Ranking Member Peters, and Members of the Committee, thank you for the opportunity to participate in today's hearing. My name is Randy Horton, and I am a senior program manager at the Electric Power Research Institute.

EPRI takes electromagnetic threats seriously and has conducted extensive research to improve understanding of the potential impacts that high-altitude EMP and GMD events can have on the electric grid.

As an example, EPRI launched a focus research effort in April 2016 to evaluate the potential impacts of a high-altitude EMP attack on the U.S. electric grid and to identify and test options for mitigating those potential impacts.

Currently, there are more than 60 U.S. utilities participating in this research project. Using various unclassified or bounding high-altitude EMP environments, including those provided by DOE and Los Alamos, we have evaluated the potential impacts of high-altitude EMP on the electric transition system.

Additionally, we have evaluated and tested several options for mitigating impacts that were identified.

A final report of this research, including assessment results and mitigation options, is expected to be made available on April 30th of this year.

A key to our success has been our close collaboration with subject-matter experts at the DOE, the three DOE weapons labs, and the Defense Threat Reduction Agency (DTRA). The sharing of knowledge and information that has occurred over a 3-year period has been very valuable to our research and also to the industry.

GMD is also concerned for the bulk power system, and over the last four decades, EPRI has been a leader in this area. We are currently performing research to improve industry's ability to predict and mitigate the potential impacts of a severe GMD event, and the results of this research may be used to inform future revisions of NERC GMD standards.

In closing, EPRI is committed to developing science-based solutions to these complex problems and will continue to offer technical leadership and support to the electricity sector, public, policymakers, and other stakeholders.

Thank you for your time. That concludes my testimony.

Chairman JOHNSON. Thank you, Mr. Horton.

Our next participant is David Roop. He is the Director for Electric Transmission Operations and Reliability at Dominion Energy. Mr. Roop.

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[1] The prepared statement of Mr. Horton appears in the Appendix on page 96.

TESTIMONY OF DAVID ROOP,[1] DIRECTOR, ELECTRIC TRANSMISSION OPERATIONS AND RELIABILITY, DOMINION ENERGY

Mr. ROOP. Good afternoon, Chairman Johnson, Ranking Member Peters, and Members of the Committee.

I am the director of Electric Transmission Operations and Reliability at Dominion Energy. My company very much appreciates the opportunity to participate in today's hearing.

Dominion Energy is headquartered in Richmond, Virginia, and provides electricity or natural gas to 7.5 million homes and businesses across 18 States. The service area for our regulated utility, Dominion Energy Virginia, is in close proximity to the District of Columbia, and it includes many vital national security and defense operations.

We also provide electricity to a large percentage of the Internet traffic in the world.

During my 43 years with Dominion Energy, my focus has been on electric transmission and substation operations. At Dominion Energy, we consider all hazards, manmade or acts of man as well as naturally occurring events, in both our planning and operations. Protecting our system for GMD and EMP is part of that mission.

Over many decades, we have hardened our substation components to better enable them to survive the impact of GMD events. This hardening has occurred as we upgrade or replace equipment at the end of a life.

Over the course of many years, Dominion Energy has made investments and developed contingency plans to improve the resiliency of our network that may confront it with EMP events.

Making these simple changes has also improved our day-to-day operations for challenges such as lightning and transients.

But we now come to a point that requires additional research to guide our future efforts to improve system resiliency for EMP events. This research is extremely important in helping us to make prudent investments. The tremendous support of our Federal partners has allowed us to get to the point we are today. This assistance has really improved our knowledge, and we are grateful for it. I ask the U.S. Government to continue this effort to get us across these next few research areas.

Thank you for the opportunity to be here today.

Chairman JOHNSON. Thank you, Mr. Roop.

Our next participant is James Vespalec.

Mr. Vespalec is the Director for Asset Planning and Engineering at the American Transmission Company (ATC) headquartered in Waukesha, Wisconsin. Mr. Vespalec.

[1] The prepared statement of Mr. Roop appears in the Appendix on page 108.

TESTIMONY OF JAMES VESPALEC,[1] DIRECTOR, ASSET PLANNING AND ENGINEERING, AMERICAN TRANSMISSION COMPANY

Mr. VESPALEC. Thank you. Thank you, Chairman Johnson, Ranking Member Peters, and Members of the Committee.

I am with American Transmission Company as was mentioned. We were formed in January 2001 as a transmission-only utility. We operate 9,600 miles of transmission lines and assets in about 560 substations in portions of Wisconsin, Michigan, Minnesota, and Illinois. We do not own generation, and we do not have load-serving customers. We serve other utilities that serve the load.

We have been active in many different industry organizations, such as EPRI and North American Transmission Forum (NATF) and others, where we monitor the research and follow the steps that are being taken in the industry, trying to identify prudent steps that we can take to mitigate these risks.

I think one of the reasons I am here, in 2015, ATC purchased the first commercially available transformer neutral-insertion device and installed in one of our substations. We found a substation that was ideal for that device, and we installed that prototype, which is meant to automatically protect the transformer from harmful geomagnetic-induced currents. To my knowledge, it is the only one currently installed and operational in the industry.

We set the threshold on it very low so that we could get a lot of operations on it and get some experience with it. So far, it has operated dozens of times and has performed as designed.

It is not meant to be done without forethought to just put one in. You need to do a little bit of thinking and studying of the transmission network so you can fully understand what the impacts might be.

We take many other steps, defense-in-depth approach, as highlighted in my statement, sharing information like we are doing today, and some of the research that is going on at EPRI are critical for tackling this issue and finding prudent effective decisions to make.

Chairman JOHNSON. Thank you.

Our next participant is Justin Kasper. Mr. Kasper is an Associate Professor of Space, Science, and Engineering at the University of Michigan. Mr. Kasper.

TESTIMONY OF JUSTIN KASPER, PH.D.,[2] ASSOCIATE PROFESSOR OF SPACE, SCIENCE, AND ENGINEERING, UNIVERSITY OF MICHIGAN

Mr. KASPER. Chairman Johnson, Ranking Member Peters, Members of the Committee. Thank you for this opportunity to discuss with you what we know about the solar origin of geomagnetic disturbances and how we can improve our ability to predict their occurrence.

The famous Carrington event of 1859 started with a visible flare on the Sun, and then 18 hours later, a magnetic tsunami engulfed Earth, sending compasses spinning, bringing the Northern Lights

[1] The prepared statement of Mr. Vespalec appears in the Appendix on page 117.
[2] The prepared statement of Mr. Kasper appears in the Appendix on page 119.

down to the Caribbean, making telegraph lines spark. We might not rely on a telegraph today, but our power lines are equally susceptible.

The risk from these events is real, and unfortunately, the Carrington event was not some unique event. On July 23, 2012, for instance, a spacecraft operating on the other side of the Sun was immersed in a similar eruption that would have hit Earth square on if it had happened just 9 days sooner.

Multiple researchers estimate the probability of a similar event happening in any one decade at between 3 and 10 percent.

Now, I would also like to stress in addition to these extreme events, smaller but more frequent GMD also have a significant cumulative impact. For example, commercial insurance claims for damage to electronics spike around 20 percent during periods of heightened geomagnetic activity. This translates to an average of $10 billion in damage each year in the United States so if we could address those major GMDs, we might also be able to protect ourself from those smaller events.

What can we do about this? Well, right now, telescopies detect an eruption at the Sun, and we make a forecast. We do not have any confirmation until it reaches the National Oceanic and Atmospheric Administration (NOAA) Deep Space Climate Observatory (DSCOVR) spacecraft. Now, any earning is better than none, but an extreme event would get from that spacecraft to Earth in less than 10 minutes, and this is not enough time to assess the risk and recommended action.

We need spacecraft closer to the Sun, providing earlier warning of Earth-directed events and their properties that are models of those eruptions and regional forecasts of GMDs. Most importantly, I think we need leadership with the authority to coordinate and direct the research and operational components of space weather that are spread now over multiple agencies.

Chairman JOHNSON. Thank you, Mr. Kasper.

Our final participant is Caitlin Durkovich. Ms. Durkovich is currently a Director at Toffler Associates and previously served as Assistant Secretary of Infrastructure Protection at the U.S. Department of Homeland Security. Ms. Durkovich.

STATEMENT OF CAITLIN DURKOVICH,[1] DIRECTOR, TOFFLER ASSOCIATES

Ms. DURKOVICH. Good afternoon, Chairman Johnson, Ranking Member Peters, and Members of the Committee. Thank you for inviting me to testify today on protecting the electric grid from an EMP or GMD, and thank you for your leadership on this issue.

In addition to having served as the Assistant Secretary for Infrastructure Protection, I also co-chaired the Space Weather Operations Research and Mitigation (SWORM), Task Force, which produced "The National Space Weather Strategy" and action plan in 2016.

There is no doubt the risk facing our critical infrastructure has grown. We are reliant on aging infrastructures that increasingly le-

[1] The prepared statement of Ms. Durkovich appears in the Appendix on page 124.

verage data and technology to enable more efficient, reliable, and distributed operations.

This highly interconnected, electrified, and digitized ecosystem is not only being used for purposes we never could have imagined when it was built a century ago, but it must be resilient to risks, as Senator Peters said, that we never could have imagined or fully appreciated 100 years ago.

What is encouraging is the partnership and coordination between government and industry, which owns most of our Nation's critical infrastructure. It has matured, and it is providing more visibility into emergent threat vectors and potential consequences guiding join action on risk mitigation.

The Electricity Subsector Coordinating Council (ESCC) is one such example. The SWORM Task Force is another. DHS's strategy for protecting and preparing the homeland against threats of EMP and GMD is another. The strategy's three goals are practical steps, the critical infrastructure community can coalesce around.

I do agree with DHS's assessment about the potential severity of both the direct and indirect impacts of an EMP or GMD incident and that it should compel our national attention.

One of the biggest challenges I believe we face is risk awareness and sustained focus on this hard problem. Lower probability, high-consequence threats are overshadowed by real-time threats that require 24/7 attention, such as cyberattacks.

I believe that we can take a page from hurricane preparedness to help improve action around this important issue, and I look forward to talking to you about it over the course of the next several hours.

Thank you very much, and I think we can get to the heart of the matter now.

Chairman JOHNSON. Let us get to it.

Normally, what ends up happening in these Senate types of hearings is we go down a list, and we each get 5 minutes to 7 minutes. That works fine, but we end up with a pretty disjointed conversation from my standpoint.

So what I want is a little bit more of a free-for-all. I expect Senators to be respectful of each other. We will chime in, but what I would like, because there is so many of you, if you want to chime in on a particular topic or question, just put your name tag up like that, and we will try and get to you sort of in the order that you have done that.

I would just quick-start out the line of questioning, getting back to what I was saying in my opening statement.

Do not take offense by this. I heard a number of you talk about we take this very seriously. OK, good. We have to. What have we done about it? We have known about this since—well, GMD, Carrington effect, in terms of high-altitude nuclear blasts since the early 1960s.

By the way, when I was interviewing General Kelly for Secretary of Homeland Security, I asked him about his understanding of the threat of EMP and does he take it seriously because we have had people on this Committee say it is hokum. I asked General Kelly. I said, "What is your evaluation of this? Is this going to be a top priority of you as a Secretary?" He said, "Well, Senator, I am not a technologist, but I do know in the Defense Department, we spent billions of dollars hardening our defense assets."

In part of Dr. Baker's testimony, it is that we have the military spec for this. We have known about this. We are not doing high-altitude nuclear tests. We do not have the specific information on current electronics, but we have standards now.

I want to start out with Mr. McClelland with FERC. FERC did establish a spec for GMD. Why did we not establish a spec for EMP?

According to Dr. Baker's testimony—I do not want to throw you under the bus, Dr. Baker, but the GMD spec is set at too low intensity, and we are assuming the survivability of these transformers and equipment is just too high.

Can you explain what happened with FERC? Because that is certainly one of the recommendations of Dr. Baker is we have to establish a higher standard for GMD and we have to establish standards for EMP or the industry will not do anything. I do not blame them because they have no direction.

But, please.

Mr. MCCLELLAND. To that point, we have been discussing this and been before panels multiple times, and we have said in the open—I know I have said it under testimony—that the NERC standards development process is a consensus-based process with industry. FERC cannot write or author the standards. It can conduct research, and it has done that.

So, in 2010, it, with DOE and DHS, sponsored extensive studies on GMD, EMP, and Intentional Electromagnetic Interference (IEMI) as a basis for further action. It then sua sponte or on its own motion directed NERC to develop a GMD standard. That was after there was significant contentious discussions between subject-matter experts and industry, and the argument went like this. If the grid collapses—first of all, FERC came out with a study with the Oak Ridge National Lab (ORNL), with DHS and DOE, and said that up to 368 bulk power system transformers would be damaged—could be damaged or destroyed after a significant GMD event.

There was a counter-study then performed by EPRI and DOE that asserted that the grid would collapse before that damage occurred. That is a great point.

We established in either case, it does not matter. Wholesale collapse of the power grid for days or a week or more would cost so much money and so much suffering that the standard was justified.

So FERC on its own motion ordered the standard to be developed. It gave guidelines to NERC. NERC developed the consensus process. FERC than approves it because it establishes a baseline. At least there is a baseline.

But when it approved these standards, subsequent standards from NERC, there were iterations. Three separate times when FERC approved the standard, it directed modifications to that standard, and that really goes back to the crux of the standards themselves.

What we have said openly is that for national security purposes—and this is part of the oral remarks and the written testimony—the standards development process is too slow. It takes years to develop a standard. It is too open. Our adversaries can read the standards and design around them as quickly as the standards are put into place, and it is not necessarily responsive to the Commission's directive.

The standard that we have is a result of industry consensus, and at least it is a basis. That is why FERC uses a dualfold approach and works with—I have known Dr. Baker for years, and we worked together on this issue. We use best practices collaborating with the Department of Energy, Department of Homeland Security, the intel community, and we do classified briefings with industry members to say, "You do not have to put this everywhere."

But for those most critical points—and if you remember our last hearing, we modeled those critical points and said here are the most critical points on the system where if you use best practices, it may be enough to dissuade adversarial action.

Chairman JOHNSON. OK. Somebody answer the question. You guys be willing to jump in here.

We already had specifications to harden our military assets. I believe in the "Keep it simple, stupid" (KISS) principle: Keep it simple. Why would we not just go to that?

Those things have been available for how long, Dr. Baker? How long have we been hardening our military assets against EMP and GMD?

Dr. Baker; We started in the 1960s with the Minuteman System. Our first EMP protection standard came out in 1992, I believe.

Chairman JOHNSON. We have had a standard that required no further research whatsoever to start hardening critical assets.

One of the parts of your testimony—and this is one of the reasons I have a fire under my you-know-what on this is we are now creating these microgrids that, according to your testimony, Dr. Baker, would cost 2 to 5 percent more to hit the military standard——

Mr. BAKER. Yes. And the GMD.

Chairman JOHNSON [continuing]. For protection?

Mr. BAKER. Right.

Chairman JOHNSON. But unless we have a top-down standard set by FERC and NERC or the Department of Energy, Department of Homeland Security, it will not happen, correct? I mean, you could ask industry about this.

Again, why would we not do that? Is there any reason not to do that? Is there any reason why Senator Murkowski's staff and her Energy Committee should not hop on this right away and pass a law that says this will be the standard? Particularly for microgrids because that is right now sort of the urgent problem.

Mr. BAKER. This is a watershed moment for microgrids. Yes.

Chairman JOHNSON. Go ahead, Mr. Horton.

Mr. HORTON. I know you are aware that our final report is not out, so I cannot go into a whole lot of detail, but your question is basically the initial question that we were answering as a part of our research is the mil standards—and to be specific, it would be the unclassified mil standards. Those exist. Could you go apply them to a utility?

One of the first things we did as a part of our research was, without knowing anything else, if you took the unclass. military standards and applied them to a substation, for example, in an electric grid, what would that look like? Through that process—and keep in mind that those standards—and I am speaking to the military standards—were never designed to hardened utility-type assets.

As we got into the details a little bit, a lot of it, you could use, but there were some things that if you were to use them, you could actually create potential issues.

I guess the basic answer to your question is when you take those standards and begin to apply them to utilities, the devil is in the details. So working out some of that is a research need, which we have done as a part of this research project.

Chairman JOHNSON. We have been doing this for—let us just go back, instead of the 1960s, to 2001, the first EMP Commission. So this is 18 years. The question I would ask what have—we have taken this seriously. What have we actually done other than literally admire the problem?

Mr. HORTON. As a part of our research, we have identified—I would prefer not to go into that today, but we have identified actions that utilities can do to harden against E1 EMP, for example, using nonmilitary——

Chairman JOHNSON. Issuing your report when?

Mr. HORTON. April 30th of this year, 2 months from now basically.

Chairman JOHNSON. OK. Good. Look forward to seeing it.

Senator PETERS. I do not want to get off track here, but I want to get back to the GMDs and the discussion.

Mr. McClelland, you mentioned that the standards are put in place for the industry now. My understanding, though, is that the standards are—assuming it is a Carrington-type event that we have talked about, it is a thousand-year event. Is that accurate? You are not really planning for that? That, basically, that type of event would overwhelm the grid?

Mr. MCCLELLAND. I do not know the specific tie-back to Carrington, but I can say that it does not consider a Carrington-type event. No, the standards would not do that.

Senator PETERS. Right. If we had a Carrington-type event, we would be in serious trouble because the standards do not do that.

Dr. Kasper, I think the industry thinks, or at least based on these standards, that this is like a thousand-year event. You mentioned in your testimony every decade, it could be up to a 10 percent chance. We missed one just a few years ago by 9 days. What does the science tell you?

Mr. KASPER. Well, I reviewed the standard, and I see the argument. It is largely based off of events like an event in 1989, which is well studied. One of the problems with the Carrington event is we did not have spacecraft back then, so we do not have enough data.

If you had asked me and my community 10 years ago, we would say maybe this is a one-in-a-thousand-year event, but since then, we have had more events.

In 2012, one of our spacecraft called Solar Terrestrial Relations Observatory (STEREO) intercepted a larger than Carrington, actually, we think, event heading away from the Sun, and it actually took a year or two to realize just how substantial that event was and really process it.

But we were clearly seeing it happening on a repeating basis. We know that they are happening, and we have spacecraft observations that tell us how strong the magnetic field is.

It would be wonderful to be able to model what that event would have done to Earth and use that as a basis for probably a more common large-scale event.

Chairman JOHNSON. Is there any scale we can compare? If that was a 10, what is the FERC specification? Are we hardened to a 3? Are we hardened to a 9? How far behind are we? Dr. Baker?

Mr. BAKER. There was a FERC Oak Ridge National Lab study that was based on a 1921—it is called the "Railroad Storm," which in the Earth magnetic field disturbance terms was a 5,000-nanotesla-per-minute storm.

The 1989 event, which is pretty close to what we have in the GMD standard, was a 500-nanotesla-per-minute storm.

Senator PETERS. Wow.

Mr. BAKER [continuing]. Nanotesla-per-minute, one-tenth of a 1921 storm, which was 100 years ago.

Chairman JOHNSON. The standard is set really low. Anybody want to dispute that? The GMD standard right now by FERC to NERC to industry is really low.

Mr. BAKER. It is not defense conservative.

Chairman JOHNSON. It would be nice to try and get it down to those types of terms so we can kind of describe this to people, but that is what we are trying to look for.

Senator PETERS. Does anybody dispute that, that they are very low?

Mr. HORTON. I would add maybe a technical detail. The March 1989 event—so we are talking nanoteslas. Another way to look at this is electric field levels. It is on the order of 2 volts per kilometer, and the benchmark TPL–7, 1-in-100-year event for the same geomagnetic latitude is 8 volts per kilometer. It is actually about four times higher than the 1989 event.

Now, that compared to the 1921 event, I do not know the details of that.

Mr. BAKER. The 1921 event, if you believe Faraday's Law, would be 20 volts per kilometer.

Chairman JOHNSON. The length of transmission line, it just keeps growing too, right? It is not necessarily the intensity of just the burst. It is how long a transmission line you have that it just accumulates, correct? Or am I misinterpreting that?

By the way, just hop in. Just start talking.

OPENING STATEMENT OF SENATOR ROSEN

Senator ROSEN. OK. Well, I know I am new to the Committee, so I have a couple of questions about the resiliency and the redundancy of our grid. Of course, we have multiple grids, our military grid, our commercial grid, what I like to call our "distributed grid." It will have solar, wind farms, geo, thermal, water power, and of course, cyber communications now, wireless communications, all part of the interconnectivity of this grid.

Can you tell me how these bursts are impacting the wireless communication between these distributed grids? And then the second part, what is the resiliency and redundancy that is built in? We know everything is connected. If one cyberattack, maybe they can just hit us from a satellite down to a grid, and it goes out. What is the resiliency and redundancy you have built in for that, please?

Mr. AARONSON. I will start, but I am going to rely heavily on a couple of the engineers who are sitting to my left.

You raise a really important point about interconnectivity, not just of the grid itself, but to other critical sectors.

Senator ROSEN. Not so much transmission lines as wireless——

Mr. AARONSON. It is the actual communication.

Senator ROSEN [continuing]. Communication between our satellites as they circle around the Earth now.

Mr. AARONSON. That is exactly right.

So for us to be able to operate, I think one of the things that I want to kind of challenge is that the electric sector would not do anything but for standards.

I think that may be true 15 or 20 years ago. That might be older history, but I think given the shift in geopolitical threats to our Nation and our sector of being particularly key to our national sector, this is why this sector came together at the Chief Executive Office (CEO) level to start really focusing on some of the threats that we are facing.

We are proud of the progress that we have made. I would kind of push back on we would not do anything. There are good examples of things that we are doing to protect our systems, but what you have to recognize is we could harden everything to mil spec.

Senator ROSEN. That is right.

Mr. AARONSON. It would probably cost an awful lot of money to provide electricity to our customers, but if we do not have water, we cannot generate steam or cool systems. If we do not have telecommunications, we cannot operate. If we do not have transportation and pipelines, we cannot move fuel.

So looking at this, to use Dr. Baker's language of a top-down, holistic, sort of defense minimum, we do have to be thinking about this in terms of a lot of cross-sector impact.

That said, we also have to be doing this from a risk-based approach. One of the things that is most important—and again, I think the military did it similarly, which is you prioritize. We were not putting mil spec, EMP hardening on the Post Exchange (PX), but we were on command-and-control assets.

So what are those key assets in the North American electric grid that we ought to be hardening to a particular level?

Senator ROSEN. What is connected to it outside? You can harden this building, but there are so many connections into this, not necessarily hard transmission lines.

Mr. AARONSON. The one thing I would respond to you on that is one of the defenses that we have as a sector is the biodiversity. If you have seen one control center, you have seen one control center. If you have seen one sort of company's structure and we will call them their substation settings—you have seen one.

From a cyber perspective in particular, that gives us an awful lot of resilience because an adversary can attack one company and they have attacked one company. Because of the resilience, the redundancy, the biodiversity in the grid, we do have excess capacity, spending reserves, the ability to move electricity in different ways.

Now, one of the things that I am passionate about is from an engineering perspective—I have talked to engineers before who have said, "Oh, we would just reengineer the system," if blank happened. Do we know what that looks like? Have we done that before? Can we test it? Can we prove it?

Senator ROSEN. Right.

Mr. AARONSON. This goes sound science needs sound—or sound science results in sound policy.

These studies, while we call it admiring the problem, it is not admiring the problem. It is making sure we are doing the right things so that we can have more resilience and do it in a cost-effective way.

Senator ROSEN. Now with quantum computing, with all kinds of things, what do you feel that you can do with predictive modeling so you can simulate these things and you can actually run some disaster recovery plans, all on a computer? Right?

Mr. AARONSON. There is terrific modeling, and I am going to look over at Karen Evans for that.

Senator ROSEN. What can we do to help you improve that modeling, thus, improving not only the predictability, but also bringing us back up in case of an event?

Ms. EVANS. OK. There was a lot in your question. No, which is——

Senator ROSEN. Sorry. It is an exciting topic.

Ms. EVANS. No. Which is awesome because to get to your point about the discussion and what our agency is doing and how we are approaching this, this situation from a whole-of-government approach.

But to the modelings and what we do at the National Labs and so what we are doing within Department of Energy, which was required through the Fixing America's Surface Transportation (FAST) Act of 2015, that other components within DOE, we are looking at.

We are currently building a model right now. We call it the North American Resiliency Model (NARM), which Assistant Secretary Walker has talked about. And that is what he is building.

It is to model exactly what you are talking about, but the requirements under the FAST Act that Senator Murkowski and that Committee's leadership has said was you have to identify what are the critical assets across in the energy sector and then what are the interdependencies.

In the defense critical energy infrastructure base as well, it is what are those energy resources that are critical to the Department of Energy. Then they can do certain things within the DOD parameter. Then what is outside that parameter, which is in the energy sector? How do we rely on private sector with that? Collect the data. The critical points that Mr. McClelland is talking about is in this model.

So we anticipate, as DOE, that this first modeling will be done by the fall.

Then, to your point, there is capabilities in the National Labs under quantum computing, under the data, what we are doing in the CESER program, and the work that we are doing with—tri-sector with DHS is you put the data on top of that so that you can actually start doing the modeling and what is the impact of that and integrate that in under these scenarios and test scenarios.

So that, to your point about should we put this standard in place, there is a cost associated with all of these, right? And most of this infrastructure is owned by private industry.

As we go forward, what we are going to have to do is provide enough information with good science that informs the investment. Does it make sense on this list from a top-down approach? How much does the Federal Government do in order to protect? What is the risk associated with these types of events? What does industry match us as what is that risk and what is going to happen so that we can do the modeling?

Chairman JOHNSON. I remember a hearing a couple of years ago where we had GAO. They had issued a report on the results of the EMP Commission, and they had, I think, an A through O list about quick fixes, things we have to do. The testimony after years of those recommendations being out there, we had done none of them. These were tasked to the Department of Energy and to DHS. And they had done nothing.

Again, I keep coming back to the point, prioritization. Listen, I would like to operate with perfect information. If you make a one-dollar investment, that is a solid dollar investment. It is not wasted at all.

I do not blame industry. You are not going to act until government forces you to act. I blame government for being very slow off the mark.

We finally, after a couple of years, got Critical Infrastructure Protection Act (CIPA) passed, which basically the argument was is it a strategy or plan? Well, we called for a report from DHS. We got it a year late. It is 23 pages of basically a strategy to develop a strategy to develop a plan. There are no action items.

I go back to the EMP Commission, some quick fixes. We have talked about, OK, we do not have perfect science, but we do know if we start blowing large power transformers, we cannot replace them. The redundancy in terms of sharing with other utilities, well, if you are all wiped out, that does not work very well. If we are completely down, how do you black-start the entire grid?

Again, I am looking for prioritization of action to actually do something to start mitigating this as opposed to we are going to wait for the model. We will inform our study, which we will start maybe developing a plan. Then there will be a new Administration. Then we will have another law passed, and we will have to do a study on that. Are you sensing some frustration from at least the Chair?

Ms. EVANS. Sir?

Chairman JOHNSON. OK. Ms. Evans. Sure.

Ms. EVANS. OK. Yes, sir. I sense your frustration, and the model is not the only activity that is being done jointly within the community.

When you look at the list and you look at the action items, again, I believe Secretary Perry and what this Administration has done is take the frustration of what you are saying and what is the responsibilities and what is expected of Congress back to the Department of Energy.

That is exactly why my office was formed. It is not just cybersecurity, but it is energy security and then the response.

So to some of this stuff that you are talking about as it relates to response, we hold joint exercises. The exercises are critical. The exercises are tangible. They are scheduled, and they are scenario-based. The point of that is to test out. You have a plan in place. The time that the incident occurs is not the time for us to be testing the plan. The exercises are set up for us to actually test do we have the right things in place and where are the gaps in our research, so that we can then redirect the research.

I did bring specific activities of the research that we are doing in the Department, how much we have applied to that, and how we are moving forward with our National Labs to be able to do the modeling, to do the predictive pieces.

Chairman JOHNSON. You are confusing activity with action to actually mitigate, OK?

Ms. EVANS. No. No, no, no, no.

If you have an exercise and you see where you do not have the strategy—for example, we did it jointly with DOD, the Liberty Eclipse exercise up in Plum Island. That is a black start. If you do not have the equipment prepositioned, which is things that we have learned from the hurricane responses of doing mutual assistance, then you can start looking at how do you redo some of those things, how do you reach out, and what are the interdependencies, and then how do we have to then either come to Congress and say we have gaps in our authorities or we have to go out to industry and our industry partners and say we have to adjust the mutual assistance agreements that we have out there or this is how some of these things—or eventually, to your point, we have enough information that we then go to FERC and NERC and say we need to establish a standard.

Senator ROSEN. But how can we help you here in Congress to bridge these gaps? I have worked on disaster recovery plans and computer systems. That is how you learn. That is how you find out the holes. You go back and you keep practicing. Of course, it is like practicing for the big game, right?

And so you have private industry. They are not going to do anything maybe unless we make them. Maybe not. They do have assets to protect.

But what do you need from us, I think, specifically to try to help from this maybe triad or multiple partnerships, so we are working on a goal with action items that is tangible? Not saying, “We did our test. We show the hole. Will you? Can you? Maybe?” What can we do here, legislatively, to support you and the mission that you have reaching out to your different communities?

Chairman JOHNSON. Can we start with Mr. Roop? We will work our way down here.

Senator PETERS. Get everybody, yes.

Mr. ROOP. I wanted to get back to your point: Is the industry doing anything?

As I indicated in my written testimony, we have replaced all of our capacitor banks and all of our major power transformers with ones that are hardened to handle, the GMD and the E3 event.

We have also gone beyond the NERC planning standards to understand severe stress levels on our system and put monitoring equipment on so we know what actions to take to separate the system and take stuff out of service before it could fail. Those are actions we have done because we know we have to protect our grid. That is part of our business.

The issue we have is we have to use mil specs where it makes sense. We just built a new operating center. It is a full mil-spec operating center. Everything is protected in it, but the problem with that, I cannot do it in the substations because of the consequences it has on the protection equipment I have that protects our system every day. I do not want to do something that will cause daily harm to our system.

The next study and hopefully in the next 12 months with the EPRI work with the Federal partners, we can figure out how to protect reasonably that kind of equipment so that we can now implement that solution.

We also need EMP communications, and we are trying to get that stood up and do that by October of this year through the Electric Sector Coordinating Council (SCC).

This industry is working very hard at it, but we just cannot assume something and throw it out there because I do not want to collapse a grid in the process. That is the issue we have got.

Chairman JOHNSON. I understand.

Mr. ROOP. That is what we are trying to get through right now.

Chairman JOHNSON. I understand that. I realize Dominion is forward-leaning on this, but to what GMD spec did you harden your——

Mr. ROOP. Well, we have gone beyond the spec, and we have stressed our system.

I will be honest with you. We are trying to push the bounds, and we are working with National Aeronautics and Space Administration (NASA), U.S. Geological Survey, NOAA, and EPRI. We are trying to understand what are the limits of the network, and we are not the only ones. We are working with other utilities across the United States to understand, and they are also doing the same exercise we are doing because we are trying to understand really where is the issue.

But we have also got a sparing plan where if everything goes out, I can get my system back up with the spares I have, and we have done that proactively because they are out of service. They are not going to be impacted by a solar storm. They are not going to be impacted by electromagnetic——

Chairman JOHNSON. You already have the large power transformers?

Mr. ROOP. Yes, sir. We have already done it, and we have done it based on the work with DOE on a minimum grid model. We did that as part of the FAST Act work with them, and that has really helped us kind of understand where your stress levels are.

This work they are doing now is extremely important to give to the rest of the industry.

Senator PETERS. If I could just follow up there. That you have higher standards, you have gone further. You have made additional investments into your grid. I think it is partly because of a lot of the sensitive assets here in the D.C. area that will need that kind of protection from disturbance.

You are assuming—and I think all of you are assuming—that you are taking on the storm, the GMD event, that your systems are taking on the storm. You have not changed anything.

What would it be if we had better forecasting, that we actually know the storm is coming? Would anything change in terms of your preparedness?

Right now, that detection, my understanding is we can detect GMD events like we could hurricanes in the 1930s. So that is not all that great, but if we made those kinds of investments, how would you react?

Mr. ROOP. That would be excellent, and I will be honest with you. That is why we are working so close with NASA.

We think right now, the way we do the studies, we assume the field is moving all the time, and at different orientations, they are going to strike transmission lines. In reality, that is probably not what is going to happen, but we do not know how it is going to affect us. So you make the worst case guess, if you can.

So, forewarning and better computer models that we are getting and with what NASA and others are working on, it would very much help us.

Senator PETERS. How much time would you need?

Mr. ROOP. If we had 24-to-48-hour notice, it would be wonderful.

Chairman JOHNSON. We had testimony with that kind of notice, and we can shut down the grid. The question I asked, OK, who is going to make that call? There was, of course, no answer.

Mr. BAKER. Secretary of Energy. [Laughter.]

Mr. AARONSON. There is an answer now because of the FAST Act, and security emergency authority now resides at the Department of Energy.

Chairman JOHNSON. So who would make the call?

Senator PETERS. Who would make the call?

Ms. EVANS. The Secretary would make a recommendation to the President saying that we are in a grid emergency, and then the President would then make the call. It would be based on information that we are jointly working with, with the industry.

But the FAST Act put that in place, and one of the things that I am working on right now is what is that level of gradation that goes up, that constitutes this is a grid emergency, so therefore the Secretary needs to make that recommendation.

Senator PETERS. How much time do you need?

Ms. EVANS. How much time do we need to declare?

Senator PETERS. To go through that process.

Ms. EVANS. I am accelerating everything we are doing. We are testing several data collection things now that we should be with the National Labs, have an operational capability, to see if we can do it by April, of having the data that then can get into the hands of everybody looking at it to be able to then say, OK, at this circumstances, it constitutes this. We would work jointly with our whole-of-government approach and with the National Security Council to make that determination.

Senator PETERS. But if NOAA gave you a warning that a major space weather event is heading here now, how much time do you need to go through that process?

Because I think, Dr. Kasper, you said sometimes it is 10 minutes warning. That is not going to happen, really.

Mr. KASPER. Right now, with our spacecraft at L1 with NOAA's DSCOVR spacecraft, for a severe storm, it is 19 minutes. For typical storms, it is more like an hour.

Senator PETERS. So 19 minutes to an hour, would you act that fast?

Ms. EVANS. Yes, sir. The intent is to have the information available for the Secretary to respond that fast for the Nation. That is what we are building.

Chairman JOHNSON. But would the order be to shut the entire grid down?

Ms. EVANS. Not necessarily.

Mr. AARONSON. Not necessarily.

One of the things that the Sector Coordinating Council has been doing in partnership with the Department of Energy is to develop template orders, so that we are not figuring out what orders look like the day that they happen, but actually have some things and have an understanding of if this, then this. So that is going to be extremely important.

I would say shutting down the grid so that equipment is not impacted is an option, but one of the things that the existing operating procedure standard requires would be—or not requires, but enables is reliability coordinators who have responsibility for liability within a region would be able to spin out the additional reserves or have additional capacity in that particular area in case of some sort of loss of load.

I would rely on the engineers over here, but there are a lot of different ways to protect against GMD.

Chairman JOHNSON. The point of shutting down would be to protect the equipment. You are not talking about throwing more things on the load.

Dr. Baker, you have been pretty patient. Then Mr. McClelland. Dr. Baker.

Mr. BAKER. In answer to the question about what do we need to do, one of the most important things is to get EMP up on the same footing as GMD. We have a GMD standard. There is nothing. There is no guidance at all on EMP. As a result, industry is not doing very much of anything.

On the question of modeling, we have done modeling of the grid. FERC has done it. Wellinghoff pointed to if you could take out—if the right nine substations, you could shut down the United States for 18 months, 9 substations. We have a pretty good idea.

Chairman JOHNSON. Do not tell us which ones. [Laughter.]

Mr. BAKER. What?

Chairman JOHNSON. Do not mention which ones.

Mr. BAKER. OK.

But there have been models, and there are things that we know that we could take charge, move out now to protect the substations that are the key to keeping the bulk power grid running, anyway.

Chairman JOHNSON. We know that, but we have not done anything about it——

Mr. BAKER. No.

Chairman JOHNSON [continuing]. Or very little about it.

Mr. BAKER. Right.

Chairman JOHNSON. Do you dispute the fact that we do not have any EMP standards and we are really not doing anything about EMP.

Mr. ROOP. The industry has done quite a bit, ever since the FERC comments over the number of substations could be impacted across the grid. That is one of the reasons why we work with Oak Ridge Labs and the industry to develop the probability risk assessment is to really understand where your stress points were.

That has been shared with the industry. It has really helped us pinpoint which substations need to be hardened, physically from cyber, for EMP, and we have almost completed that hardening, all of ours.

The industry is doing the same. It has been shared through NERC now in a guide.

So there is a lot that has been done, and we have refined the early FERC work. I think we have better actions as to where to go. We have done a lot. That is the type of risk you do not share because it is telling the adversary what the targets are.

Chairman JOHNSON. I understand.

OPENING STATEMENT OF SENATOR TOOMEY

Senator TOOMEY. Can I ask you a quick technical question? In the scenario in which you had some notice of a significant GMD event and you were able to shut down some portion or all of the grid, how much protection does that provide? When it passes, do you turn the switch back on, and everything is fine, or has a great deal of damage been done, but not as much as what would have been done? Doctor.

Mr. BAKER. I was involved in a big DOE session to define their EMP action plan, and we had a very large utility, electric power grid contingent there. They told me—I was leading the discussion—that they wanted to resist shutting the grid down at all costs, that shutting the grid down would cause more problems because of the startup voltage transients. When you try to restart the grid, you get these electric voltage overshoots that will damage equipment, and so a shutdown is not a panacea.

Chairman JOHNSON. That is not a solution. Mr. McClelland.

Mr. MCCLELLAND. There is so much to comment on.

To begin with, if we look at operator action, manual action, there is a standard by NERC now, EMP 10, that does require a space weather forecasting and mitigation plans in the event of a space weather event.

To answer the question from earlier on, a good forecast would help an operator better prepare to take action.

However, the Commission found that operator action alone is not sufficient. There will be times whenever operators make errors, there should be automatic equipment available that would override and take action to stop the GMD event.

To the other point concerning the rigor of the NERC standards, any level, any threshold that one picks for GMD is certainly going to be exceeded.

The question would be how far in excess, or a better question would be what to do to automatically protect the equipment.

The assessments that NERC lists are the beginning of a process. That process, the expectation I would have for the process, is that any transformer manufacturer or any transformer owner is going to look at the exceed level. What is the level at which that transformer is going to be overwhelmed and take damage or be destroyed? At that point, that transformer should be tripped off automatically. That is not an expensive solution. That is a very targeted solution that can be put into place. The technology exists, so a relay with a pickup coil on the neutral bushing of the transformer, and then you can debate and study what level of space weather event you might have.

Also, to the question about notice, although better forecasting would certainly help with the GMD event, if the operator were prepared to take action and everything goes right, it is not going to necessarily help with an EMP event.

One of the nice things about mitigating GMD, if the GMD is done right, it will also mitigate E3 on the EMP event, regardless of what level one selects.

Randy and I can talk about that level later on, but for a GMD event, FERC did find—and it is a matter of perspective also. You asked earlier on why the subject-matter experts disagree. It really is a matter of assumptions, and it is a matter of a basis for setting the threat. What is the threat, and how much rigor do you place on the threat? What level of space weather, for instance, do you pick to mitigate against?

But if you are doing it on a protection basis—because even if you harden a transformer, at what point will the transformer be exceeded?

Chairman JOHNSON. Let me just say—and I will turn to Mr. Kasper—if I were king, I would say shutting down the grid is not an option, it is not going to happen, cannot react in time. It is just going to be too damaging in and of itself. That goes to your automatic mitigation. That is what we are trying to do. What technology can we bring to bear?

Richard Garwin said $100,000 capacity for protection of all this. I do not think that is necessarily true. You are talking some kind of breaker system.

For GMD, might be able to do it. EMP is just too rapid-acting.

What we are trying to accomplish in this roundtable is to set up a—I do not want to say a “process.” I want to come up with things we can actually do. We will spend the money.

We heard in your testimony. You said about $50 billion. In comparison to the catastrophe, that is money pretty well spent, and it can certainly be recovered through fees and everything else.

We have to come up with some action items, even if we do not get it right. I do not care if it is not 100 percent perfect. It is a lot better than the position we are in, and it is well worth the money spent to mitigate the risk. Mr. Kasper.

Mr. KASPER. One of the items I touched on earlier was the regional forecasts, and I think one of the issues right now is not only do we only provide an hour to 20 minutes warning, but we have like a thumb-up in the solar wind, "It is OK," "It is getting intense now." Well, you can clearly see there is more than one parameter that affects the severity of the storm.

I also think if we could deliver a regional forecast, I think it would be a lot easier to contemplate shutting off New England for a few hours than shutting off all of North America.

So now only do I think we need spacecraft that are closer to the Sun to give more time, but we need to be able to provide people with better data than just one number for how all of Earth is going to respond to each event.

Chairman JOHNSON. Mr. Roop, again, please speak to shutting down the grid.

Mr. ROOP. Yes. That is something we do not do lightly. I will be very honest with you.

Chairman JOHNSON. Right. And why?

Mr. ROOP. But we have a lot of resiliency built into the grid, and what we have done with the power transformers is—typically, they have a lot of "thermal margin," we call it. That is what they get stressed at.

What we have done now is every one we buy, it has 125 percent overload, extra thermal margin to it, and they have also have components to reduce the stress level from heating.

If you overload a transformer or you overheat it, we may lose life, but that does not mean it is going to fail right away.

So you take risk every day. If we have a major event going on in the United States today and we have to overload a transformer for a period of time, we will do that and take risk on the loss of life of that unit. That is what we would do in those kind of events in lieu of collapsing the grid.

Chairman JOHNSON. It all depends on the magnitude of the overload, and the problem with EMP or a significant GMD event, the overload may be so dramatic that there is just no safety factor in the transformer, right?

Mr. ROOP. Well, if you get to that level, you are going to have voltage collapse, and our protective systems will drop the system out automatically at that point.

I call it "safety valves," for a better word, in the system built in to be able to react to that.

We also have system operators that if they see a severe contingency, they have the rights and the authority to drop that area, and we do that.

Chairman JOHNSON. But, again, EMP occurs in fractions of a second, right?

Mr. ROOP. That is right.

Chairman JOHNSON. Dr. Baker.

Mr. BAKER. This same group of industry representatives at the DOE plan development, I was surprised. They said, "We would like to protect the grid, so we do not have to shut it off." There are protective devices where—they are still under test, but it may be possible that you could at least protect portions of the grid, so it would operate through a GMD, a severe GMD, or an EMP.

Chairman JOHNSON. Again, that is really the purpose of this roundtable is to identify those priority items that we can actually do. If there is equipment now and we can upgrade as technology improves, but start doing something now.

Senator PETERS. Mr. Vespalec, you mentioned something in your system. What was it? A device?

Mr. VESPALEC. A neutral-insertion device.

Senator PETERS. Yes. Would you elaborate on that, and would that be a potential action——

Chairman JOHNSON. That is strictly for GMD, though, correct?

Mr. VESPALEC. Well, it has some effect too on the E3 for EMP.

Senator PETERS. Yes. Would you elaborate on all that and let us know what it would protect?

Mr. VESPALEC. It is an automatic device that senses when that DC type of current is flowing, and it will interrupt it to protect the transformer.

It is a prototype, what we have, and we put it in a substation with just one transformer, knowing that if it interrupts that current, we want to know what would happen to the rest of the system. It is a little bit like Whack-A-Mole. If you stop the current flowing in that transformer, it has to go somewhere. It looks for another path.

Chairman JOHNSON. Right.

Mr. VESPALEC. We are trying to monitor to see how is this going to react with the rest of the system and the effect to other transformers.

Chairman JOHNSON. I am certainly mindful of the complexity of this and that you put something in here and you have to be really careful about how to fix the rest of the grid.

Mr. VESPALEC. Correct.

Chairman JOHNSON. I do understand that.

Again, if you want to talk, put your name tag up like Dr. Baker.

Senator PETERS. Mr. Aaronson, go ahead.

Mr. AARONSON. Thank you both.

Similar to Mr. McClelland, I have a lot that I want to react to, but I think what you just heard from both Mr. Vespalec and Dr. Baker about the complexity, about the testing, and the potential unintended consequences is a really big deal. This notion that nothing is happening, except we are admiring the problem, actually we are admiring the problem in the wild right now by actually deploying different potential solutions and mitigation strategies.

Some of the mitigation strategies, as you are noting, are to prevent impact from happening.

Another way that we look at resilience is you cannot protect everything from everything all of the time. If we are talking about an intelligent adversary, we have to be right 100 percent of the time. The adversary has to be right once. We also have to be focusing on response recovery, preparing for a potential impact.

In addition to what we are talking about with blocking devices and some of those things, Mr. Roop referred some of the spare equipment programs that we have.

Something else that we are developing at the direction of the Sector Coordinating Council known as "Supplemental Operating Strategies (SOS)", this notion that can we operate the grid in a degraded sense. So there is impact.

I will push back on that nine substation remark real quickly too. That was based on static modeling, and the idea is if those nine substations evaporated and we had no other contingencies, there would be impact to the system. Even if they evaporated, we have other ways to pick up that load. We have other ways to engineer around those problems.

You see it all the time. You saw what happened in Mexico Beach, for example, down in the Panhandle of Florida after Hurricane Irma this past year—or Hurricane Michael, rather, this past year. There was impact there. We were able to rebuild the system in a short order, and the rest of the surrounding area was able to get back up and running fairly quickly.

This is one of the ways that we are taking physical natural hazards and applying our resilience and recovery methods to potential cyber, physical, or EMP-type events.

So looking at it at all hazards, looking at it not just before the incident, but what we do to respond and recover, having Supplemental Operating Strategies, being able to operate manually, being able to move equipment around, these things—and I think you noted it Chairman Johnson. These pieces of equipment are enormous. They are critical to the effective operation of the grid.

We have a lot of spare equipment that is not operational today that cannot just be put into service in a place where it might need to be, but also we have been working with, again, cross-sector, the transportation sector to be able to move these things as expeditiously as possible.

The last thing I want to say—and I am sorry that Senator Rosen is not here anymore, but very direct question of what can Congress do to help, I think we are all kind of falling on some things that would help.

Money is always. If you are talking about national security and you are talking about mil spec, rather than customers bearing the cost of something that is a national security issue, there are ways that I think we can find Federal money to do some of these things.

I think in the spirit of money, also, working with us in our commissions at the State and Federal level so that these costs can be recovered, so support for cost recovery, having your leadership, "This really matters, State commission. This is why this company is coming for cost recovery," I think is going to carry a lot of weight.

Earlier warning was already discussed.

Chairman JOHNSON. Let me just chime in.

Mr. AARONSON. Yes.

Chairman JOHNSON. As a fiscal conservative, I will carry the water as long as I know what it is we are supposed to do.

Mr. AARONSON. Amen.

Chairman JOHNSON. That is what has been so frustrating to me. It is just what can we do? Let us actually act. Let us actually spend some money on things that actually mitigate.

Mr. AARONSON. This is why EPRI's work is so important.

I think if we would have done some of the—"Oh, this is the right thing to do. It is mil spec. It is easy. We have done it for 20 years. Why are not we doing it on the electric sector?" we might have had unintended consequences. We might not have had sound mitigation. We probably would have lost 3 or 4 years.

By doing sound science not, getting specific mitigation, and then—and I do not know if Randy is able to say this or not, but following this report, companies are not just going to take the report and say, "Oh, now we know what mitigation looks like." Companies are going to pilot some of these mitigation strategies so that we can do it out in the wild.

Once we have a better sense of what mitigation looks like, there might be ways—maybe very specific asks for funding.

The last thing I would say, access to classified information, I do not think this has been as big a problem this go-around with EPRI and their work with DOD, but being able to see what does an EMP from a high-altitude nuclear weapon really look like on our system at a very highly classified level so that we can make informed decisions based on the things that Dr. Baker probably knows.

Chairman JOHNSON. OK. Mr. Harrell, Dr. Baker, and then Ms. Evans.

Mr. HARRELL. Thank you very much.

Just as a former regulator and kind of somebody who has been regulated and now kind of seeing this through a government lens, I do want to suggest that a lot of investments within industry, within particularly this industry, have been made.

I will point back to some of the action items that have come up over the last number of years, really since 2006–2007 timeframe, and I will point to the grid security exercise that NERC did many years ago.

The first one was back in 2011. Every other year, there has been an exercise since, and they have really taken a hard look at some of the catastrophic grid reliability issues, and this certainly would be in that same vein.

I do want to suggest that there is a lot of work and a lot of thought that has gone behind a reliability issue.

As DHS pushed out their 2018 strategy and soon to be an implementation plan, I do want to suggest that we have started to get a lot more granular as to the risks associated with not necessarily EMP, but all risks.

So right now, we are in the process of moving toward mapping the national critical functions, and what does that mean kind of underneath it where we get a little bit of granular? The things that we need in which to operate critical infrastructure in this country, what is it? So that we can kind of pinpoint what actually needs to be mitigated based off of a risk.

Chairman JOHNSON. That is fine. I want to solve all the problems, but I would like to solve this one now. Let us kind of take a step-by-step approach.

I believe it is Dr. Baker and then Ms. Evans.

Mr. BAKER. Yes, a couple of things.

One is the NERC exercises did not include EMP, at least to my knowledge. The other point is I would venture—this is something we need to check, but I suspect if you protect transformers to the EMP E3, as specified in the Mil-Standard 188–125, they will also survive any GMD.

Now, we have not done any testing of the large transformers, but the first transformer, which Duke Energy has made available, we are going to test down in South Carolina.

I think we need to look into the possibility that if you protect the heavy duty grid components, the transformers and substations and generator step-up transformers to the EMP E3, they will also survive GMD.

Chairman JOHNSON. But, again, they are still vulnerable to E1 and E2, correct?

Mr. BAKER. Right. But I am just looking at the GMD.

If you protect to the EMP standard, mil spec, you will also have protected to GMD.

Chairman JOHNSON. OK. I think I have always assumed that. I thought GMD pretty well was EMP, correct?

Mr. BAKER. It is very close, but we need to do some testing, obviously.

Chairman JOHNSON. Good enough for government work. [Laughter.]

Mr. BAKER. But, again—and I am pushing back on what Randy said—the Mil-Standard 181–125 tells you how to test transformers, 1,000 amps per phase, and that is unclassified.

Chairman JOHNSON. I am going to lose Senator Peters here pretty quick, but do not worry. I will stick around.

Senator Peters, do you have any other questions before you have to leave?

OK. Ms. Evans.

Ms. EVANS. Oh, thank you.

The one thing that I really want to stress and I think Dr. Baker has put this in his action items is it is not to reinvent the wheel but to leverage a lot of the work that has already been done by DOD.

Our National Labs, because a lot of this stuff that people are talking about is, oh, we are actually testing on the live system, we have directed our National Labs to be able to actually simulate and do assessments under these scenarios.

To your point about you need to have the data in order to be what can we do today, what is the long-range plan, and what is that road map, that is specifically why we are a putting this road map together so that we can have this data.

But the labs are working on this now. We—and whether you agree or not—and I think it has been said by DHS and also by Caitlin earlier—is that the risk of some of this is low in how it is going to happen, but when it does happen, the effects are catastrophic, right? So we all agree on that.

So the way that we are doing the work is prioritizing it based on the risk across the board, but taking into effect, especially what Mr. Aaronson has said, is, OK, we do this in other areas, so this is another threat that we have to build into the current scenarios that we have.

To your point, there is testing. There is the assessments. We are leveraging the National Lab capabilities because they do the work for DOD as well. So we are not reinventing that. We are trying to make sure that we have the data that we can share out so that it informs everyone's decision as we go forward.

Chairman JOHNSON. The extent we are designing solutions, if you can have a solution for multiple problems. If you are shut down and you have to recover, probably similar process, whether it is cyber, whether it is EMP, whether it is GMD.

Ms. EVANS. Absolutely.

Chairman JOHNSON. So, again——

Ms. EVANS. So you have to be able to test that scenario in a testing lab environment because you really do not want to affect your customers while you are putting on, OK, this is a prototype equipment. What is the effect of that going to be? What are the scenarios? What are the assumptions if we implement this type of standards?

We have directed the labs. They have been working on this since—on 2018 and 2019, we are continuing this work, so that we can say, "And here is the data. Here is the impact. Do you want to accelerate that? Because that is a risk that we are not willing to take as a Nation." That is the kind of information I think Congress needs to have to be able to get to the point that you want to take an action and I am willing to do this."

Chairman JOHNSON. I think that is the purpose of this roundtable. I realize this is, hopefully, a very low probability. Certainly, EMP is a very low probability. I think it is a growing probability, unfortunately. GMD is not if, but when.

So we are trying to raise this profile. We have sat back and we just have not done very many things. It has not raised the type of—let us face it—the awareness like climate change. Let us throw hundreds of billions of dollars at climate change, just in case. Well, I think we ought to do something just in case here.

A little off point, because I am the Chairman of Homeland Security and on Foreign Relations, I am aware of what Russia did from a cyber standpoint in Ukraine, and it is my understanding, being nontechnical, the only reason Ukraine was able to reestablish and startup their grid is because they had the old-fashion breakers.

I know there is a bill pending. I think it is Senator King and Senator Risch.

By the way, I was at Idaho National Lab, great facility, wonderful people, talking way over my head, but I appreciate that.

I think $10 million a study, where should we maybe put some lower-technology breakers? I am hoping all of you take a look at that as well.

Mr. Roop, are you smiling on that one? We will get back into EMP GMD as long as I have raised that issue. What are your thoughts on that?

Mr. ROOP. Well, what we have tried to do in the design of our system is have manual override so we can bring the system back up. That is extremely important, and you use a human remote terminal unit (RTU), if you have to, to try to bring your system back. We have manual overrides built in our system.

The problem is some of the protective relaying with the dynamics we have on the system now, we have to use power electronic relays or else the system gets unstable. That is the reason why this next point, the next phase with the EPRI work is so important. It is how I protect those relays cost effectively is to me, where we have to get soon as an industry so we can fast deploy that.

So there are some very specific research areas that we have been led to with the EPRI work. The stuff that is low-hanging fruit—and I will call it—it will not hurt the system, we go ahead and do. We have already done that in our standards. The industry is doing it. Other utilities across this industry are already looking at the preliminary reports with EPRI, and we have been doing that across the networks.

But there are some specific areas that we really need to address quickly if we want to get ahead of this problem, and that is where the labs can help us because if some of the technology we try do not work, we are going to need to figure out what will work. So that partnership is extremely important for us, and that is where the government really can help us in the next phase here.

Chairman JOHNSON. But, again, do you not agree that until the government establishes a standard, you are going to be incredibly reluctant to invest a whole lot of money? Because you just might get the standards next year and have to redo the whole thing. Is that not a real deterrent?

I appreciate what Dominion has already done, what Edison has done, but I think you probably would have done a lot more if we would had given you some kind of basic standards to adhere to.

Mr. ROOP. That always makes it easier, but I am not sure standards is the answer in this case, at this point yet.

Chairman JOHNSON. OK.

Mr. ROOP. We really need to know what to do, and that is where I am at right today, I think.

Chairman JOHNSON. I want to respond to the people putting the name tage up, like this.

Dr. Baker. I got rules.

Mr. BAKER. Yes. Good point from Roop there.

Another thing—and it is going along with his observation—one of the things that we really need are some national test beds that are dedicated to testing integrated systems, the relays, the generation stations, the substations in a connected mode.

We found with EMP that assessments and models that are just based upon analysis are wrong. They are wrong. They are inaccurate. You may as well flip a coin as to whether the system is hard or not. The only way that you get any kind of confidence that you have a system that is hard is to test it, and so these test beds are important.

Chairman JOHNSON. Creating a test bed is not that expensive, is it? I know you have one in Idaho.

Mr. BAKER. Idaho is building one. There is one at Tennessee Valley Authority (TVA), and there are some in situ tests that are being set up. But that is an area where I think funding could be very helpful.

Chairman JOHNSON. Mr. McClelland and then Mr. Aaronson.

Mr. MCCLELLAND. So there are really two aspects to this. One is the natural threat, and on the natural threat side, I think you have correctly said that you have to narrow the mitigation action.

Right now, it is based on operator action, and I would say that automatic protection measures should also be considered and strengthened, and that is in the implementation plan.

If I get a level that overwhelms the transformer, I could still take that transformer off automatically. It is isolated to the transformer. The whole grid does not come down.

But when it is——

Chairman JOHNSON. But, again, do you have enough time even with GMD?

Mr. MCCLELLAND. I am sorry?

Chairman JOHNSON. Do you have enough time to do that even with GMD?

Let us say it is kind of localized. We have had this in the past, go back and——

Mr. MCCLELLAND. No, no, no, no.

It would have to be—in my opinion, you should not—as an engineer that has been in the industry, one should never rely—if it is a critical function, never rely on operator action alone. There are always automatic controls, automatic relays, automatic operation of the equipment.

Chairman JOHNSON. Again, do the automatic relays work in GMD?

Mr. MCCLELLAND. Yes. You can install automatic relays in GMD, and I will talk with Dave after this. But to sense DC, DC input on a transformer is not—in my opinion, it is not difficult to sense that operator relay and take that particular transformer off because, if you looked at some of the latest modeling, the GMD vectors can be very specific to very different transformers under different GMD scenarios.

Chairman JOHNSON. Was that part of your standard, then, that FERC gave to NERC, gave to industry?

Mr. MCCLELLAND. Absolutely not. It was not part of the standard, but it was a baseline. As I said, those are baseline practices that start the discussion and start the industry moving.

So now everyone has a requirement. They have to evaluate their system. They have to do an assessment. They have to do a correction action plan, and they have to mitigate to certain levels.

Now, if it is 8 volts per kilometer or if it is 75 or 85 amps per phase, one could argue that that is certainly going to be exceeded or not adequate for a significant GMD event.

But, again, to the point, you will always have GMD events that exceed that threshold, and so in that case, I would submit one would never count on a single standard to protect that transformer. One should put protection on that transformer, and that is something industry knows how to do, and they have done it forever.

So that is something that could be done, and I feel it could be done targeted, and it could be done, I think, quickly and not very expensive. The Commission can provide cost recovery, but I am sorry. I did not want to miss the EMP issue either because EMP, the bad news is you have an intelligent adversary that studies our systems and vulnerabilities and is building weapon systems around those vulnerabilities.

The good news is you have an intelligent adversary that studies our systems and vulnerabilities and is building weapon systems around that because to DOE's work, they are working on defense critical electric infrastructure. If those facilities survive in the event of an EMP attack—and that is a very narrow subset. If they survive, my personal opinion that is a strong dissuasion for an adversary to perpetrate an attack.

Chairman JOHNSON. For a couple nuclear powers, but there may be a couple that I am not sure that you can do anything to dissuade them.

Mr. MCCLELLAND. That is correct. No doubt. That is where it is a broader subset to say what are the major societal impacts.

We are losing very specific, very critical facilities, and that comes into that narrowing, the modeling, the engagement with industry to identify those facilities and put protection in place.

Right now, DOD, DTRA, is doing a tremendous job in hardening the DOD assets. They are moving with all haste, and they are spending a lot of money.

The same thing can be done with proper engagement with the industry, not to set a standard, but to engage with them about what are these critical—brief them, to their point, about classified information. What are those critical threats? Is it real? What can we do to protect against it, and what is our really all levels of protection mitigation?

Just to go to an earlier point, there are still entities that have analog, old electromechanical relays out there, and if you read the System Electronic Registration Approval (SERA) study, they do very well against EMP attack. It may not be possible to put them everywhere, but in cases where operations could be dead-banded with electromechanical relays, that is an excellent solution set. That is one that should be considered, and that is one that some of the international partners who we are working with—that is one that they are employing.

So there are targeted mitigations for specific systems that can be put into place. These can be done quickly. My opinion, they can be done quickly with industry engagement, proper incentives, and I really do not see a reason——

Chairman JOHNSON. Reimbursement.

Mr. MCCLELLAND [continuing]. We could not get it.

Chairman JOHNSON. Mr. Aaronson, first of all, respond to what you talked about, surge protection on transformers for GMD. But just in general respond, and then make the point you wanted to make.

Mr. AARONSON. So, no, I cannot respond on that. These guys over here can.

I am actually really glad that Mr. McClelland because I want to associate myself with a number of his comments. I think he said a lot of important things. He was talking about prioritization there at the end. Is it the Defense Critical Electric Infrastructure (DCEI)? Is it that one order, one level down to some of the societal needs, life, health, safety, first responders, things like that?

The President's National Infrastructure Advisory Council, recently did a report—I happen to be on the study group—for catastrophic power outages, and I will say we have learned a lot from recent history, not just the storms that have impacted most of the United States or the wildfires out west or what happened in Puerto Rico, but now to bring back what you brought up about Ukraine, those are the supplemental operating strategies that we are talking about.

What happened in Ukraine, I like to tell people, is my favorite kind of incident because it happened to somebody else, but we can learn from it. And we are.

So you are exactly right. One of the reasons that they were able to get back up and running as quickly as they were—so 225,000 people lost power for a few hours. It was a bad day, to be sure, but it was not catastrophic to that country. They were able to go back to the good old pistol-grip handles, and I like that, the human RTU.

In order to have that human remote terminal unit, you need to be able to talk to that person in the field. You need a person in the field who is trained on what it is that they are going to be doing.

Now, it may not pretty. The other joke we have had, it is not just Supplemental Operating Strategies. It is the MacGyver Project. How do we hold the grid together with bubble gum and duct tape in the event of a truly catastrophic incident?

I will give an example about sort of levels of magnitude for an incident. In Super Storm Sandy, there was a company that had storm walls for one of their key substations for a 14-foot storm surge. The highest that had ever happened in that location was 10 feet. They were way above whatever a baseline storm would do. Super Storm Sandy was 16 feet of storm surge.

Since then, they have not ripped out that substation and started something new. Instead, they have actually built some pretty creative, pretty low-tech solutions. They have storm walls that one person can go in and shut.

I think what we have to do is not just rely exclusively on standards, to the points that have been made. They do provide a great foundation, but also understand that there are going to be incidents that strain our imaginations of what could happen. Again, this goes back to that left of boom versus right of boom. We should absolutely spend time and resources and effort to prepare, protect, detect, defend, exercise, but also to prepare, to respond, and recover, so——

Chairman JOHNSON. We should be looking for simple solutions. Take a look at after the September 11, 2001 (9/11). The simplest solution and most effective, we just hardened the cockpit doors, kind of like "duh."

The nuclear accident in Japan, put cooling towers up on top, OK? Do not rely on the electrical pumps.

Mr. AARONSON. That is right.

Chairman JOHNSON. Again, yes, absolutely. Do not look for some elegant, expensive solution. Look for the simplest solution as possible.

Real quick before I go to Dr. Baker and Ms. Evans.

Mr. Roop, I would just like to ask your opinion of basically what Mr. McClelland was talking about on GMD, the surge protectors, easy, simple, boom, or not?

Mr. ROOP. I am not sure exactly the surge protector he has referred to.

We use metal-oxide varistors (MOVs) on our transmission system, and we are looking at very high-speed surge protection on the secondary for our relay protection.

The problem is I have 65,000 relays in my system, and about 60 percent of them are digital. They have about 30 or 40 points on the back of that relay. If I had to put a surge protector across all of them, I have to make sure I do not short out something or open something that could create another consequence. That is why we are trying to see is there a simpler solution than putting one on every terminal point, and that is where we may need the labs to help us figure out what is the right answer to that.

As far as the comment about electromechanical relays, there are areas in our network we can use them, and we are still using them.

The suppliers are trying to get out of that business, so that will be a problem for us down the road. So that is also part of our strategy, but they cannot be used everywhere on some of our extra high voltage (EHV) systems because of stability concerns. But that is some of the things we have to do.

Chairman JOHNSON. So there is one of the problems you have to solve is you have to maintain a supplier base, and that is maybe something you have to support if we view that as a mission-critical or national security issue. Dr. Baker.

Mr. BAKER. Because EMP affects such larger areas—you are talking about footprints that are 1,000-plus miles in diameter—I think that we do need to have some standards or guidelines because the grids are so interconnected that if you do not have some uniform protection on the grid, if the protection is just sort of random, one part of the grid failing will pull down other parts of the grid, as we saw in 2003. A small perturbation in one location caused a large part of the Northeast grid to change.

I think standards are something that should be on the table, and we ought to think about that, just as we have the GMD benchmarks.

The other point I would make is I think right now, there is entirely too much emphasis on recovery. The way I am reading the tea leaves is people have this idea, we will just let the grid fail, and then we will just have elaborate recovery plans to be able to pick up the pieces afterwards.

We need to protect as much and keep operating as much of the grid as possible, so that we do not have to get into these modes where we are operating in the dark. We want to keep as much of the grid up as possible.

Chairman JOHNSON. I want to quickly go to Ms. Durkovich because I know you have a timeline. You have not spoken yet.

Ms. DURKOVICH. Thank you very much, Chairman, and I want to pull a string on something that Scott was talking about related to just lessons learned from other environmental hazards.

Certainly, the industry, year after year, gets better in both preparing for and responding to hurricanes. That is in part because there has been a very healthy dialogue around forecasting, and the sooner that industry can know about a storm, the sooner they start to take action.

From the moment that storm, that ingest becomes a named storm, things are done across the electric sector. I think that is an important part of the conversation certainly that we had when we did the Space Weather Task Force is really learning about what are the timeframes that industry needs to begin to take action. I think that is an important conversation that needs to continue.

One of the things that I think would be interesting, again, around preparedness, especially as we come to some conclusions about what are helpful mitigation measures is each year, FEMA hosts an annual hurricane briefing, where they bring together all of the interagency. Industry comes in. There is also a national hurricane conference. The goal of this is both to talk about what the hurricane season is going to look like. Do we expect it is going to be bad? Do we expect it is going to be good? We know a little bit, something about the cycles of space weather, right, and where we are and what we can anticipate, and especially if we are in this—if not, when and the 100-year storm window.

I also think that it would serve to both continue to raise awareness. You are sitting with people who think about this, who have learned forward. There is a large part of industry and other industries, the mid to small-size power providers that maybe do not have as much awareness or as much resources, and we need to continue to make sure that what David is learning at Dominion can be passed down to them, but that we can also learn from events where we do have near-misses or mild storms, what worked, what did not work, and continue to promulgate those among industry and academia.

I think it is a simple thing, but doing it on an annual basis continues to raise awareness about the risk. That is where we have a problem. It brings people together to talk about what we know is working, what we can do better, and I think there is an element here that might also contribute to public awareness about this, which I will tell you is very low.

And you ask the average American. I will ask you when I stepped into DHS and into my role as Assistant Secretary, I certainly did not know that space weather would be something that we would be dealing with.

Chairman JOHNSON. It is not why I ran for Senate.

Ms. DURKOVICH. Thank you, if I do not have an opportunity to provide comments again, for including me today in this important conversation.

Chairman JOHNSON. Well, thank you for attending, you raised a pretty interesting point. It kind of harkens back to some of the points that Dr. Baker made in his testimony.

Here in the Federal Government, we are talking about the top down. What do we need to do? Top down. But there is an awful lot of bottom up. That is why I appreciate the types of things that Dominion Electric is doing on its own, absent better direction from the Federal Government.

Again, thank you for coming and safe travels home. Ms. Evans.

Ms. EVANS. I wanted to follow on exactly what Caitlin is saying is that I think I would offer a way to look at this is that there are a lot of lessons learned from what we do from a natural disaster type of prevention, prepositioning resources in order to be able to do things.

My particular office is focused on energy security as well as emergency response and cyber. So the whole idea is what do we have to look at from a sector-specific? How do we respond, and how do we preposition?

I think some of the things that Dr. Baker is looking at is that that is after, as we continuously do things. OK. This is the way the response works. This is how things are happening. This is the data associated with it, and it leads into we should have a minimum standard.

I think several of these things are going on concurrently, and to go out on one versus the other, it all has to inform it. I think that is really what—to Joe's point, we are doing these things currently. To leap right out and say yes, you have to have a standard, it is a long process, but it has to be informed by the practical exercises and activities that industry is doing now, so that we know what the impact of that is going to be, so that we can answer the question to you. So these are all going on concurrently, and it informs the standard process.

I know you want an action like, yes, let us do a standard, but I think you want a standard that is informed that then can actually be able to say, "Yes, we are prepared. We are prepositioning. We work with industry. We are utilizing these things going forward," and this is how the Nation is responding to the risk.

Chairman JOHNSON. What I am looking for is—somebody mentioned the low-hanging fruit. Let us at least start doing the low-hanging fruit. You are never going to have perfect information. We have been doing this a long time, and I will still say there has been minimal mitigation efforts that would really be effective, that are really protecting us here. We are still incredibly vulnerable to this.

I am trying to reduce our vulnerability. I am trying to take actions to start mitigating it, so that there is some level of survivability. Mr. McClelland.

Mr. MCCLELLAND. I am not sure my comment will help in that perspective, but with your permission, I did want to make one clarification, and that was to the E1 mitigation that Mr. Roop comments on.

E1 is not as easy. If there are electromechanical relays in place, E1 is—and if you can leave those in place, then you have a simple solution to leave those in place. Coincidentally, they are impervious to cyberattacks. So you sort of have a convergence of two threats there.

But I do think that E1 is solvable if the universe is narrowed. To the industry's point, if this is truly a national security matter and an important and urgent national security matter and action needs to be taken, then the industry needs to be told that this is what needs to occur, and then the engagement has to begin—and if you want it done quickly, on a narrow subset. I would suggest that what the work that DOE has done and to some degree DHS also, but that narrow subset should pick up, to your earlier point on what are the best practices we are using with DOD—because we are rushing and with haste. We are mitigating against EMP at those critical DOD facilities.

It is not going to do any good if they do not have service to the bases. So the point would be that is an area of focus that I think could be done quickly. It would be complex, I think to Dave's point, much—many of the relays, since the time I was in the industry have become digital relays. They are much more functional, and the grid is much more complex.

But it can be done, and it can be done, I think, much more quickly on a narrow focus.

Chairman JOHNSON. Let us face it. I think the IC will always assess that EMP is a very low-probability event, and I would agree with that. God, let us hope so.

To a certain extent, I am looking at not a full solution here, but are there common solutions? That if you had an EMP attack and the grid was down, the same type of solutions, same type of recovery systems would apply to cyber or GMD as well? That is where I am—what are the common solutions here? What are the common mitigating factors we can do?

I am not looking for perfection here. I am just looking to start taking some steps.

Before we disband this, I do want to—because this is—as I read your testimony, Dr. Baker, one of the action items that really is very urgent is the whole issue about microgrids. I do not fully understand them, so I would like to have people respond a little bit to what Dr. Baker was talking about. There are more and more microgrids being established. It does increase the complexity of the grid, and if we do not—and the mitigation cost to military standards for E1, E2, and E3, and GMD is only 2 to 5 percent of construction cost. If all that is true, it would seem to me—and if all that is required is the Federal Government better create a standard for microgrids to have them put that into the construction process, we ought to do that pretty fast.

I would be looking to Senator Murkowski and my Senate colleagues to raise the awareness, and let us get at least this done.

I kind of want people's assessment of the whole microgrid issue.

OK. There you go. I actually saw you wiggle.

Mr. AARONSON. I knew I had to put the sign up.

So a couple things about microgrids. I think people look at them as the answer to resilience, if only we had all this redundancy through microgrids.

Well, the existing grid is effectively a grid of grids. That said, there is deployment of a lot of microgrids now.

Some of the companies that are deploying them, non-utilities, are doing it on a very low margin to be cost competitive in a lot of places, so 2 to 5 percent matters a lot to them.

We see that problem with cybersecurity as well. You are talking about very competitive technology space right now. Adding complexity——

Chairman JOHNSON. What is the cost of a microgrid? What is the cost range?

Mr. AARONSON. I would have to ask one of these guys.

Chairman JOHNSON. Are you talking $100 million? Are you talking about $5 million?

Mr. AARONSON. Well, I mean, it really depends on the application.

There is a good example of what would be considered a microgrid that is jointly operated or that is operated by the Hawaiian Electric Company.

Chairman JOHNSON. I am an accountant and a business guy. I understand that 2 to 5 percent could kill us. That is where I think the Federal Government can step in. If this was such an important issue——

Mr. AARONSON. Right.

Chairman JOHNSON [continuing]. If this was so urgent, this would be a blown opportunity not putting the standard into those things. Just sort of allocate the money because it is well worth it.

Mr. AARONSON. The 2 to 5 percent, that is something—so if you are talking about a microgrid deployment on a military installation, that is good for the military installation for them to island themselves, if necessary, or to support the surrounding community—again, there are examples of that. One is particularly well known out in Hawaii, Schofield Barracks, really built out a spectacular system. That is the kind of place where you would absolutely look at, and especially when you are talking about greenfield deployment.

There are examples of some of our companies who are building new control centers, who are hardening some of their control houses as they build new substations.

When you are talking about greenfield construction, adding 2 to 5 percent, that is worth every penny.

When you are talking about retrofit, the costs go up tremendously.

Chairman JOHNSON. It is more expensive.

Mr. AARONSON. That is right.

With respect to the microgrids, though, I think what we have to do is look at it in two ways. One is if it is a microgrid deployment in a critical facility supporting critical load, we need to think about all of the different ways that we would harden and protect against—EMP, cyber, physical, etc.

If you are talking about a more commercial application that does not have the same impact to life, health, and safety, well, they are going to try to be cost competitive in whichever way they can.

I am sorry I do not know the hard numbers, but I do think you have to think about it from a cost-effectiveness standpoint and where the deployment is.

The last thing I would say about microgrids is while they do add both resilience, because you have some redundancy and complexity, you still need that backstops, the enabler of the broader grid. That is where companies like Dominion and ATC and others come in.

Chairman JOHNSON. Dr. Baker.

Mr. BAKER. The microgrids are normally used on systems that are so critical that they cannot stand outages. They cannot stand the .99 or .999 outage probability that you get with the rest of the grid.

So the services, the infrastructure services you would be protecting are going to be very, very critical. So that is another impetus for looking at these.

The other point I would make that Scott—echo his, you need to do not just EMP, but you need to look at cyber. When they install microgrids, they are connecting the microgrid controls to the regular grid controls and the controls on other microgrids. So they call this "aggregation," and just remember this. Aggregation means aggravation in terms of vulnerability.

But these things are proliferating and none of them is hard. I do not think they are either EMP or cyber-hard, most of them. So that is a low-hanging fruit for you.

Chairman JOHNSON. You are talking to an accountant that had a PC with a 5½ inch floppy on my accounting system because I knew that would never get hacked. I think since I have left, they have improved that. I am reasonably cautious about those things.

I am kind of out of questions. I think we have gone far enough here.

I do again apologize for the clip nature of opening statements. I hope you found this informative. I hope you found it helpful. I certainly found it informative.

I want to give you a homework assignment, if you choose to address it, because I did talk to Dr. Baker. I valued all of your testimony. I truly did. I read all of it, and it was very helpful.

Dr. Baker, because of what he has done in the military, he has actually been participating in a system in government that actually did this, hardened it, but also in his testimony, throughout it, there were action items. I called him up, "Can you lay those out as a priority?"

What I would like all of you to do is make sure you have his testimony. I would recommend you read it, but then look at his priorities. You do not have to comment on all of it, but if you have a comment on his testimony or a particular action item, if you disagree with it, let me know. Then we can try and figure out where is the discrepancy there. Otherwise, what I will do is kind of view this as pretty authoritative and move forward based on that.

So here is your chance to rip into poor old Dr. Baker and say, "We do not agree with this guy." [Laughter.]

Mr. BAKER. You never explained that to me.

Chairman JOHNSON. I have been doing this a long time, and the problem you have with EMP is you have people who have been involved in this. God bless them because they have been raising the alarm, they may be viewed as alarmists, maybe discounted. I am not necessarily saying they should, but I think that has been part of the problem.

I think on the other hand, you have industry that—I do not blame you there is not a spec here. We are going to do what we think is important, and we are going to address—what are the high-probability threats? We have enough things to worry about here versus addressing these low probability threats when government is really not giving us any direction.

I am not laying any blame here. I understand exactly what the dynamic is here. There is, I believe, a moment in time here.

I like the fact that Senator Toomey, after I presented this to our conferences as one of my top priorities, he came up to me, "Hey, Ron, I really want to work on this."

Senator ROUNDS. I have talked to Senator Inhofe and Senator Murkowski, Chairmen of both Senate Armed Services and the Senate Energy Committee. These are the committees, the committees of jurisdiction. Or where there is a must-pass piece of legislation, maybe through the National Defense Authorization Act (NDAA), we can actually do some of the top-down legislation and enact it into law.

I will use the one example when I was interviewing Secretary Nielsen for a position at DHS, and she talked about CISA. That took us too long. We were kind of holding that, and I thought corroborate so we could actually do the full DHS reauthorization. The other thing she talked about was the fact that we have no authority to mitigate against the malign use of drones. I was shocked. Are you kidding me?

Fortunately, we had a video of an Islamic State of Iraq and Syria (ISIS) drone going over an Iraqi target, lowering itself, and then bombs away and pinpoint, destroying an Iraqi target. Fortunately, I had that because I could show it in a Committee Business Meeting, and at Senate lunch, and it got people's attention. Not enough to get it through the NDAA, which I tried to do, but finally through the Federal Aviation Administration (FAA) Reauthorization.

So there are ways of doing what I think needs to be done, but I would love to have everybody at this table in full agreement of what the action items certainly are, from a top-down approach, coming from the Federal Government, but then as a best practice, through industry, the bottom up.

I just met with the local utilities, the electric co-ops. They obviously do not want overregulation. I do not want to overregulate them, but I certainly want to recognize this problem and utilize the Federal Government because we are the only entity that can really provide this kind of direction to create action.

I could throw it open and say if anybody just has a burning desire to say something, I will let youif you want it. If you want to say a closing comment here, put your little name tage up, and you are going to get glares from your fellow panelists. [Laughter.]

Chairman JOHNSON. But if anybody wants to say something, I will let you. Otherwise, do your homework assignment, and please work with this Committee at determining what action steps we should take, how can we codify it, because these things, we will have to enact this into law. I think we have some good partners, talking to Senator Murkowski, talking to Senator Inhofe, talking to the Ranking Members, and talking to Senator Peters. We have some people here that recognize this is an issue, and that has not always been the case. I think we can actually do some good work here and help you improve your systems and keep this Nation safe.

So, again, thank you all for your testimony, for putting up with me. I look forward to working with you. It may not be vice versa, but let us work together and solve this problem, OK?

This business meeting is closed.

[Whereupon, at 4:31 p.m., the Committee meeting was adjourned.

APPENDIX

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance"
Opening Statement of Chairman Ron Johnson
February 27, 2019

As prepared for delivery:

We have known about the existential threat posed by electromagnetic pulses (EMP) and geomagnetic disturbances (GMD) for decades. Because most people are either unaware of the danger, or view these as very low probability events, there has not been sufficient public pressure to take effective action to mitigate these threats. Instead, we establish commissions and study panels, conduct research, and develop plans to develop strategies. It is way past time to stop admiring this problem, and actually begin to do something concrete to protect our vulnerable electrical grid, control systems, and the ever increasing array of electronic devices our society has become dependent upon.

We have known for almost 60 years that a high-altitude nuclear weapon can cause a destructive EMP. In 1961 and 1962, the former Soviet Union conducted a series of high-altitude nuclear tests in Kazakhstan, causing damage to communications systems, the power supply, and safety devices. The United States also conducted the STARFISH Prime test in 1962, and some EMP effects were felt approximately 900 miles away in Hawaii.

Similar to an EMP, we have known for almost 160 years that a GMD event can cause widespread damage to our nation's critical infrastructure. Severe GMD events have occurred in the past, including the September 1859 Carrington Event and the March 1989 Quebec Blackout. The National Academy of Sciences has estimated the economic impact of a severe space weather event - similar in strength to 1859's Carrington Event - from \$1 to \$2 trillion dollars in the first year alone. We also know that a GMD of that magnitude occurs once every hundred years. We are long overdue, having missed a solar storm of that size by only 9 days in July, 2012.

Dating back to 1997, Congress engaged in a number of oversight activities requiring the federal government to address the EMP and GMD threat. And yet, little progress has been made to mitigate these risks. In 2000, the Commission to Assess the Threat to the United States from Electromagnetic Pulse Attack was established to assess the risk of EMP events. The Commission produced reports with actionable recommendations in 2004, 2008, and 2017, but the federal government has not implemented most of these recommendations.

Our Committee has held three hearings on the EMP and GMD threat during the 114th and 115th Congress, passed the Critical Infrastructure Protection Act, and included language in the National Defense Authorization Act of 2017 to enable additional planning, research and development, and protection and preparedness. But now is the time to act.

Today, Ranking Member Peters and I have assembled a roundtable of key stakeholders that can "do something" to address the risk posed by EMPs and GMDs. We welcome representatives from the public, private, and nonprofit sectors, including representatives of companies that operate segments of the electric grid, both large and small. Although collaborative efforts are underway to research and test potential technologies, we must begin to identify solutions capable of fortifying the grid against an EMP and GMD event.

I would like to thank everyone for joining this roundtable. I look forward to engaging in a conversation with all of you here today, as well as with Chairman Murkowski and Ranking Member Manchin of the Energy and Natural Resources Committee, on potential solutions to this important problem.

U.S. Senate Committee on Homeland Security and Governmental Affairs

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance"

February 27, 2019

Ranking Member Gary Peters

Statement for the Record

Thank you, Mr. Chairman. I mentioned at our organizing meeting that I am looking forward to working with you to examine and strengthen the security of our nation. The Senate Homeland Security and Governmental Affairs Committee has a long history of conducting rigorous oversight and advancing bipartisan legislation.

I am confident that we will work together to continue that tradition.

I would also like to take a moment to again welcome our new Committee members, Senators Kyrsten Sinema, Jacky Rosen, Mitt Romney, Rick Scott, and Josh Hawley. It's the nature of Congress for committee membership to shift with every new session, but the important contributions of Senators Claire McCaskill, Heidi Heitkamp, and John McCain to this Committee, the institution of the Senate, and to our country will long endure.

The purpose of this roundtable to is hear perspectives from government, industry, academia and nonprofits on the threats posed by electromagnetic pulse (EMP) and geomagnetic disturbance, or GMD, events.

These threats have the potential to impact the electric grid, causing widespread power outages, disrupting daily life and could even cost our economy billions and possibly trillions of dollars in lost productivity.

During today's discussion, we will hear from experts about the possible catastrophic consequences of EMP or GMD threats, as well as what government can, and should, do to make our electric grid and other critical infrastructure resilient to these potential disasters.

I am particularly interested in safeguarding our infrastructure from space weather events, which are naturally occurring eruptions from the Sun.

In addition to harming the electric grid, space weather events also have the potential to disrupt cell phone communications, GPS satellites, air traffic control and other critical operations.

Despite the serious consequences posed by space weather induced GMDs, our understanding of these events and our ability to forecast them is lacking. Experts say our current capacity to predict space weather is so underdeveloped that it is comparable to our ability to predict weather on Earth a century ago.

In both of the last two Congresses, I introduced the Space Weather Research and Forecasting Act, a bill to advance our scientific understanding of these events, clearly define roles for the agencies responsible for prediction, and streamline U.S. government coordination in reacting to them. I intend to reintroduce the bill in the coming weeks.

Two of the panelists at this roundtable helped me refine this legislation over the years. Dr. Justin Kasper, University of Michigan Associate Professor of Space Science and Engineering, studies the impact of space weather on Earth and our ability to generate early warnings using satellite monitors in deep space.

His work as a principal investigator on NASA's Parker Solar Probe improves our understanding of the Sun and space weather events.

Caitlin Durkovich and I met during her tenure at the Department of Homeland Security (DHS) where she served as Assistant Secretary for Infrastructure Protection during the last administration. Her background as co-chair of the Space Weather Operations, Research and Mitigation (SWORM) Task Force, uniquely positions her as a valuable resource for the Committee's work on this topic.

Thank you to both Dr. Kasper and Ms. Durkovich for joining us today. I look forward to hearing from all of the panelists about how to protect our infrastructure and keep this nation safe.

RICK SCOTT
FLORIDA

United States Senate

ARMED SERVICES
HOMELAND SECURITY
COMMERCE, SCIENCE, AND TRANSPORTATION
BUDGET
SPECIAL COMMITTEE ON AGING

February 27, 2019

Chairman Ron Johnson
U.S. Senate Committee on Homeland Security
and Governmental Affairs
340 Dirksen Senate Office Building
Washington, DC 20510

Dear Mr. Chairman:

My apologies to the committee for my absence today. I am unable to attend the roundtable as I will be in Florida to honor the life of Master Sergeant Daniel Hinton, a fallen law enforcement officer.

Preparing against threats from Electromagnetic Pulse (EMP) or a Geomagnetic Disturbance (GMD) is extremely important to the safety of our nation, and I hope the dialogue today covers actions needed to prevent these potentially catastrophic events.

Sincerely,

Rick Scott
United States Senator

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Testimony of Assistant Secretary Karen S. Evans

Office of Cybersecurity, Energy Security, and Emergency Response

U.S. Department of Energy Before the

Committee on Homeland Security and Governmental Affairs

United States Senate

February 27, 2019

Chairman Johnson, Ranking Member Peters, and Members of the Committee, thank you for the opportunity to discuss the risks posed by electromagnetic pulses (EMPs) and highest extreme geomagnetic disturbances (GMDs) to our energy infrastructure and how the Department of Energy (DOE) is coordinating with other agencies and industry to help manage those risks.

Our economy, national security, and even the health and safety of our citizens depend on the reliable delivery of electricity. From his first days in office, Secretary Perry has conveyed that he has no higher priority than to support the security of our Nation's critical energy infrastructure. By the Secretary proposing and Congress affirming the Office of Cybersecurity, Energy Security, and Emergency Response (CESER), the Secretary clearly demonstrated his commitment to achieving the Administration's goal of energy security and, more broadly, national security.

CESER leads the Department's efforts to secure our Nation's energy infrastructure against all hazards, to reduce the risks of, and impacts from, cyber events and other disruptive events, and assist with restoration activities. This office works closely with the private sector, as well as Federal and SLTT (State, Local, Tribal, and Territorial) government partners, to enable more coordinated preparedness for and response to disruptions caused by natural and manmade events, such as severe weather, physical attacks, cyber-attacks, GMD, and EMP.

CESER has demonstrated our Emergency Response function through multiple weather events, including hurricanes, by activating our Emergency Response Organization. In 2018, CESER responded to a wide range of incidents, including six hurricanes, three wildfires, two typhoons, a cyclone, an earthquake, and a volcanic eruption. Recently, we worked closely with Federal, State, and industry partners to monitor the impacts to the energy sector from the January 2019 "arctic blast" that affected the central and eastern portions of the country.

Today, I would like to focus my testimony primarily on how CESER will meet the priorities of the Administration and Congress, and work in conjunction with our Federal agency, State, local, tribal, and territorial governments, industry, and National Laboratory partners to address enhancing security and resilience in the face of EMP and GMD risks.

Let me begin by discussing what these risks are and why DOE is addressing them. An electromagnetic pulse, or EMP, can be created by non-nuclear events and by the high-altitude detonation of a nuclear weapon. High-altitude electromagnetic pulse (HEMP) attacks have the potential to damage power delivery assets and impact bulk-power system reliability over a wide area. The resulting EMP is characterized by a high-magnitude, short duration pulse (E1), an intermediate pulse that has characteristics similar to lightning (E2), and a late-time pulse referred to as (E3), which is similar to an extreme geomagnetic disturbance (GMD) event.

GMDs caused by Coronal Mass Ejection (CMI) may result in geomagnetically-induced currents (GIC) in man-made structures such as rail lines, pipelines, electric transmission lines, and some communications lines. DOE is concerned about the impacts of GIC flows on power transformers. Transformer damage, although highly unlikely even in the most extreme storms, is possible and in certain situations can destabilize the electric grid if proactive measures are not undertaken (e.g. reducing load).

DOE's role in addressing energy sector risks and energy sector security is well established. From the Department's role in nuclear security through the National Nuclear Security Administration (NNSA) to the ground-breaking grid modernization research at our National Laboratories, DOE has the expertise and relationships to support the energy sector and help protect its critical infrastructure in coordination with the Department of Homeland Security (DHS) and other Federal and non-Federal stakeholders. CESER is leading efforts within DOE to take the necessary steps to develop cost-effective strategies for all hazards to mitigate, respond to, and recover from potential disruptions. For addressing EMP risks, we have a multi-pronged approach: sharing knowledge and expertise with industry on a timely basis; allowing the electric subsector to advance readiness for potential EMP impacts through research to quantify the risk; and scientific development of mitigation strategies, and analysis of the policies needed for the future.

DOE's role in energy sector security is described in both statute and Presidential directive. For example, Section 215A of the Federal Power Act provides that the Secretary of Energy may order emergency actions related to grid operations during a Presidentially-declared grid security emergency caused by a high impact event, such as an EMP attack. In light of that statutory responsibility, the Department has enhanced planning for events such as EMP to ensure the President and our Nation are ready to respond.

Within the very first few days of CESER's establishment in 2018, our senior staff reached out to key Federal agency officials that have shared responsibilities in the energy sector. As an example, in our initial discussions with the Nuclear Regulatory Commission (NRC) on the issue of EMP risks, a study commissioned by the NRC that concluded that nuclear power plants can safely shut down following an EMP event was reviewed.

DOE's work on EMP builds upon the findings of the Joint Electromagnetic Pulse Resilience Strategy (Joint Strategy) issued in 2016, which represented a collaboration between DOE and the Electric Power Research Institute (EPRI). The Joint Strategy reflects a shared vision of how industry and government should best proceed to understand, manage, and mitigate EMP risks to the electric grid. The Joint Strategy included five strategic goals: 1) Improve and Share

Understanding of EMP: Threat, Effects, and Impacts; 2) Identify Priority Infrastructure; 3) Test and Promote Mitigation and Protection Approaches; 4) Enhance Response and Recovery Capabilities to an EMP Attack; and 5) Share Best Practices Across Government and Industry, Nationally and Internationally. In furtherance of the Joint Strategy, DOE developed an Electromagnetic Pulse Resilience Action Plan that refines and directs the Department's efforts to reduce EMP vulnerabilities and improves the energy sector's response and recovery after EMP events through coordination with the whole of government, national labs, industry, and international partners.

To implement the Joint EMP Resilience Strategy, DOE has been working on GMD and EMP projects over the past several years to improve our understanding of the effects and expected impacts and to share these findings with government and industry partners. DOE is continually undertaking efforts to address the EMP risks to the electric grid and to understand what measures can mitigate its potential adverse impacts. We are continuing to close gaps we have identified in our understanding and beginning to test, evaluate, and validate mitigation and protection technologies on the grid.

DOE's recently completed reports include: the "Vulnerability of the Electric Grid to an Electromagnetic Pulse and the Potential Impact on Electric Power Delivery and Reliability" released in June 2018; the "Geomagnetic Disturbance Monitoring Approach and Implementation Strategies" dated November 2018; an unclassified EMP overview titled the "High Altitude Electromagnetic Pulse (HEMP) and The Electric Grid; A Brief Overview" report; and an October 2018 classified tri-lab assessment of the impacts of EMP on the electric grid titled "Assessment of the Impacts of EMP on the Electric Grid."

Ongoing projects include: improving unclassified E3 waveforms, code and databases, (to be able to share EMP effects with our partners); enhancing the Nation's EMP and GMD capabilities through CE-SMART (Center for EMP/GMD Simulation, Modeling, Analysis, Research, and Testing); and implementing a pilot project to field deploy and evaluate technologies to mitigate the effects GMD and the E3 from EMP on the electric grid. We also plan to develop a hardening and resilience roadmap this year specifying what can and should be done, working with industry partners with available resources, to deploy technologies to protect critical components, equipment, and systems on the electric grid from EMP and GMD effects and impacts.

DOE is also collaborating with the CEO-led Electricity Subsector Coordinating Council's (ESCC)'s task force to coordinate with the government and other critical infrastructure sectors on a national effort to enhance resilience against EMP, GMD, and other high-impact, low frequency events. Notably, DOE and the ESCC task force are supporting EPRI's EMP Project, which will determine the vulnerability of and mitigation approaches for high-voltage and electronic equipment installed on the transmission system to EMP/GMD; provide a scientific basis for investments to mitigate EMP/GMD risks to the energy grid; and inform response and recovery efforts.

DOE is fully committed to helping forge the grid of the future that will be more resilient to all hazards, including EMP/GMD. Continued progress in grid modernization is vital to helping us protect the grid from EMP and GMD.

Furthering those goals, CESER considers one of its core missions to be the improvement of the mutual understanding and trust between the electric industry and government. These productive relationships are necessary to improve our ability to respond to EMP and GMD and other potential high impact but low frequency events. One measure of success of the productive nature of our relationships is evidenced in the exercises undertaken and the lessons learned from those exercises.

DOE sponsors and participates in hundreds of preparedness exercises annually, focusing on the energy sector, as well as and broader emergency management hazards and situations. Two DOE-sponsored exercise series include Clear Path, the Department's cornerstone all-hazards-focused exercise series, and Liberty Eclipse, the flagship cybersecurity-focused exercise series. Both exercise series stress the building of relationships within the energy sector and the importance of closing identified gaps found in past exercises and real world incidents.

In 2018, DOE also participated in a National Security Council (NSC)-sponsored exercise which focused on a GMD incident for the purposes of reviewing government authorities under the Fixing America's Surface Transportation (FAST) Act (Public Law 114-94). Findings from that exercise contributed to the strengthening of the NSC's communications protocol and expectations in the event of a GMD.

Similarly, DOE understands the importance the results of these exercises have on informing updates to our response plans on a continuous basis, and specifically addressing identified gaps in coordination with our industry, government, and coordinating council partners.

Communications capabilities that are survivable, reliable, and accessible, by both industry and government, will be key to coordinating various efforts showcased in the exercise, including the unity of messaging required to successfully coordinate recovery from a real-world version of the exercise scenario.

In preparation for any future grid security emergency, it is critical that we continue working with our government and industry partners to further shape the types of orders that may be executed under current authorities, while also clarifying how we communicate and coordinate the operational implementation of these orders. We recently worked with the North American Transmission Forum as they developed proposed Fast Act Grid Security Emergency options that could be directed before, during, and after the highest extreme GMDs. Continued coordination with Federal, SLTT, and industry partners and leadership in preparedness activities such as Liberty Eclipse, enables DOE to identify gaps and develop capabilities to support appropriate responses.

Establishing CESER was the result of the Administration's commitment to and prioritization of energy security and national security. Our long-term approach strengthens our national security and positively impacts our economy.

I appreciate the opportunity to appear before this Committee to discuss efforts to address EMP and GMD risks to the energy sector, and I applaud your leadership. I look forward to working with you and your respective staffs to continue to address EMP and GMD risks, as well as other cyber and physical security challenges.

Testimony

Brian Harrell
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FOR A HEARING ON

Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance

BEFORE THE
UNITED STATES SENATE
COMMITTEE ON HOMELAND SECURITY AND GOVERNMENTAL AFFAIRS

February 27, 2019

Washington, DC

Chairman Johnson, Ranking Member Peters, and members of the Committee, good morning and thank you for the opportunity to discuss the U.S. Department of Homeland Security's (DHS) ongoing efforts to secure our Nation's critical infrastructure against threats from electromagnetic pulses (EMP) and geomagnetic disturbances (GMD).

As a short introduction, I am the Assistant Director for Infrastructure Security within the Cybersecurity and Infrastructure Security Agency (CISA) at DHS. I want to thank all of you for your leadership in passing the *Cybersecurity and Infrastructure Security Agency Act of 2018*. I appreciate the interest of this Committee on threats from EMP and GMD. While I am new to my current role, I previously served as the Managing Director of Enterprise Security for Duke Energy and I am the former Director of Critical Infrastructure Protection Programs at the North American Electric Reliability Corporation (NERC), so I am very familiar with the risk management issues we are discussing today.

CISA serves as the Nation's risk advisors for critical infrastructure owners and operators. We lead the national effort to secure and protect critical infrastructure from all threats and hazards, to include EMP and GMD. CISA's primary role in managing EMP and GMD risks is through cross-sector coordination and information sharing, to ensure stakeholders have access to current information on risks and any resources to assist with mitigation efforts. This includes sharing information on EMP and GMD risks with stakeholders through a variety of mechanisms, including: Sector Coordinating Councils (SCCs), Government Coordinating Councils (GCCs), Cross-Sector Councils, and Information Sharing and Analysis Centers (ISACs), among other fora.

The potential effects from nuclear EMP and GMD events on critical infrastructure are related, and some risk mitigation measure may have synergies. However, the threat is very different, and so it is important to address them separately for clarity. Regarding the current threat for nuclear EMP attacks, analysis completed by the the Intelligence Community (IC) and the nuclear weapons community provides periodic joint assessments of the nuclear weapons capabilities of foreign countries, including their capacity to generate EMP attacks. The IC currently has no specific, credible information indicating that there is an imminent threat to critical infrastructure from an EMP attack. However, the consequences of a successful nuclear EMP attack using a nuclear weapon detonated at high altitude are potentially severe, and may include long-term damage to significant portions of the Nation's electric grid and communications infrastructure. Under joint DHS and U.S. Department of Energy (DOE)funding, the United States nuclear weapons laboratories most recently completed a preliminary nuclear EMP impacts assessment in April 2018 for the Nation's bulk electric power system. This study developed a spectrum of EMP attack scenarios and estimates of potential impacts. Although additional work is required, this study provides a basis for more advanced risk assessments in the electric sector and a framework for risk assessments in other sectors. DHS, in collaboration with interagency partners, is working to provide owners and operators of critical infrastructure with the resulting information and frameworks to help them manage the risk of electromagnetic events.

Regarding the threat from GMD, DHS is co-leading an Administration-wide effort to develop an updated implementation plan for the U.S. Government's National Space Weather

Strategy and Action Plan that addresses the mix of short- and medium-term objectives laid out in that plan. The Department's focus is on risk mitigation for critical infrastructure from EMP and GMD effects as well as emergeny preparedness planning. The prioritization of efforts undertaken by DHS will derive from this plan and will be coordinated with industry groups, our interagency partners, and the research and development community to ensure that DHS resources are providing value. The DHS efforts on GMD will also benefit some aspects of assessing and mitigating the effects of nuclear EMP attacks. It should be noted that the electric industry, through NERC and Federal Energy Regulatory Commision (FERC) have already taken steps to screen for and mitigate the effects of GMD at many utilities in the country.

All critical infrastructure sectors are, to some degree, at risk from EMP and GMD events due to the potential loss of critical functions. However the precise extent of critical infrastructure vulnerabilities to such events remain uncertain. We acknowledge that sectors like energy and communications are of greatest concern due to their vulnerabilities to EMP, however, other sectors are also at risk due to their dependencies on these two sectors. For those reasons, relative to other sectors, there have been a lot of energy and communications sector activities to mitigate EMP and GMD threats. This activity is important.

EMP and GMD threats present specific risks to the communications sector, which has a cascading effect on other sectors that depend on communications for daily operations. As the Sector-Specific Agency (SSA) for the Communications Sector, CISA has worked with federal, local, state, and private sector stakeholders on EMP and GMD issues. CISA provides regular briefs to the Communications Sector at the federal, state, and local levels on the evolving threat and risk of EMP attacks, and published EMP Protection and Restoration Guidelines for Equipment and Facilities in 2016.

In an effort to broaden the focus on EMP risk, DHS finalized a strategy to protect and prepare the Nation's critical infrastructure against EMP events in October 2018. The Strategy sets strategic goals that promote risk awareness, outlines preparedness actions to reduce the impacts from EMP and GMD events, and lists activities to facilitate response and recovery should an EMP or GMD incident occur. DHS is currently developing an Implementation Plan for the Strategy, which will identify responsibilities across the Department and key activity milestones for achieving Departmental goals to protect the Nation's critical infrastructure from a major electromagnetic incident. CISA recently hired a senior official to function as DHS's EMP Coordinator to serve as a subject matter expert and central point of contact to ensure we advance EMP and GMD activities in a coordinated manner. Together with our partners in the interagency and the private sector, we can now better understand the risks from EMP and GMD threats and implement appropriate mitigation actitivities.

Thank you again for this opportunity and I look forward to discussing further DHS's efforts in securing our critical infrastructure from EMP and GMD.

Electromagnetic Events Roundtable Discussion
February 27, 2019

Key GAO Findings and Recommendations (2016-2019)

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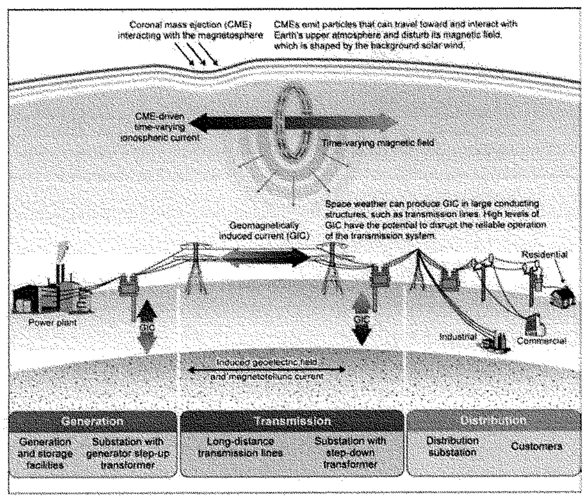
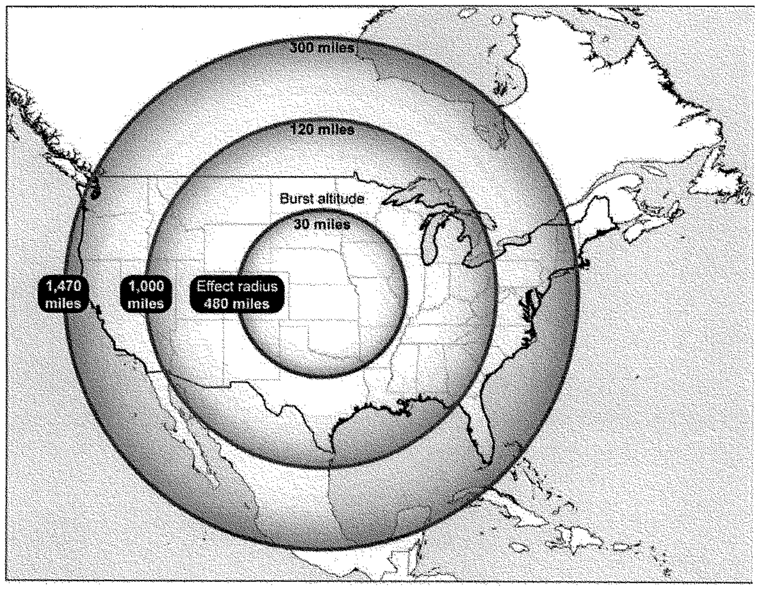
Summary: Since 2016, GAO issued three reports reviewing aspects of electromagnetic events. Such events are characterized as geomagnetic disturbances (GMDs) or electromagnetic pulses (EMPs). GMDs are a result of solar weather—conditions in the solar system that are driven by emissions from the sun. Solar emissions that are directed toward Earth interact with its magnetic field and can cause GMD that can disrupt the normal operations of a variety of technologies including satellites, communications networks, and navigation systems. EMPs are from human-made sources, such as the high-altitude detonation of a nuclear device to create a high-altitude electromagnetic pulse (HEMP).[1] A HEMP event can result in a burst of electromagnetic radiation that can disrupt or destroy electronic equipment.

Coronal mass ejections cause geomagnetic disturbances that may interact with the electric power grid



[1]Non-nuclear EMP weapons—those that produce electromagnetic radiation such as devices that generate localized EMP using microwave-type technologies—can also be designed to intentionally disrupt electronics, but these weapons generally have a short range and are not a threat to multiple assets. For example, a non-nuclear EMP weapon might damage a power substation but would not widely affect the electric grid.

Estimated Impact Area of High-Altitude Electromagnetic Pulse (HEMP), by Height of Burst



Source: Gary Smith, "Electromagnetic Pulse Threats," Testimony before the House Committee on National Security (July 16, 1997); MapInfo (map). | GAO-18-67

GAO's previous related reports covered a variety of electromagnetic issues, including:

1) *federal role in addressing GMD and EMP risks*
2) *electricity supplier activities to address GMDs/EMP risks*
3) *technology available for mitigating GMD effects*
4) *status of research on GMD/EMP effects*

In GAO's 2016 review of the federal role in addressing both GMDs and EMPs, GAO made 2 recommendations to the Department of Homeland Security (DHS) and 2 recommendations to both DHS and the Department of Energy (DOE). Subsequently, as of February 2019, DHS fully implemented both of its recommendations and DHS/DOE fully implemented 1 of 2 recommendations directed to both departments. DHS and DOE are taking actions to address the remaining open recommendation, discussed in more detail below.

1. Federal agency actions to address electromagnetic risks to the electric grid

In 2016, GAO found that key federal agencies had taken various actions to address electromagnetic risks to the electric grid, and some actions align with the recommendations made in 2008 by the Commission to Assess the Threat to the United States from

Electromagnetic Pulse Attack (EMP Commission).[2] Since 2008, DHS, DOE, and the Federal Energy Regulatory Commission (FERC) have taken actions such as establishing industry standards and federal guidelines, and completing EMP-related research reports. GAO found that their actions aligned with some of the EMP Commission recommendations related to the electric grid. For example, DHS developed EMP protection guidelines to help federal agencies and industry identify options for safeguarding critical communication equipment and control systems from an EMP attack.

GAO also reported that opportunities existed to enhance federal efforts to coordinate and address electromagnetic risks to the electric grid and made several recommendations.

- **Recommendation**: GAO recommended that DHS designate roles and responsibilities within the department for addressing electromagnetic risks and communicate these to federal and industry partners.
  Status: **Implemented**: In August 2017, the DHS Office of Strategy, Policy, and Plans provided GAO with documentation regarding the status of ongoing DHS efforts to develop an EMP/GMD Strategy in consultation with federal and industry partners, as called for in the National Defense Authorization Act for 2017. As part of this effort, DHS identified for partners the DHS components that comprised the EMP/GMD Strategy Working Group including a description of their key roles and responsibilities related to addressing electromagnetic risks.

- **Recommendation**: GAO recommended that DHS and DOE direct responsible officials to review FERC's electrical infrastructure analysis and collaborate to determine whether further assessment is needed to adequately identify critical electric infrastructure assets.
  Status: **Not fully implemented:** As of February 2019, GAO was awaiting additional information about DHS' plans to implement actions identified in its EMP/GMD Strategic Plan regarding DHS's determination of critical utilities and national security assets at risk from EMP and GMD events. GAO is also monitoring DOE efforts to develop a North American Energy Model that DOE officials reported would also help identify critical electric infrastructure assets.

- **Recommendation**: GAO recommended that DHS work with other federal and industry partners to collect and analyze key inputs on threat, vulnerability, and consequence related to electromagnetic risks.
  Status: **Implemented**. In June 2016, DHS reported that the department completed the planned refresh of the Strategic National Risk Assessment, which incorporated information on potential impacts to the power system from electromagnetic events. In June and November 2017, DHS provided additional documentation identifying joint efforts between DHS's then National Protection and Programs Directorate and DOE to enhance federal efforts to analyze the hazard environments, impacts, and consequences of EMP and GMD on U.S. electric power infrastructure.

- **Recommendation**: GAO recommended that DHS and DOE direct responsible officials to engage with federal partners and industry stakeholders to identify and implement key

[2]GAO, *Critical Infrastructure Protection: Federal Agencies Have Taken Actions to Address Electromagnetic Risks, but Opportunities Exist to Further Assess Risks and Strengthen Collaboration,* GAO-16-243 (Washington, D.C.: March 24, 2016).

EMP research and development priorities, including opportunities for further testing and evaluation of potential EMP protection and mitigation options.

Status: Implemented. In June 2016, DHS reported completion of key activities to address this recommendation, including (1) further engagement with DOE and a coordinating council for federal, state, and industry partners to develop a joint government and industry approach to addressing EMP events, and (2) ongoing utilization of the DHS Science and Technology Directorate's process for identifying and pursuing additional opportunities to address potential EMP research and development capability gaps. In January 2017, DOE issued the Electromagnetic Pulse Resilience Action Plan. This document serves to further refine and direct the Department's efforts to reduce EMP vulnerabilities and improve the energy sector's response and recovery after EMP events through coordination with interagency partners and non-federal stakeholders. The Action Plan identifies specific deliverables and associated timeframes. Among these are specific actions to test and promote mitigation and protection approaches, such as developing and validating EMP test requirements. DOE also reported that, as of September 2017, they had funded additional research to test and evaluate GMD Mitigation Devices.

2. <u>Electricity supplier actions to address electromagnetic risks</u>

In February 2018, GAO reported that electricity suppliers had identified information on GMD and HEMP effects on the grid and most suppliers GAO interviewed had taken some steps to protect against GMD and HEMP.[3]

- U.S. and Canadian electricity suppliers—electricity generation and transmission owners and operators—have identified information on the potential effects of a severe GMD, resulting from a solar storm, but have identified less information about the potential effects of a HEMP, resulting from the detonation of a nuclear device, on the electric grid.
    - Government and industry have publicly reported on the potential impacts of GMD on the grid. For example, one study identified two main risks: (1) potential voltage instability, causing power system collapse and blackouts; and (2) possible damage to key system components. However, these studies do not address the unique aspects of individual suppliers' networks. Recognizing this, 11 of the 13 selected suppliers GAO contacted said they had assessed their network vulnerability; of these 11, 6 expected GMD effects to be relatively small.[4]
    - In contrast, DOE and industry officials told GAO that information on HEMP effects is limited in that suppliers lack key information to fully understand HEMP effects on their networks. Historically, the study of HEMP effects focused on impacts to military equipment rather than the commercial electric grid. Recently,

[3]GAO, *Critical Infrastructure Protection: Electricity Suppliers Have Taken Actions to Address Electromagnetic Risks, and Additional Research Is Ongoing,* GAO-18-67, (Washington, D.C.: Feb. 7, 2018).

[4]Of the remaining 5 suppliers, four did not characterize what their studies revealed with respect to the potential severity of the impact and one supplier had not completed its study. The 13 suppliers GAO interviewed were a nongeneralizable sample of 13 U.S. and Canada electricity suppliers, selected based on factors such as GMD experience and preparation for GMD and HEMP events.

DOE and industry began research to better understand HEMP effects. Of the 11 suppliers who responded to GAO about their HEMP efforts, 3 reported having studied the impact of HEMP on their networks.

- Of the 13 selected suppliers GAO contacted, 10 reported making technological and operational improvements to enhance overall network reliability that also provided some protection against GMD and HEMP risks. For example, suppliers reported making technological improvements such as replacement of some older transformers and unprotected control centers. As of May 2017, all 13 suppliers stated they had complied with a GMD regulatory standard issued by the North American Electric Reliability Corporation (NERC)—the federally designated regulatory authority responsible for developing and enforcing reliability standards—to develop operating procedures to mitigate GMD effects.[5] A second regulatory standard—which is to be implemented in phases through 2022—will generally require suppliers to further assess their vulnerability to GMD.

Electricity suppliers GAO interviewed also described the range of costs incurred to protect against GMD and HEMP.

- Projects providing collateral GMD or HEMP protection at no specific, incremental cost—series compensation systems installed on transmission lines, replacement of older electro-mechanical protective relays used in the suppliers' grid control systems with newer digital relays, and acquisition of spare transformers or participation in shared spare transformer programs.
- Projects providing supplemental GMD or HEMP protection at minimal added cost—transformers and other transmission equipment used to control voltage levels can be made more resistant to GMDs by using certain designs or materials (2-3%+ in cost). Also, added HEMP protection to the design of new control centers has increased total project costs from about 5 to approximately 20 percent.
- Projects built primarily for GMD or HEMP protection—blocking device, with one required per transformer ($500,000); hardened control centers ($10 million); and plans or procedures to mitigate for GMD (costs vary considerably depending on level of demand and electricity generation resources available during the event).

3. **<u>Technologies available or in development that could help prevent or mitigate the effects of GMDs on the U.S. electric grid</u>**

In December 2018, GAO reported that some types of electric power transmission equipment currently in use can help prevent or mitigate the effects of GMDs.[6]

- The use of transformer designs, such as those with non-magnetic structural components and certain three-phase transformers, can limit the effect of geomagnetically induced current on transformers. The effect of geomagnetically induced current (GIC) on

[5]See NERC Reliability Standard EOP-010-1 (approved by FERC at Order No. 797, Reliability Standard for Geomagnetic Disturbance Operations, 147 F.E.R.C. ¶ 61,209, 79 Fed. Reg. 35,911 (2014)).

[6]GAO, *Critical Infrastructure Protection: Protecting the Grid from Geomagnetic Disturbances,* GAO-19-98 (Washington, D.C.: Dec. 19, 2018).

transformers is the root cause of nearly all GIC-induced disturbances in power transmission systems.[7]

- The use of auxiliary equipment, such as series capacitors and digital protective relays, can reduce the risk of service outages from GIC.
- Inductors or resistors on neutral grounds are generally used for safety purposes, but they can also reduce GMD effects, though their effectiveness is uncertain.

Technologies designed specifically to limit geomagnetic disturbance effects hold promise, but are not ready for widespread operational deployment.

- One system was developed, operationally tested, and piloted, known as neutral capacitor technology. However, following initial operational tests, the transmission system operator stated that the system was not yet ready for widespread deployment. The primary advantages of neutral capacitors over series capacitors are that only one neutral blocking capacitor is needed per transformer instead of three series capacitors, and therefore they may be less costly.

4. Research on GMD and HEMP effects on the electric grid

GMD effects

In December 2018, GAO reported that federal policymakers face three broad questions that need to be addressed regarding GMD effects on the electricity grid: (1) What is the likelihood of a large scale GMD? (2) What is the risk such storms pose to the electricity grid? and (3) What are potentially effective solutions to mitigate the effects of a large scale GMD?[8] Efforts are under way to address aspects of each question that will help inform whether additional actions are needed to prevent or mitigate the effects of GMDs on the U.S. electric grid. For example:

- NERC and the Electric Power Research Institute (EPRI) collaboratively developed a GMD research plan in response to FERC direction. This plan, in part, proposes to develop guidelines and tools to perform system-wide assessment of GIC-induced harmonics which, when completed and implemented, should improve the understanding of the effects that large GMDs and its resulting GIC flow could have on grid performance.
- NASA scientists and other researchers are exploring the physical limit of GMD.
- Vendors are developing and beginning to release GIC packages for commercially-available grid modeling tools that allow utilities to model the effects of GMD on their systems.

According to NERC, the ongoing research will advance understanding of GMD events and the potential impact on the reliable operation of the electric transmission grid.

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[7]Strong GMDs can create large GIC on the grid. The degree to which GMD and accompanying GIC affect the electric power system depends on several factors, including the magnitude of the GMD, design and geomagnetic latitude of the power system, and geology of the local area, among other things.

[8]GAO-19-98.

HEMP effects

In February 2018, GAO reported that, according to DOE, more research is needed to fully investigate and evaluate how an electric utility could protect itself from, or mitigate the effects of, HEMP on its systems.[9] DOE also noted that government and industry have ongoing research efforts to better understand these potential effects and develop possible mitigation measures. For example, DOE has three ongoing research efforts related to HEMP. First, DOE is collaborating with DHS to advance the understanding of HEMP effects on the grid through research at the Los Alamos National Laboratory. Second, DOE has funded efforts underway at the Idaho National Laboratory focused on developing potential HEMP strategies, protections, and mitigations for the electric grid—including hardening of infrastructure, blocking of currents, developing a strategy for stocking and prepositioning of spare parts, as well as developing operational and emergency planning tools. Finally, DOE has enlisted the Oak Ridge National Laboratory in analyzing the vulnerability of the grid to a HEMP event, along with the potential damage from such an event, and how it would impact on the reliability and delivery of electric power.

[9]GAO-18-67.

Testimony of Joseph McClelland
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Federal Energy Regulatory Commission

Roundtable on "Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance" Before the Committee on Homeland Security and Governmental Affairs
United States Senate February 27, 2019

Chairman Johnson and Ranking Member Peters:

Thank you for providing me with the opportunity to participate in this roundtable discussion and provide some perspectives on efforts to protect the United States bulk power system from electromagnetic pulse (EMP) and geomagnetic disturbance (GMD). My name is Joe McClelland and I am the Director of the Federal Energy Regulatory Commission's Office of Energy Infrastructure Security. I am here today as a member of the Commission staff and my remarks do not necessarily represent the views of the Commission or any individual Commissioner.

The Federal Energy Regulatory Commission's authorities pertain to certain aspects of the U.S. hydroelectric, oil, natural gas and electrical infrastructures. Relative to the U.S. electric grid, the Commission regulates wholesale sales and transmission of electricity, ensuring that rates, terms and conditions of sale are just, reasonable, and not unduly discriminatory. The enactment of the Energy Policy Act of 2005 gave the Commission a major new responsibility to approve and enforce mandatory reliability standards for the Nation's bulk power system. This authority is in section 215 of the Federal Power Act. It is important to note that FERC's jurisdiction and reliability authority under section 215 is limited to the "bulk power system," as defined in the FPA, which excludes Alaska and Hawaii, as well as local distribution systems. Under the section 215 authority, FERC cannot author or modify reliability standards, but must depend upon an Electric Reliability Organization (or ERO) to perform this task. The Commission certified the North American Electric Reliability Corporation or NERC as the ERO. The ERO develops and proposes new reliability standards or modifications to existing standards with industry for the Commission's review, which it can either approve or remand. If the Commission approves a proposed reliability standard, it becomes mandatory in the United States and is applicable to the users, owners and operators of the bulk power system. If the Commission remands a proposed standard, it is sent back to the ERO for further consideration. The Commission is required to give "due weight" to the technical expertise of the ERO when reviewing any of NERC's proposed standards.

Section 215 of the Federal Power Act provides a statutory foundation for the ERO to develop reliability standards for the reliable operation of the bulk power system. However, the consequences of a severe naturally-occurring event or a national security threat by entities intent on attacking the U.S. by exploiting vulnerabilities in its electric grid using physical or cyber means stands in stark contrast to other major reliability events that have caused regional blackouts and reliability failures in the past. Widespread disruption of electric service can undermine the security of the U.S., its government, military, and the economy, as well as endanger the health and safety of its citizens. Given the national security dimension to this threat, it is imperative that action be taken quickly and effectively protect America's energy infrastructures from all forms of attacks including, cyber and physical as well as EMP and GMD.

For these reasons, the Commission uses a dual-fold approach; employing both mandatory standards to establish foundational practices while also working collaboratively with industry, the states and federal agencies to identify and promote best practices to mitigate advanced threats. Specific to the topic of this roundtable, GMD and EMP events are generated from either naturally occurring or man-made causes. In the case of GMDs, naturally occurring solar magnetic disturbances periodically disrupt the earth's magnetic field which in turn, can induce currents on the electric grid that may simultaneously damage or destroy key transformers over a large geographic area. Regarding man-made events, EMPs can be generated by devices that range from small, portable, easily concealed battery-powered units all the way through missiles equipped with nuclear warheads. In the case of the former, equipment is readily available that can generate localized high-energy bursts designed to disrupt, damage or destroy electronics such as those found in control systems on the electric grid. The EMP generated during the detonation of a nuclear device is far more encompassing and generates three distinct effects, each impacting different types of equipment; a short high energy radio-frequency-type burst called E1 that can destroy electronics; a slightly longer burst that is similar to lightning termed E2; and a final effect termed E3 that is similar in character and effect to GMD, with the potential to damage transformers and other electrical equipment. Any of these effects can cause voltage problems and instability on the electric grid, which can lead to wide-area blackouts.

In 2001, Congress established a commission to assess and report on the threat from EMP. In 2004, 2008 and most recently in 2017, the EMP Commission issued reports on these threats. One of the key findings in the reports was that a single EMP attack could seriously degrade or shut down a large part of the electric power grid. Depending upon the attack, significant parts of the electric infrastructure could be "out of service for periods measured in months to a year or more." It is important to note that effective mitigation against solar geomagnetic disturbances and non- nuclear EMP weaponry can also provide an effective mitigation against the impacts of a high-altitude nuclear detonation.

In order to better understand and quantify the effect of EMP and GMD on the power grid, FERC staff, the Department of Energy (DOE) and the Department of Homeland Security (DHS) sponsored a study conducted by the Oak Ridge National Laboratory in 2010. The results of the study support the general conclusion of prior studies that EMP and GMD events pose substantial risk to equipment and operation of the Nation's electric grid and under extreme conditions could result in major long-term electrical outages. Unlike EMP attacks that are dependent upon the capability and intent of an attacker, GMD disturbances are inevitable with only the timing and magnitude subject to variability. The Oak Ridge study assessed a solar storm that occurred in May 1921, which has been termed a 1-in-100 year event, and applied it to today's electric grid. The study concluded that such a storm could damage or destroy over 300 bulk power system transformers interrupting service to 130 million people with some outages lasting for a period of years. From the time of that study however, others have concluded that the power grid may collapse before significant damage was done to transformers; resulting in a potentially wide-spread, but relatively short, power outage.

To date, a few U.S. entities have taken some steps to address EMP on their systems. Efforts such as EMP hardening of power control centers and substation control buildings have been implemented but much work remains. Internationally, the United Kingdom, Norway, Sweden, Finland, Germany, South Korea, Japan, Australia, New Zealand, South Africa, Israel and Saudi Arabia have GMD and/or EMP programs in place or are in the early stages of addressing or examining the impacts of GMD or EMP. The costs of these initiatives can vary widely depending on factors such as the threshold of protection, the service requirements of the load, the type of equipment that is to be protected, and whether the installation is new or a retrofit.

In response to the GMD threat, the Commission convened a technical conference in April of 2012 inviting subject matter experts from industry and government with diverse views on the effects of a GMD event. A general consensus from this conference was that a wide-spread outage resulting from a GMD event should be prevented. Based on the record, the Commission has initiated action under both the establishment of baseline standards and the identification and promotion of best practices to help address GMD events.

Regarding the establishment of mandatory standards, beginning in May 2013, the Commission directed NERC to develop and submit for approval proposed reliability standards that address the impact of geomagnetic disturbances on the reliable operation of the Bulk-Power System in two stages.

Stage 1, which was approved in June 2014, requires entities to develop plans and implement operator action in response to a GMD event. Stage 2, which was approved by the Commission in September of 2016 requires entities to perform GMD vulnerability assessments and develop corrective actions as necessary to address the threats. From this time, the standards have continued to evolve requiring the GMD assessments to be completed by 2023, completion of the corrective action plans by 2024, and implementation in two stages; non-hardware mitigation by 2026 and hardware mitigation by 2028.

Simultaneous with its standards activities, the Commission continues to collaborate with other federal agencies and industry members to identify key energy facilities, conduct threat briefings to industry members on GMD and EMP threats and assists with the identification and adoption of best practices for mitigation of these threats.

FERC's regulatory authority with respect to rates also may be relevant to addressing these issues. For example, FERC issued a policy statement entitled "Security Cost Recovery Policy Statement", on September 14, 2001, three days after the September 11, 2001 attacks. That two-paragraph policy statement stated that FERC would "approve applications to recover prudently incurred costs necessary to further safeguard the reliability and security of our energy supply infrastructure in response to the heightened state of alert." Further examples include subsequent orders by FERC providing clarity on how it will address services provided by the Edison Electric Institute and Grid Assurance for emergency spare transmission equipment. Work in this area is ongoing, with FERC and DOE recently announcing a Security Investments for Energy Infrastructure Technical Conference on March 28, 2019. The purpose of the conference will be to discuss current cyber and physical security practices used to protect energy infrastructure and will explore how federal and state authorities can provide incentives and cost recovery for security investments in energy infrastructure, particularly the electric and natural gas sectors.

FERC continues to prepare for a more EMP and GMD resilient grid through collaboration on federal, state and international levels. Including participation in DOE's Electric Sector Coordinating Council, the Energy Infrastructure Security Council's national and international efforts to foster collaboration on both foundational and best practices for EMP and GMD preparedness, briefings to the

EMP Commission and collaboration with DHS, DOE, the Department of Defense, the national laboratories, and industry including the Electric Power Research Institute (EPRI) the electric industry's research organization. The Commission also participates as a member of the Space Weather Operations, Research, and Mitigation (SWORM) Subcommittee studying the threats, vulnerabilities and best practices to address them. Among the accomplishments of this subcommittee has been the issuance of the National Space Weather Strategy and the Space Weather Action Plan which developed high-level strategic goals for enhancing national preparedness for a severe space weather event. In addition, FERC continues to assist both DOE and DOD to identify defense-related critical electric infrastructure as directed under the FAST Act, thereby assisting with their decisions regarding EMP and GMD protection at these facilities. As a final example, FERC also provides outreach to the states through meetings, closed briefings and participation on panel sessions with public utilities and regulatory commissions.

In conclusion, EMP and GMD threats pose a serious threat to the electric grid and its supporting infrastructures that serve our Nation. The Commission is taking both a standards and a collaborative approach to protect and provide a more resilient electric grid to these threats.

Testimony of Dr. George H. Baker
Professor Emeritus, James Madison University
Director, Foundation for Resilient Societies

United States of America
Before the
Senate Committee on Homeland Security and Governmental Affairs
February 27, 2019

Many thanks to Senator Johnson and Senator Peters for this opportunity to share my thoughts on the protection of our critical national infrastructure against the wide-area electromagnetic threats posed by the nuclear electromagnetic pulse (EMP) and solar storm geomagnetic disturbances (GMD). Protection is urgently needed to assure electric power grid reliability.

My name is George Baker and I have spent most of my professional career protecting the U.S. military from the nuclear electromagnetic pulse (EMP). At the Defense Nuclear Agency and successor Defense Threat Reduction Agency (DTRA), I managed the development of the military standards used to protect and test Department of Defense (DoD) systems against EMP. I also directed the Springfield Research Facility, DTRA's assessment arm, responsible for vulnerability assessments of critical military facilities and supporting infrastructure and organizing and deploying the initial Joint Chiefs of Staff (JCS) Force Protection vulnerability assessment teams. In my second career as an academic, I directed James Madison University's Institute for Infrastructure and Information Assurance, developed courses on complex infrastructure systems and how they fail and nuclear energy technology, and organized five national symposia on Critical Infrastructure Assurance in conjunction with the National Research Council. During 2001-2008, and again in 2017-2018, I served as a Senior Advisor to the Congressionally-mandated Commission to Assess the Threat to the United States of Electromagnetic Pulse (EMP) Attack.

The nature of EMP and GMD effects on our grid can be severe, to be sure. These phenomena introduce abnormal transient electrical currents into systems precipitating upset and thermal damage within electrical and electronic components. Consequences involve risk measurement units of millions of casualties (EMP Commission), trillions of dollars (Lloyds of London), and, dents in the history of civilization (Center for Policy on Emerging Technology). The good news is that well-known, effective, and practical engineering solutions are available to counter these threats. We have the engineering know-how and tools to protect ourselves. What is lacking is resolve.

I will use today's Senate Roundtable to address questions posed by Senator Johnson and his staff regarding the severity of EMP and GMD system/network effects and the status of national preparedness to operate through and recover from these effects.

Question 1: What are your thoughts on how an EMP/GMD would impact the electric power grid?

Atmospheric nuclear tests and simulated threat-level EMP testing reveals that systems connected to long lines are especially vulnerable to component damage, necessitating repair or replacement. All three time phases of the EMP waveform (E1, E2, and E3) couple most efficiently to long lines, and would induce thousands of amperes on each overhead line that you see as you drive down major highways. Because the strength of EMP fields is measured in volts per meter, to first order, the longer the line, the more EMP energy will be coupled into connected systems and the higher the probability of system damage. Furthermore, the levels of EMP current and voltage induced on lines increase with lines' height above ground. Because of its organic, elevated long lines, the electrical power grid is, itself, highly vulnerable to component damage when exposed to EMP and will couple large electrical transients to most other (dependent) infrastructure systems. It is ironic that our most critical infrastructure is also the most vulnerable to EMP, i.e. the grid couples the highest EMP/GMD levels into its own components and those of connected facilities and systems.

The U.S. 1962 Starfish Prime high altitude burst nuclear test 900 miles from Hawaii provided partial evidence of EMP's capabilities. The absence of large-scale infrastructure failure in Honolulu is the favorite anecdote of EMP skeptics, used over and over as evidence that we need not worry about long-term grid collapse from EMP. However, the Hawaiian Islands were in the far-field, low-amplitude fringe of the EMP geo-pattern, the burst height and weapon design were non-optimal for EMP field generation, and the electronics technology common in today's electric power, communication, Internet and control systems was absent from the Hawaiian networks. The small geographic size of the islands and corresponding short lengths of power lines, greatly reduced E3 effects on the grid. Thus, the Starfish Prime test offered a highly limited ensemble of possible EMP effects – just a small taste of things to come.

Because their high-altitude nuclear bursts were over a continental landmass, exposing long line networks spanning thousands of miles, the Russian atmospheric nuclear test experience has provided many more insights into EMP effects. But, just as with U.S. tests, the Russian test lessons are limited by the absence of today's electric power, communication, Internet and control systems. The Russian tests caused overhead transmission and telecommunications line disconnects and damage including electrical arc breakage of powerline support insulators, causing overhead power lines to drop to ground. Dr. Valery Kondrat'ev reported they experienced fires from EMP and loss of communications gear. Military generators (fixed diesel generation plants) and substations were damaged. Overhead line network damage was due to early-time EMP and buried cable damage by late-arriving EMP. The Russians also reported malfunctions of radio stations.[1]

Since the atmospheric test era, government and industry laboratory tests of hundreds of items have revealed EMP vulnerability of grid distribution transformers, grid control electronics, computers, and communication networks and indicate that we have become more vulnerable to EMP due to technology advances and the foundational role of electricity and electronics in our everyday life and enterprise-enabling infrastructures.

Without protection, there is real evidence from atmospheric testing and laboratory testing that the grid will collapse, causing long-term, large-scale cascading debilitation of dependent infrastructures and services. EMP system debilitation is due to the upset and thermal burnout of grid-essential command, control, and communication electronics, and physical damage to the heavy-duty grid components that supply our power including transformers, and possibly generators. The military has the benefit of decades of system testing and a classified database documenting EMP effects on hundreds of systems that has caused them to recognize that the electric power grid, in its present unprotected state, cannot be relied on following an EMP attack. The military includes hardened backup power as part of mission essential system design. DoD is installing hardened "microgrids" on key bases to make them independent of the surrounding grid.

Because the power grid is essential to the recovery of all critical infrastructure sectors, the ability to operate through an attack or to be rapidly restored is paramount. For example, emergency responder experience during multiple severe hurricanes indicates that electric power availability is critical for their operations.

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[1] H. Seguine, U.S.-Russian meeting – HEMP Effects on National Power Grid and Telecommunications, National Communication System Memorandum for Record, 17 Feb. 1995

I'm sure you'll hear from other witnesses that "EMP effects are not that bad – not to worry" and "it's not necessary to harden the grid, rather let's put our money into recovery phase activities, spare parts, etc. so we can pick up the pieces afterwards." Threat levels, as defined by many utilities and their research arms, is based on optimistic assessments using EMP/GMD waveforms that are lower than levels predicted by the latest empirically-verified science and, in the case of GMD, lower than measured solar storm levels.

The utility industry's "minimization mindset" is dangerous. As a case in point, the Federal Energy Regulatory Commission (FERC)/North American Electric Reliability Corporation (NERC) GMD standard (TPL-007-2) which set GMD Earth potential levels lower than those measured during past solar storms and set transformer failure thresholds higher than known malfunction levels. The result of this rosy industry analysis was that only fourteen of the thousands of transformers included in the model, would need protection – a result far from consensus among independent experts. Even with enforced utility compliance with the present GMD standard, our grid will remain vulnerable to major solar storms.[2]

Government officials and utility executives must transition to a "defense-conservative" mindset for our power grid and other lifeline infrastructures – just as our military does in protecting our strategic systems.

Question 2: How is the private sector evaluating and attempting to address the threat of an EMP/GMD?

The FERC GMD standard (TPL-007-2), though its specified environments and system thresholds are not defense-conservative, has at least brought industry attention to GMD effects. Because there is no corresponding federal EMP directive, the private sector is not doing very much of anything to address the EMP threat. The absence of federal EMP directives and standards for the electric power grid has resulted in inconsistent industry interest, approaches and questionable protection effectiveness.[3] The NERC/electric industry EMP approach appears to be to let the national grid fail and concentrate attention, investments and preparedness on elaborate recovery plans to rebuild the grid in the aftermath of an EMP-caused grid collapse. This approach is fraught with risk.

There have been a few glimmers of EMP interest and action including several uncoordinated efforts within the electric power industry and IT/Communication/Data Center industry. Center Point, PJM, and Dominion Energy have each hardened a major control center. AEP has protected 400+ substation control shelters. Generation stations have not been addressed because of cost-recovery limitations (unlike transmission systems where federal regulations allow cost recovery). Notwithstanding, other than a beta-test of a GMD protection device for one transformer in Wisconsin, no hardening of the bulk power system's high voltage, heavy duty, long-lead-time replacement items has occurred. The grid, in its current unhardened state, would likely be out of service for long periods following a major solar storm or EMP attack.

Within the communications/Internet sector, one major data center in Indiana, belonging to an insurance company, has been protected. A data center in Minneapolis that serves electric utility industry has installed a small protected space. One data center in Pennsylvania has EMP-protected a space of about 2000 square feet. Companies are reluctant to harden because there are no EMP/GMD regulations or requirements for civilian infrastructure. Power industry officials have expressed reservations that any

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[2] Electric Power Research Institute, Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid. Palo Alto, CA, February 2017.

[3] W. R. Graham et al, Assessing the Threat from Electromagnetic Pulse (EMP), Executive Report, Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, July 2017

near-term protection initiatives could well be rendered obsolete if they don't conform to unknown future regulations and standards.

A major national concern is that a significant number of local electric power microgrids are being installed around the U.S. with no EMP protection. Microgrids are being justified and installed at highly-critical of infrastructure sites that cannot tolerate even short-term electric power grid outages. Thus, failure in an EMP event would likely terminate essential microgrid-powered services. Another major concern is that installation of unprotected microgrids actually harms the resilience of the existing grid by increasing the "vulnerability of complexity."[4]

Microgrids add another layer of complexity to the existing grid. Grid EMP vulnerability is increased by the additional coupling pathways inherent in microgrid control electronics networks and interconnecting powerline pathways. Federal requirements would be very helpful to ensure microgrids will survive and not increase the EMP vulnerability of the rest of the grid. Note that microgrid EMP protection introduces a small incremental cost if included in initial system design, adding only 2-5% to microgrid acquisition costs. Based on DoD experience, retrofit EMP protection costs run ten times higher. We are at a watershed moment where we must decide between designed-in protection on microgrid installations yielding much improved electricity supply resilience – or proceed in our current lazy-faire manner with resulting increases in local and regional electric power grid vulnerability.

Regrettably, industry and government are largely ignoring the Congressional EMP Commission's findings and recommendations. Recent National Infrastructure Advisory Council (NIAC) and Congressional Research Service (CRS) reports have also ignored recommendations from knowledgeable public interest groups, including the Foundation for Resilient Societies[5,6,7], JINSA[8], The American Foreign Policy Council[9], Infragard's EMP Special Interest Group[10] and the US Air Force Training Command's Electromagnetic Defense Task Force (EDTF)[11]. A survey of recent government reports that address the protection of critical infrastructure reveals that none mention EMP, although critical infrastructure risks, resilience, protection, and availability are central to each report and to each Departments' mission[12]. Key reports on infrastructure protection and nuclear posture neglect to address

[4] The "vulnerability of complexity" was coined by Yale professor Charles Perrow in his book, Normal Accidents. "Normal accidents" in complex infrastructure systems involve system interactions that are not only unexpected, but are incomprehensible for some critical period of time. For instance, it took an expert NERC investigation team three months to determine the exact combination and sequence of system failures that led to the 2003 Northeast blackout.

[5] G. Baker, W. Harris, T. Popik, Protecting the Electric Power Grid from Electromagnetic Pulse: Legal and Policy Aspects, Critical Infrastructure Protection Report, George Mason University, July 2013.

[6] T. Popik, W. Harris, G. Baker, Comments of the Foundation for Resilient Societies on The Federal Energy Regulatory Commission Reliability Standard for Transmission System Planned Performance for Geomagnetic Disturbance Events, Docket No. RM15-11-000, 10 August 2015.

[7] T. Popik, Testimony of the Foundation for Resilient Societies before the Federal Energy Regulatory Commission Reliability Technical Conference, Docket No. AD16-15-000, 1 June 2016

[8] B. Gabbard, R. Joseph, Threats to U.S. Critical Infrastructure, Gemunder Center EMP Task Force, September 2015

[9] R. Harrison, I. Berman, Strategic Primer: Electromagnetic Threats, American Foreign Policy Council, Winter 2018.

[10] M. Laskey, W. Harris, S. Volandt, Powering Through: From Fragile Infrastructures to Community Resilience, Infragard EMP Special Interest Group, November 2016.

[11] D. Stuckenberg, R. Woolsey, D DeMaio, Electromagnetic Defense Task Force (EDTF) 2018 Report, Air University Press, Maxwell Air Force Base, Alabama, November 2018.

[12] These reports include Mitigation of Power Outage Risks for Department of Defense Facilities and Activities 2015, National Infrastructure Protection Plan 2013: Partnering for Critical Infrastructure Security and Resilience (DHS), U.S. Department of Energy Strategic Plan 2014-2018, and the 2018 Nuclear Posture Review.

EMP. EMP is not included in the DHS list of top 100 threats. EMP programs will greatly benefit from attention to reports from all concerned organizations and must have more attention at the highest policy levels.

On a positive note, several commercial enterprises have developed turn-key EMP services and product lines and stand ready to harden critical infrastructure facilities and systems (see Figure 1). I am confident that, once we have national, state and local protection initiatives, American companies will be ready to harden critical infrastructure facilities and systems. Because U.S. firms are world leaders in EMP protection technologies, there is good potential for well-paying manufacturing jobs in this emerging industry. Our allies also need EMP protection, so there is the opportunity for robust export of EMP protection devices and services.

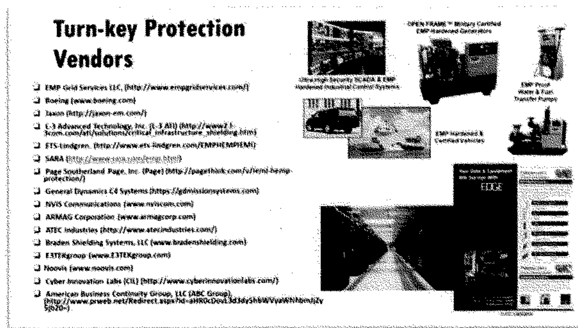

Figure 1. Turn-Key EMP/GMD Protection Vendors.

Question 3: What is the potential cost of hardening our nation's electrical grid with respect to available technical options?

There have been several efforts to quantify the cost to harden the grid. None have been conclusive. An early effort by the Foundation for Resilient societies estimated costs in the several tens of billions of dollars for the bulk power system and supporting communication, fuel and transportation infrastructures (Figure 2). Note that generation stations, not subject to FERC protection standards, likely represent the largest share of EMP/GMD protection costs.[13]

[13] Note: DTRA has recently (Fall 2018) begun HV the first-generation station EMP testing.

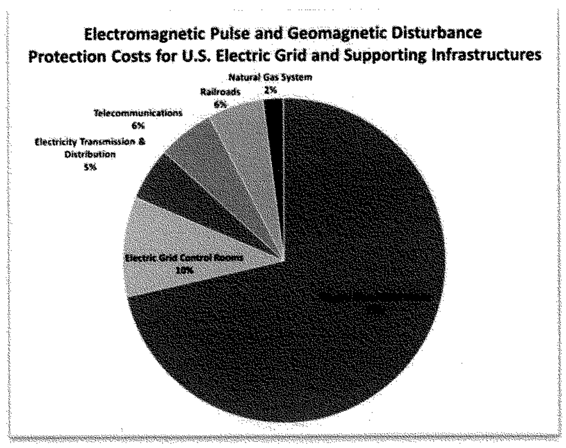

Figure 2. Protection Costs Breakout for Electric Power Grid and Supporting Infrastructures, Foundation for Resilient Societies.

Based on the work of the Foundation for Resilient Societies and DoD experience in hardening military systems, my preliminary estimate for prioritized protection of the existing electric power system is on the order of $50B, representing about 1% of the grid's replacement cost. From a cost-benefit standpoint, this amount is reasonable when compared with the dollar losses from a national-scale blackout which would be measured in multiples of the U.S. GNP (tens of trillions of dollars). The estimate considers protection of a top-down "thin-line" of priority grid systems including selected HV generation plants with priority given to nuclear plants and black-start plants, selected transmission substations (e.g., FERC's analytical result of nine critical substations in the U.S. electric grid), plus the control centers and communication networks necessary for monitoring grid status and controlling post-event restoration efforts. Some of the necessary fuel logistical tail (transportation assets, pipelines, transfer terminals, refineries) is also included in this rough estimate. This level of investment would allow faster reconstitution of the bulk grid following an EMP or GMD-caused grid collapse but would not offer complete protection. The investment strategy is based on identifying a top-down "thin-line" of grid assets necessary to restart the bulk power grid. For a more rigorous and complete cost estimate I recommend cost studies by DOE, industry, and independent think tanks.

A bottom-up EMP protection approach (local, State efforts) and cost estimate is also required since communities could be on their own for extended periods in a wide-area blackout. Local community awareness is essential to develop effective programs that address a thin-line of life-support infrastructures including local backup power generation systems, emergency services (law enforcement, fire, EMS, and their communications), water supply/treatment, hospitals, and the necessary logistics tail (food, fuel). The Carolinas' Lake Wylie project provides a model for costing a bottom-up EMP/GMD protection program. The federal government needs to coordinate the interface between the top-down and bottom-up efforts. The interface demark occurs where the high voltage transmission grid (bulk power) meets the distribution grid (lower voltage electric network supplying local infrastructure services).

Low cost stop-gap measures will be important, including hardened microgrid installations as a near-term solution for life-line infrastructures. As mentioned, we are presently at a watershed moment due to the onset and rapid acceleration of microgrid installations. Federal EMP standards are desperately needed to inform and govern the protection of microgrids. Otherwise, microgrids will actually increase the vulnerability of the existing grid due to the added layer of complexity, including heavy reliance on microprocessor controls vulnerable to the E1 pulse. While I commonly learn about efforts to protect commercial systems against EMP, I would be hard-pressed to give a good example of EMP-protected microgrids in the civilian infrastructure. Accordingly, I estimate that the microgrids now being developed and installed would fail under EMP attack conditions.

Question 4: What additional authorities would you recommend and should be involved to assure national preparedness to withstand an EMP/GMD event?

To sharpen our resolve and policy objectives for EMP/GMD preparedness, federal authorities must recognize that America's grid is the prime target infrastructure of our adversaries. Because the electric power grid is the foundation of our technical society, in military parlance, an EMP attack engenders the ultimate "functional defeat" of the American society and enterprise. Debilitation of the electric power grid would lead to an internecine fight for survival. Without protection and planning, our society would internally self-destruct, greatly diminishing an attacker's required follow-on war effort to take over America's land possessions, island territories such as Guam, the remote states of Hawaii and Alaska, and even the continental United States.

The single most important recommendation of the 2018 EMP Commission Executive Report was to establish an office of EMP coordination within the National Security Council (NSC).[14] The Commission recommended immediate action to advance U.S. security and survivability with the President establishing an Executive Agent having the authority, accountability, and resources to manage U.S. national infrastructure protection and defense against EMP. The Commission expressed concern that the current institutional authorities and responsibilities – government, industry, regulatory agencies – are fragmented, incomplete, under-resourced, and unable to protect and defend against foreign EMP threats or major solar storms.

The new EMP executive order, if signed, will help in this regard by designating the Assistant to the President for National Security Affairs (APNSA), through the NSC and in consultation with the Director of the Office of Science and Technology Policy (OSTP), as responsible for coordinating the development, and implementation of executive branch activities related to national EMP preparedness.

Certain aspects of the Energy Power Act of 2005 have become detrimental to national preparedness against EMP attack. The self-regulatory system for electric utilities, with NERC as the designated Electric Reliability Organization (ERO) has, in effect, neutered FERC. Under the Act, FERC can request standards but cannot write them. In the quest for national EMP/GMD preparedness, FERC serves only as the brake pedal rather than the driver. Through a sua sponte order to NERC, FERC requested only a GMD standard, intentionally excluding EMP protection. The resulting NERC GMD standards (TPL-007-1 and TPL-007-2) enable utilities to sidestep grid protection engineering using paper studies. The few items of long-replacement-time grid equipment that would be protected to NERC's sub-threat TPL-007-1/2 solar storm standards would remain vulnerable to substantially higher magnitude HEMP E1 and E3 hazards, with risk of E1 damage to circuits and relays required to protect against E3. A combined-threat EMP-GMD standard is a needed and cost-effective solution.

[14] W. R. Graham et al, Assessing the Threat from Electromagnetic Pulse (EMP), Executive Report, Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, July 2017

New legislation is needed to empower FERC, specifically to enable the Commission to write and enforce grid protection standards.[15] We must give FERC authority commensurate with Nuclear Regulatory Commission's reactor authority, but over the US power grid. FERC should have explicit authority related to improving national security. FERC should also be asked to identify regulatory and non-regulatory mechanisms, including cost recovery measures, to incentivize private sector engagement to address the effects of EMP. In legislation, FERC should also be asked to develop a national-level blackstart plan. Currently we have only local and regional black start plans where utilities assume they can blackstart themselves by tapping into nearby, unaffected grids – an untenable approach in a continental-scale EMP/GMD contingency.[16]

NERC's role should also be redefined to coordinating and assuring industry compliance with FERC EMP/GMD standards. FERC and NERC should report to NSC and Congress on a regular basis on the status of the overall resilience, security, and protection state of the U.S. electric power grid.

A persistent barrier to the approval and implementation of effective grid reliability standards has been inadequate cost recovery opportunities.[17] Potential mechanisms for cost recovery include FERC-approved tariffs, federal tax credits, and appropriations for cost sharing, as with the Smart Grid Investment Grant program of 2010-2015. Under deregulation, competition has had a countervailing effect on reliability. The adage, "private efficiency leads to public vulnerability," applies here.[18] Better designed electricity markets with incentives reducing multi-hazard risk of catastrophe would lead to major improvements in grid resiliency.

The Director of National Intelligence plays key role by determining foreign aggressors' intent and capabilities regarding EMP. Agencies use DNI briefings and reports in determining whether or not to include EMP in their planning and requirements. Unfortunately, the most recent intelligence community (IC) EMP report published by the Joint Atomic Energy Intelligence Council (JAEIC) is factually erroneous and analytically unsound. This report provides an effective excuse/alibi for agencies and their industry affiliates to ignore EMP in their planning and system acquisition processes. The Congressional EMP Commission recommended that the DNI circulate to all recipients of the 2014 JAEIC report the EMP Commission critique of that report and direct a new assessment that supersedes the 2014 JAEIC EMP report. The new IC report should be reviewed by experts in the subject areas being addressed and circulated to all the recipients of the defective 2014 assessment.

EMP is not mentioned in several important high-level policy documents including the U.S. Department of Defense 2018 Nuclear Posture Review. EMP is not mentioned in the Department of Homeland Security list of top 100 threats. I ask your Committee for the inclusion of the EMP threat at the highest levels of policy guidance, especially when your Committee has oversight responsibility.

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[15] The DOE Quadrennial Energy Review released in January 2017 recommended, "... in the area of cybersecurity, Congress should provide FERC with authority to modify NERC-proposed reliability standards—or to promulgate new standards directly..." EMP could be included under the cyber threat since it debilitates cyber electronic systems and constitutes the ultimate denial-of-service attack.

[16] G. Baker, Testimony before the Federal Energy Regulatory Commission Reliability Technical Conference, Docket No. AD17-8-000, 22 June 2017

[17] Ibid.

[18] P. Auerswald et al, Seeds of Disaster, Roots of Response: How Private Action Can Reduce Public Vulnerability, Cambridge University Press, 2006.

Question 5. How can current DHS and DOE programs improve efforts to protect critical national infrastructure against EMP and GMD?

The impending EMP Executive Order will help and goes a long way in clarifying DHS and DOE EMP/GMD roles and responsibilities.

Because we can't protect everything, progress will be spurred by a prioritized list of EMP-susceptible infrastructure from DHS. Developing criteria for prioritization would benefit from coordination with Assistant Secretary of Defense (Homeland Defense and Americas' Security Affairs) on their criteria for assembling the Defense Critical Asset (DCA) and Defense Critical Infrastructure Protection (DCIP) and lists. A recovery time objective (RTO) should be specified for critical infrastructures and used as a criterion for priority assignment.

Due to its 50-plus year learning from actual EMP specification, design, build, and test experience, DoD information sharing and assistance to DHS and DOE is crucially important to national preparedness. The U.S. military already has EMP protection approaches that are practical, affordable, tested and well understood that can be translated directly to electric power grid control facilities and supervisory control and data acquisition electronics and networks. For more than a half-century, DoD has protected high priority military command, control, and computer assets for nuclear deterrence and response. DHS and DOE EMP/GMD protection programs should emulate DoD's efforts.

In this vein, it will be important to preclude temptations to re-invent the wheel by giving DHS and DOE full access to DoD standards, handbooks and data bases. Existing EMP standard waveforms are more than adequate for specifying a standard unclassified EMP environment for use by industry. In particular, the International Electrotechnical Commission's (IEC) E1 and E2 waveforms[19] coupled with the EMP Commission's E3 waveform[20] provide an excellent, unclassified basis for national infrastructure EMP protection. These coupled with the MIL-STD-188-125 shielding effectiveness acceptance test and pulsed current injection (PCI) acceptance test specifications will provide high confidence in critical infrastructure system survivability. Systems complying with the MIL-STD-188-125 E3 PCI acceptance test will also survive 100-year solar storm GMD-induced currents.[21]

It will be important for DHS and DOE to develop expertise with DoD EMP protection, testing and hardness maintenance and surveillance HM/HS programs. EMP/GMD assurance does not end with initial installation of protection hardware. DoD has found that EMP hardness degrades with time, necessitating periodic system surveillance and maintenance. Critical infrastructure protection (CIP) programs should include outyear funding for this. A paragon hardness maintenance program is STRATCOM's Minuteman HM/HS activity.

Stove-pipe attention to single threats necessitate needless and unnecessarily expensive redundancies in system protection. DTRA's blue ribbon assessment programs have found that all hazards protections are imminently practical – that once key "single-point failure" locations are identified, protection of these against multiple hazards is straightforward. And it is important that EMP is not ignored. The failure of current GMD protection efforts to address nearly identical vulnerabilities and protection measures for he EMP/E3 waveform has been a lost opportunity.

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[19] International Electrotechnical Commission, EMP Environment Standard 61000-2-9

[20] Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack. *Recommended E3 HEMP Heave Electric Field Waveform for the Critical Infrastructures.* Report of the EMP Commission, July 2017.

[21] Note: EMP protection covers GMD effects. Late-time EMP (E3) protection hardware will suffice for GMD protection.

Grid vulnerabilities can be reduced by hardening the electric grid and, procedurally, by executing well-planned load shedding given adequate warning time (EMP can occur with no warning). Smart, timely reconstitution of the grid following a planned or unplanned shut-down is an equally important part of the planning process. All of these – prioritized system hardening, smart shutdown and smart reconstitution – will require improved multi-threat grid modeling. A major objective of modeling will be the identification of the most critical system and network failure points to enable generating the list of system protection priorities. This will be key to cost reduction. DOE has included provisions for improved grid modeling in its 2016 EMP Action Plan.

Empirical validation of models is essential for confidence building. Electromagnetic system effects and hardening requirements are tried and true for communication, computer, and control electronics due to DoD protection and test programs and standards development. However, there are still holes in our system testing and hardening data bases. Of most concern, we have not yet tested or hardened HV generation plants and HV/EHV transformers. Threat level testing will be required to determine EMP/GMD vulnerabilities, develop and validate models, and verify protection methods. To this end, new and upgraded EMP/GMD integrated system test beds are needed. The Idaho National Laboratories (INL) and Tennessee Valley Authority (TVA) are excellent candidates for test beds and have begun initial development. And Duke Energy has recently provided a large transformer for the first U.S. HV transformer test.

Pilot demonstration programs in selected grid sectors are all-important to answer questions on feasibility and cost of local and regional infrastructure EMP protection. The cost of grid EMP protection is the biggest question out there. The ongoing Lake Wylie Protection Project and the San Antonio Joint-Base microgrid development programs are good examples and should be encouraged, expanded, and funded.

DHS should publish an official, unclassified EMP/GMD standard. DHS is to be commended for issuing a coordination version of a communication/data center protection standard.[22] This document should be expanded to include HV/EHV electric power assets (HV generators and substation transformers/breakers). In addition, a DHS-endorsed national EMP/GMD planning scenario would provide an overarching scope for public and private stakeholder awareness, grid protection and recovery planning. DHS expand its complement of EMP/GMD scientists and engineers.

Summary and Action Items.

To sharpen our resolve and policy objectives for preparedness, Federal authorities must recognize that America's grid is the prime target infrastructure of our adversaries. Despite witness arguments to the contrary, the grid, in its current unhardened state, would likely be out of service for long periods following a major solar storm or EMP attack. Our strategy must be defense conservative and to enable as much of grid to survive as possible. I recommend the following steps to achieve grid resilience, including 'top-down' actions and a set of equally important 'bottom-up' actions.

- From a Top Down perspective:
    - The most important recommendation of the 2018 EMP Commission was to establish an office of EMP coordination within the National Security Council (NSC). The new EMP executive order does this.

[22] Electromagnetic Pulse (EMP) Protection and Resilience Guidelines for Critical Infrastructure and Equipment, Version 2.2, DHS National Coordinating Center for Communications (NCC), National Cybersecurity and Communications Integration Center, February 2019,

- The FERC GMD standard (TPL-007-2), though its specified environments and system thresholds are not defense-conservative, has at least brought industry attention to GMD effects. This standard, even if rigorously enforced will leave the grid dangerously vulnerable to GMD and needs to be revised.
- Without a corresponding FERC EMP directive, the private sector is not doing very much of anything to address the EMP threat. An EMP directive and protection standard are sorely needed.
- New legislation is needed to empower FERC, specifically to
  (1) Enable FERC to write and enforce grid protection standards.
  (2) Identify mechanisms, including cost recovery measures, to incentivize private sector engagement on EMP protection and increase on-site fuel stockpiles.
  (3) Develop a national blackstart plan.
- A national EMP protection standard is needed. DHS is to be commended for issuing a coordination version of a communication/data center protection guidelines. DHS should expand this to include HV electric generator stations and electric substations.
- For more than a half-century, DoD has protected high priority military command, control, communication, and computer assets for nuclear deterrence and response. DHS and DOE EMP/GMD protection programs should emulate DoD's efforts.
- We must preclude the temptation to re-invent the wheel by giving DHS and DOE full access to DoD standards and data bases. There is no need to recalculate a standard EMP waveform. Note that current EPRI grid vulnerability assessment models are using low-bound recalculated E3 waveforms. Existing IEC and EMPC EMP waveforms are more than adequate. Use of the unclassified MIL-STD-188-125 test regimen will assure power grid survivability to both EMP and 100-year solar storms.
- A prioritized list of EMP-susceptible infrastructure is needed. System protection and reconstitution prioritization requires improved grid modeling. Integrated system test beds will be important for model validation. Top priority is HV generation plants and HV/EHV transformers, heretofore untested. The INL and TVA test beds look promising.
- The most current EMP Intelligence report is technically flawed and misleading in a manner that downplays the need for action – a new assessment is needed.
- I estimate cost of EMP protection for the bulk power system to be in the $50B range. The investment strategy is based on identifying a top-down "thin-line" of grid assets. More rigorous cost estimates are needed by DOE & industry.

- From a Bottom-Up perspective:
  - EMP protection programs must be pursued at the local and State levels since communities would be on their own for extended periods in a wide-area blackout.
  - Pilot demonstration programs of selected grid sectors are all-important to address the feasibility and cost of local EMP protection. The ongoing Lake Wylie Demonstration Project and the San Antonio Joint-Base microgrid development program are good examples and should be expanded and funded.
  - Bottom-up protection should address a thin-line of essential life-support infrastructures including distribution substations, backup power generation systems, emergency services, water supply and treatment, hospitals, and the necessary logistics tail.
  - Low cost, stop-gap measures will be important, including hardened microgrid installations as a near-term solution for life-line infrastructures. We are presently at a watershed moment due to the recent onset and rapid acceleration of microgrid installations. Federal requirements and standards are important to ensure that microgrids will survive and not increase the EMP vulnerability of the rest of the grid. Microgrid EMP protection is only a small incremental cost if included in initial system design.

- The federal government must coordinate the interface between the top-down and bottom-up efforts. A useful interface demark occurs where the high voltage transmission grid (bulk power) meets the distribution grid (lower voltage electric network supplying local infrastructure services.
- On a positive note, several commercial enterprises have developed turn-key EMP protection services and product lines and stand ready to harden critical infrastructure facilities and systems one directives and programs are in place.

STATEMENT OF SCOTT I. AARONSON

VICE PRESIDENT, SECURITY AND PREPAREDNESS

EDISON ELECTRIC INSTITUTE

BEFORE THE U.S. SENATE HOMELAND SECURITY AND

GOVERNMENTAL AFFAIRS COMMITTEE

"PERSPECTIVES ON PROTECTING THE ELECTRIC GRID FROM AN

ELECTROMAGNETIC PULSE OR GEOMAGNETIC DISTURBANCE"

February 27, 2019

Summary

America's electric companies work every day to produce and deliver energy that is reliable, affordable, safe, and increasingly clean for their customers and the communities they serve. The energy grid powers our economy and our way of life, and providing reliable service is a responsibility electric companies take very seriously.

Threats to that reliability have changed over time and continue to evolve. So, too, has our approach to security. The Edison Electric Institute's (EEI's) member companies prepare for all hazards—that includes man-made threats, such as physical and cyber attacks or impacts from intentional electromagnetic interference, and naturally occurring events, including severe weather of every kind, earthquakes, and geomagnetic disturbances. Our security strategies are not put in place with one threat in mind. Our companies take a "defense-in-depth" approach with several layers of security strategies, which are designed to eliminate single points of failure. Finally, since our companies cannot protect every asset from every threat all the time, we must prioritize based on the likelihood and severity of a threat, as well as work to manage impacts by restoring power quickly and safely regardless of why an outage occurred.

There are three main components to the electric power sector's defense-in-depth approach: mandatory and enforceable reliability regulations; industry/government partnerships; and efforts to enhance our ability to respond and recover following incidents.

Security is a shared responsibility. While most critical infrastructure is owned largely by the private sector, government at all levels can and must play a role in protecting it. Through partnerships like the Electricity Subsector Coordinating Council (ESCC), government and industry leverage one another's strengths. This partnership manifests itself in many ways, including deployment of government technologies, multi-directional information sharing, exercises, and facilitating cross-sector coordination.

Addressing dynamic threats to the energy grid requires vigilance and a coordinated approach that leverages government and industry resources. We appreciate both Congress and the Administration's support of the electric power sector, and we look forward to continuing our close collaboration to meet the evolving threats.

Introduction

Chairman Johnson, Ranking Member Peters, and members of the Committee, thank you for the opportunity to testify. My name is Scott Aaronson, and I am Vice President for Security and Preparedness at the Edison Electric Institute (EEI). EEI is the association that represents all U.S. investor-owned electric companies. Our members provide electricity for 220 million Americans and operate in all 50 states and the District of Columbia. For EEI's member companies, securing the energy grid is a top priority. I appreciate your invitation to discuss this important topic on their behalf.

The electric power industry—which includes investor-owned electric companies, public power utilities, and electric cooperatives—supports more than 7 million American jobs and contributes $865 billion annually to U.S. gross domestic product, about 5 percent of the total.

While I am here today in my EEI capacity and am testifying on behalf of our membership, I would like to highlight another thread that ties the electric power sector together: the Electricity Subsector Coordinating Council (ESCC). The ESCC is comprised of the chief executive officers of 22 electric companies and 9 major industry trade associations, including EEI, the American Public Power Association (APPA), and the National Rural Electric Cooperative Association (NRECA). This group—which includes all segments of the industry, representing the full scope of electric generation, transmission, and distribution in the United States and Canada—serves as the principal liaison between the federal government and the electric power sector, with the mission of coordinating efforts to prepare for, and respond to, national-level incidents or threats to critical infrastructure. While I am not representing the ESCC officially, I serve as a member of the Secretariat that supports the Council, so my perspectives are shaped by that role and are aligned with the broader industry.

We appreciate the continued interest the Committee has on grid security and, specific to this hearing, the impacts of electromagnetic pulse (EMP) and natural geomagnetic disturbances (GMDs) on the energy grid.

All Hazards: The Electric Power Industry's Approach to Security

America's electric companies work every day to produce and deliver energy that is reliable, affordable, safe, and increasingly clean for their customers and the communities they serve. The energy grid powers our economy and our way of life, and providing reliable service is a responsibility electric companies take very seriously.

Threats to that reliability have changed over time and continue to evolve. So, too, has our approach to security. EEI's member companies prepare for all hazards—that means physical and cyber events, naturally occurring or manmade threats, and severe weather of every kind. Our security strategies are not put in place with one threat in mind. Our companies take a "defense-in-depth" approach with several layers of security strategies, which are designed to eliminate single points of failure. Finally, since our companies cannot protect every asset from every threat all the time, we must prioritize based on the likelihood and severity of a threat, as well as work to manage impacts by restoring power quickly and safely regardless of why an outage occurred.

Defense-in-Depth: Standards, Partnerships, and Response

I would like to highlight three main components to the electric power sector's defense-in-depth approach: mandatory and enforceable reliability regulations; industry/government partnerships; and efforts to enhance our response and recovery to incidents.

Standards. Under the Federal Power Act and Federal Energy Regulatory Commission (FERC) oversight, the electric power sector is subject to North American Electric Reliability Corporation (NERC) Reliability Standards that include cyber and physical security requirements. Entities found in violation of NERC standards face penalties that can exceed $1 million per violation per day. These mandatory standards continue to evolve using the process created by Congress to allow for input from subject matter experts across the industry and government.

Through these standards, the entire bulk power system enjoys a baseline level of security and reliability. Standards are important, but with intelligent adversaries operating in a dynamic threat environment, regulations alone are insufficient and must be supplemented.

Partnerships. Security is a shared responsibility. While most critical infrastructure is owned largely by the private sector, government at all levels can and must play a role in protecting it. Through partnerships like the ESCC, government and industry leverage one another's strengths. This partnership manifests itself in many ways, including deployment of government technologies, multi-directional information sharing, drills and exercises, and facilitating cross-sector coordination.

Response and Recovery. The electric power sector is proud of its record on reliability, which includes the resilience of the system. When outages do occur, many key investments help electric companies restore power safely and as quickly as possible. Our industry invests more than $100 billion each year to make the energy grid stronger, smarter, cleaner, more dynamic, and more secure. Further, the industry's culture of mutual assistance unleashes a world-class workforce amidst the toughest conditions to restore power safely; neighbors helping neighbors during the worst of the worst.

Industry-government exercises, such as the biennial GridEx, sharpen the industry's skill set, ensuring that when incidents happen our playbook has been tested before it is put into action. These exercises sharpen not just the unity of effort between electric companies and government agencies, but also practice unity of message to ensure that we speak with one voice to our customers and your constituents during incidents.

How GMDs Differ from EMPs

The threats we are here to discuss today are EMPs and GMDs. First, I want to highlight that there are important differences between man-made EMPs, such as those from directed energy weapons or nuclear detonations, and naturally occurring GMDs, such as solar flares. Though both create magnetic disturbances, their characteristics are very different. Therefore, each threat must be addressed independently, and appropriate mitigation and protection strategies must be implemented for each.

GMDs are naturally occurring events that the electric power industry has managed for decades. The industry is subject to mandatory and enforceable standards, developed by NERC under FERC oversight, to protect the energy grid from the impacts of GMDs, and electric companies have operating processes and procedures to manage GMD risks.

To mitigate the threat of GMDs on the energy grid, there are two standards in place regarding GMDs. NERC's standard TPL-007-1 requires transmission-owning electric companies to assess and analyze their transmission systems under a severe 1-in-100-year GMD benchmark planning event. Last year, NERC developed TPL-007-2, a modification to TPL-007-1. In November, FERC approved TPL-007-2, which broadens the definition of GMDs, requires grid operators to collect certain data, and imposes deadlines for corrective actions. The other standard, EOP-010-1, requires operating plans, processes, and procedures to mitigate the effects of a GMD event.

There are two categories of intentional, man-made EMPs. The first, a high-altitude EMP caused by the detonation of a nuclear weapon in the atmosphere, is a high-consequence, low-likelihood threat that would have a potentially catastrophic impact on society. Since a nuclear attack on U.S. critical infrastructure would be an act of war or terrorism, the federal government has primary responsibility for preventing high-level EMPs as a matter of national security. The industry also is taking steps to better understand the impact of this threat to its systems to engineer greater resilience against such a catastrophic incident.

The second type of EMP is related to the use of smaller directed energy weapons against a single facility or piece of equipment. Mitigation strategies for this type of EMP threat include physical protection measures, including limiting line-of-sight and controlling access, while also relying on system redundancy. To cause significant damage to the energy grid, dozens of directed energy weapons would need to be built, deployed, and detonated in a coordinated attack without being detected or stopped by law enforcement. To address the physical protection of critical equipment, NERC developed the CIP-014-1 standard, which requires transmission-owning electric companies to identify and protect critical transmission stations and substations, along with their associated control centers.

Industry Initiatives and Collaboration

Policymakers and the electric power industry share the goal of developing capable, cost-effective mitigation to threats. Because the effects of an EMP attack on the energy grid are not understood sufficiently or remain classified, crafting appropriate mitigations and making business-risk decisions to address EMP threats require more research to better understand how EMPs could impact the grid; inform the development of EMP-resistant grid components; and develop best practices to help limit the impact of these threats.

To address these challenges, the Electric Power Research Institute (EPRI), an independent research organization funded by industry, launched a research project in 2016 to provide a scientific basis for investments to mitigate EMP threats on the transmission system, inform response and recovery efforts, and develop other partnerships that will help the nation's critical infrastructure be better prepared for existential threats to the energy grid. As the primary liaison between senior leadership in the federal government and the industry, the ESCC is working with government partners to better understand the threat posed to energy infrastructure from a man-made EMP. The ESCC also supports EPRI's efforts.

As referenced above, regardless of the cause of damage to the energy grid, preparations to ensure mitigation, response, and restoration are the same: grid operators prioritize risk to enhance protection around critical assets, engineer redundancy to avoid single points of failure, stockpile spare equipment for hard-to-replace components, and develop other contingencies to minimize impacts. The ESCC is involved in all aspects of these preparations.

- **Exercises:** Electric companies plan and regularly exercise for a variety of emergency situations that could impact our ability to provide electricity. The industry participates in numerous local, state, and national exercises every year. One such exercise, GridEx IV, involved more than 450 organizations and 6,500 participants from industry, government agencies, and partners in Canada and Mexico. Managed by NERC and the Electricity Information and Analysis Center (E-ISAC), GridEX IV also included an executive tabletop exercise where 40 electric power sector executives and senior U.S. government officials worked through incident response protocols to address widespread outages. GridEx events are conducted every two years; GridEx V is planned for November 2019.

- **Mutual Assistance Programs:** The three segments of the electric power industry—public power, investor-owned, and electric cooperatives—have long had in place mutual assistance response networks to share employees and resources to restore power after emergencies. The years of experience industry has had in deploying these resources is a valuable tool. In fact, the ESCC has led efforts to create a Cyber Mutual Assistance (CMA) program that allows electric and natural gas companies to share critical personnel and equipment in the event of cyber-related emergencies. To date, more than 150 electric and natural gas companies are participants, covering about 80 percent of the country's electricity customers and 75 percent of U.S. domestic natural gas customers.

- **Spare Equipment Programs:** Electric companies regularly share transformers and other equipment through long existing bi- and multi-lateral sharing arrangements and agreements. The industry is expanding equipment sharing programs—like the Spare Transformer Equipment Program (STEP) and SpareConnect program—to improve grid resiliency.

- **Transformer Transportation Emergency Support Guide:** The ESCC, in coordination with other critical infrastructure sectors and the government, has developed a Transformer Transportation Emergency Support Guide to expedite the deployment of large spare equipment, such as transformers, over rail, roadways, and waterways quickly in an emergency.

- **Supplemental Operating Strategies:** Following GridEx III and the cyber incident affecting Ukrainian distribution electric companies, the industry focused on energy grid operations under sub-optimal circumstances. The ESCC asked grid experts at the North American Transmission Forum (NATF) to explore "extraordinary measures" that can be anticipated, planned for, and practiced so they are not contemplated for the first time during an incident that disables significant technology used to operate the grid. These "extraordinary measures" include, but are not limited to, operating systems in "manual" configuration where systems are not allowed to automatically re-energize, engaging in planned separations of portions of the grid to avoid cascading outages, leveraging secondary and tertiary back-up systems, or operating in other degraded states.

- **Grid Security Emergency (GSE) Authorities:** To support the Department of Energy's (DOE's) GSE Authorities planning, the ESCC requested that the NATF develop a report to identify potential actions that would inform the government on how emergency orders effectively could bolster electric companies' protection, response, and recovery efforts. NATF, in coordination with DOE, determined that, since there are existing industry procedures that address operations and risk mitigation associated with GMD, the report would focus on before, during, and following a GMD event.

- **Research & Development:** The ESCC R&D strategic committee is overseeing the industry's collaboration efforts with the government, including the national labs, on resilience and infrastructure investments for grid security R&D. The Committee serves as the coordination point for EPRI's EMP and GMD work.

Government's Role in EMP and GMD

As stated above, grid security is a shared responsibility. We appreciate both Congress and the Administration's support of the electric power sector. Just as the industry evolves to meet new threats, our government partners continuously improve their posture through new initiatives.

Most notably, thanks to Secretaries Perry and Nielsen and their respective teams' efforts, as well as legislation passed by Congress last year, we believe government is well-positioned to continue its support of industry in securing the nation's most critical infrastructure. Specifically, the establishment of DOE's new Office of Cybersecurity, Energy Security, and Emergency Response (CESER) and the Department of Homeland Security's (DHS's) Cybersecurity and Infrastructure Security Agency (CISA) elevated and deepened the relationship between our industry, DOE, and DHS on issues of cybersecurity, EMP, GMD, and energy grid response and resilience initiatives.

With input from the industry, DOE released the Electromagnetic Pulse Resilience Action Plan[1] in 2017 that identified five goals: (1) improve and share understanding of EMP threats, effects, and impacts; (2) identify priority infrastructure; (3) test and promote mitigation and protection approaches; (4) enhance response and recovery capabilities to an EMP attack; and(5) share best practices across government and industry, nationally and internationally. The EPRI project is complementing and helping achieve these goals.

[1]https://www.energy.gov/sites/prod/files/2017/01/f34/DOE%20EMP%20Resilience%20Action%20Plan%20January%202017.pdf

Last October, DHS released the Strategy for Protecting and Preparing the Homeland against Threats from Electromagnetic Pulse (EMP) and Geomagnetic Disturbance (GMD).[2] The Strategy lays out an approach for DHS to take to protect critical infrastructure and prepare to respond and recover from potentially catastrophic electromagnetic incidents. As noted by DHS, the Strategy primarily is focused on Departmental activities; however, it does recognize continued close collaboration with private sector critical infrastructure owner-operators. This partnership is essential to help critical infrastructure owners and operators manage EMP and GMD risk.

Conclusion

Thank you again for holding this hearing. I am hopeful that my testimony underscores the industry's commitment to security and our willingness to address threats from EMP and GMD to the nation's critical energy infrastructure. Addressing dynamic threats to the energy grid requires vigilance and coordination that leverages government and industry resources. Through the NERC-FERC standards process, the industry will continue to address bulk power system issues associated with GMDs. In the next few months, EPRI will share its EMP findings with the industry, providing the necessary information for companies to better understand the potential impact of EMP incidents to the transmission system and recommendations for mitigation approaches and investments.

Through the ESCC, the electric power industry will continue to strengthen its government partnerships, coordinate with other critical infrastructure sectors, engage and educate external stakeholders and the public, and make necessary investments in the energy grid to help ensure it is stronger, more reliable, and more resilient in the face of any threat.

We look forward to continuing close collaboration with our government partners to meet the evolving threat. We appreciate the bipartisan support that grid security legislation historically has enjoyed in Congress and the work you have done to enhance our security posture. As policymakers, there are several ways in which you can support our efforts. First, we recommend that the newly reconstituted EMP Commission include owners and operators of critical

[2] https://www.dhs.gov/sites/default/files/publications/18_1009_EMP_GMD_Strategy-Non-Embargoed.pdf

infrastructure and EPRI. Having the knowledge of experts in grid engineering and operations would enable the Commission to produce a more meaningful and informed product. I encourage all Members of the Committee to receive a classified briefing on the EMP threat. I believe our government partners along with industry representatives, would be more than happy to continue this discussion in classified space.

I want to reiterate that this is an extremely complex issue that cannot be solved with a "one-size-fits-all" solution. Prescriptive legislative directives, especially before EPRI completes its work, could have unintended consequences on operations of the energy grid and increase costs to our customers. Similarly, as recommendations and solutions are identified, the industry will take action, engage Congress, and, if necessary, leverage the NERC/FERC standards-setting process that produces standards based upon expert input—a necessity when it comes to the vast and complex bulk electric system.

Finally, the industry will continue to work with Congress on response and recovery initiatives that support its all-hazard approach to threats. At the end of the day, it doesn't matter why the lights are out, as we must work together collectively to restore power safely and as quickly as possible.

We look forward to working with your respective committees and other relevant committees to meet this most-important mission. Thank you, and I look forward to answering any questions you may have.

Written Testimony

Hearing of the U.S. Senate Homeland Security and Governmental Affairs Committee

Dr. Randy Horton
Senior Program Manager
Electric Power Research Institute

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance"

February 27, 2019

The Electric Power Research Institute (EPRI) is a nonprofit corporation organized under the laws of the District of Columbia Nonprofit Corporation Act and recognized as a tax-exempt organization under Section 501(c)(3) of the U.S. Internal Revenue Code of 1986, as amended. EPRI was established in 1972 and has principal offices and laboratories located in Palo Alto, California; Charlotte, North Carolina; Knoxville, Tennessee; and Lenox, Massachusetts. EPRI conducts research and development relating to the generation, delivery, and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety, and the environment. EPRI's members represent approximately 90 percent of the electricity generated and delivered in the United States, and international participation extends to more than 30 countries.

The subject of today's testimony is EPRI's research efforts related to high-altitude electromagnetic pulse (HEMP) and geomagnetic disturbance (GMD) events. EPRI has been engaged in a focused research effort over the last three years to evaluate the potential impacts of HEMP on the electric transmission system and to identify potential options for mitigating effects. EPRI has also been researching GMD for nearly four decades with significant applications now implemented across the electric utility industry. This testimony provides an overview of EPRI's research activities related to HEMP and GMD.

High-Altitude Electromagnetic Pulse (HEMP) Research

The detonation of a nuclear weapon in space (~ 20 km or more above the Earth's surface) can generate an intense electromagnetic pulse (EMP) referred to as a high-altitude EMP or HEMP that can propagate to the Earth's surface and impact various technological systems such as the electric grid. Depending on the height of the explosion above the Earth's surface and the weapon yield, the resulting HEMP can be characterized by three hazard fields, denoted E1 EMP, E2 EMP and E3 EMP.

The International Electrotechnical Commission (IEC)[1] defines the three hazard fields based on their distinct characteristics and time scales:

- The early-time component (E1 EMP) consists of an intense, short-duration electromagnetic pulse with double exponential waveform characterized by a rise time of 2.5 nanoseconds and amplitude on the order tens of kV/m (up to 50 kV/m at the most severe location on the ground).
- The intermediate time component (E2 EMP) is considered an extension of E1 EMP and has an electric field pulse amplitude on the order of 0.1 kV/m and duration of one μsec to approximately 10 msec. E2 EMP is comprised of two subcomponents, E2A and E2B.
- The late time component (E3 EMP) is a very low frequency (below 1 Hz) pulse with amplitude on the order of tens of V/km or mV/m with duration of one second to hundreds of seconds. Like E2 EMP, E3 EMP is comprised of two subcomponents E3A and E3B that are often referred to as the blast wave and heave wave, respectively.

Potential impacts of HEMP vary depending on the component (E1 EMP, E2 EMP or E3 EMP) that is responsible for damage.

The geographic area exposed to varying levels of E1 EMP fields can be quite large as the area of coverage is defined by line of sight from where the weapon is exploded and the horizon. The incident E1 EMP can couple to conductive objects such as overhead lines and cables exposing connected equipment to voltage and current surges (conducted threat). The resulting E1 EMP can also radiate equipment directly (radiated threat). Potential impacts from E1 EMP on the electric grid range from damage to electronics such as digital protective relays, communication systems and supervisory control and data acquisition (SCADA) systems to more traditional power delivery assets such as insulators and unprotected transformers.

The characteristics of E2 EMP are often compared with nearby lightning strikes. However, it is important to understand that E2 EMP does not couple to conductive objects in the more traditional sense of how lightning strikes a transmission tower or a conductor. Rather, E2 EMP couples to conductive objects through the air like E1 EMP. This coupling mechanism is similar to the way in which the field created by a nearby lightning stroke couples to an overhead distribution line. Because the amplitude of the incident E2 EMP field is quite low (0.1 kV/m), impacts to the bulk power system are not expected to occur.

The resulting E3 EMP induces low-frequency (quasi-dc) currents in the bulk power system. The flow of these geomagnetically induced currents (GIC) in transformer windings can cause magnetic saturation of the transformer core, that is the steel structure that the windings are constructed around, during a portion of the 60 Hz sinusoidal voltage waveform. This phenomenon, often referred to as part-cycle saturation, causes current flow in the transformer to become highly distorted. Additionally, magnetic flux that would under normal operating conditions be primarily confined to the transformer core, induces eddy-currents in windings and structural components resulting in additional hotspot heating. Thus, transformers that are experiencing part-cycle saturation: generate harmonic currents which can affect protection

[1] *International Electrotechnical Commission. "Electromagnetic Compatibility (EMC)–Part 2: Environment, Section 9: Description of HEMP Environment–Radiated Disturbance*. IEC 61000-2-9. Geneva, Switzerland. 1996.

systems and other components, appear as large reactive loads which can depress system voltage levels and lead to voltage collapse (blackout), and experience additional hotspot heating potentially leading to damage in extreme cases. However, due to the short duration of the E3 EMP event, immediate transformer impacts are expected to be minimal.

EMP Research Project Description

When the EPRI EMP research project was launched, publicly available data on the HEMP threat, potential impacts of HEMP on the electric transmission system, and field-tested mitigation options for substations were limited. Additionally, there were differences between the findings of EMP research conducted during the 1980's through early 1990's by the DOE and others and more recent findings communicated by the former Commission to Assess the Threat to the United States from Electromagnetic Pulse Attack (former EMP Commission). Because of these differences and the potential societal impacts of a HEMP attack, EPRI launched a three-year research project in April 2016 to provide electric utilities and other stakeholders with a technical basis for making more informed decisions regarding the potential impacts of HEMP on the electric transmission system and options for mitigating potential impacts. By the conclusion of the project, the research was voluntarily financially supported by more than 60 U.S. utilities.

The EPRI research project sought to answer two important questions:

1. what are the potential impacts of a HEMP attack on the modern electric transmission system?
2. if impacts are severe, can they be mitigated in cost-effective ways, based upon science and technology?

The main goal of this research effort was to provide the electric utility industry and other stakeholders with an unclassified, technical basis for: 1) assessing the potential impacts of a HEMP attack on the bulk power system, and 2) hardening the system against those impacts, should any be found. The research specifically focused on the electric transmission system (overhead lines and substations), and did not consider the potential effects of HEMP on generation facilities, nuclear reactors, distribution systems, loads or other key elements or infrastructure sectors.

Research results were communicated to project members and other stakeholder groups throughout the project. Lastly, an important aspect of this project was the close collaboration with various government entities with extensive expertise and knowledge of the HEMP threat. Key collaborators included: DOE, Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratory (SNL), Los Alamos National Laboratory (LANL) and the Defense Threat Reduction Agency (DTRA). EPRI in close collaboration with the DOE also developed a Joint Electromagnetic Pulse Resiliency Strategy[2] that was published in July 2016.

To address the two fundamental research questions above, the project was broken up into five research areas which included:

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[2] https://www.energy.gov/sites/prod/files/2016/07/f33/DOE_EMPStrategy_July2016_0.pdf

- **Environment and Modeling** – Several conservative (bounding) unclassified HEMP environments for use in assessments were identified and/or obtained from the DOE and national labs and software tools and methods for performing assessments were developed. All three hazard fields, E1 EMP, E2 EMP and E3 EMP, were included in the environment and modeling research effort.
- **Testing** –Extensive laboratory testing of critical substation assets such as digital protective relays, supervisory control and data acquisition (SCADA) equipment and communications systems was conducted to provide data on the levels of E1 EMP induced stress that could cause operational disruption or damage of these devices. Testing included free field illumination testing to assess device performance when subjected to radiated threats and direct injection testing to assess performance when subjected to conducted threats. Direct injection testing of instrument transformers, distribution-class transformers and insulators was also conducted to assess the equipment's susceptibility to E1 EMP. Additionally, testing to evaluate potential mitigation options and shielding effectiveness of substation control houses was performed. Testing focused on E1 EMP impacts.
- **Assessment** –Assessment, using bounding HEMP environments obtained from DOE and industry standards, was conducted to improve understanding of the potential impacts of a HEMP attack on the bulk power system. These assessments included: E1 EMP, E2 EMP, E3 EMP and combined effects from E1 EMP and E3 EMP.
- **Mitigation, Hardening and Recovery** –Various mitigation and hardening approaches that could be employed to reduce the potential impacts of HEMP on the electric transmission system were evaluated. Potential unintended consequences of various mitigation and hardening strategies were also evaluated, and system recovery following a HEMP-induced blackout was explored.
- **Decision Support** - A framework for supporting risk-informed decisions regarding the implementation of HEMP hardening and mitigation measures was developed.

EPRI has collaborated with its funders and pertinent government agencies during the course of the work and that collaboration is ongoing. The final report describing this research and its findings is expected to be made available by April 30, 2019.

As the research findings and report are not yet final, this testimony provided at the request of the Committee will focus on the two reports on E3 EMP impacts that were published in 2017.

E3 Assessment of the Continental U.S. Electric Grid

As a part of this research an assessment of the potential impacts that E3 EMP could have on the bulk power system was performed. The assessment included a transformer thermal assessment[3] and a voltage stability assessment[4].

At the time these studies were performed, the Oak Ridge National Laboratory (ORNL) E3 EMP environment[5] was the only unclassified environment available that contained the *minimum* spatio-temporal characteristics[6] necessary to perform interconnection-scale assessments. The environment is based on the Starfish Prime event which was a high-altitude detonation of a 1.4 MT weapon at an altitude of 400 km over a location near Johnston Island. The peak geoelectric field (E3B) associated with this environment is 24 V/km.

Following the initial E3 EMP assessments, LANL provided additional unclassified E3 EMP environmental data for five benchmark scenarios. For comparison with the ORNL E3 EMP environment, the peak geoelectric field (E3B) associated with these environments are provided in Table 1. It should be noted that the benchmark scenarios described, as well as the results from these scenarios, are notional. No actual information about any weapon or weapons platform is contained in these results.

Table 1
E3 EMP Fields for Benchmark Scenarios (LA-UR-17-31106)

Yield (kT)	Height of Burst (km)	Maximum Field (V/km)
25	100	0.85
125	100	1.5
125	400	1.9
1,000	200	9.2
10,000	200	35

Comparing the ORNL E3 EMP environment with the data provided in Table 1 shows that this environment provides a reasonable bounding case for assessments. However, there are known limitations with this environment. First, the environment includes a significant E3A component that covers the entire contiguous United States (CONUS) while also having a strong E3B component over a portion of the same area. It is well established that the maximum E3A field does not exist to any significance over the same geographic area covered by the E3B pulse.

[3] *Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Geomagnetically Induced Current and Transformer Thermal Analysis*. EPRI, Palo Alto, CA: 2017. 3002009001.

[4] *Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Voltage Stability Analysis*. EPRI, Palo Alto, CA: 2017. 3002011969.

[5] *Study to Assess the Effects of Magnetohydrodynamic Electromagnetic Pulse on Electric Power Systems, Phase 1 Final Report*, ORNL/Sub-83/43374/1/V3, May 1985.

[6] These characteristics refer to the time-varying electric field on the ground over a large geographic area. These electric fields are used to compute time-varying geomagnetically-induced currents (GIC) that are used in the assessments.

Secondly, the direction of the geoelectric field vectors for both the E3A and E3B environments remained fixed throughout the duration of the event. This behavior is not consistent with data observed during high-altitude tests over land. Third, only a single waveform was available to represent the temporal effects which is also known to be inconsistent with test data. These limitations led the EPRI research team to explore options for obtaining additional unclassified data that could be used to improve the fidelity of previous studies. To fill this gap, EPRI obtained the full spatio-temporal environment associated with the 10 MT scenario shown in Table 1 from LANL. Additional E3 EMP assessments, with results expected to be released in April 2019, are being performed using the LANL 10 MT E3 EMP environment.

An overview of assessments that have been published and based on the ORNL E3 EMP environment is provided below.

Transformer Thermal Assessment

As discussed previously, the potential for GIC generated by E3 EMP to cause additional hotspot heating in windings and structural parts of bulk power transformers is well recognized. If heating is of sufficient magnitude and duration, it can cause damage to windings or result in bubble formation in the oil which can lead to dielectric breakdown and failure of the transformer; on a large scale, loss of numerous bulk power transformers could result in long-term blackout. Thus, one of the first steps in this three-year research effort was to evaluate the potential impacts of E3 EMP alone on bulk power transformers.

Because of the potential impacts of E3 EMP on bulk power transformers such studies have been included in prior government-sponsored research activities. Findings from one such study are documented in a final research report published by Oak Ridge National Laboratories (ORNL) in 1993[7] and another is documented in a U.S. Federal Energy Regulatory Commission (FERC) Interagency Report prepared by Metatech and published in 2010[8]. The results presented in these two research reports have diverging conclusions. The earlier ORNL report concluded that E3 EMP would not result in significant damage to bulk power transformers while the Metatech study concluded that transformer damage was likely, and that up to 100 transformers could be damaged depending on the target location.

The purpose of the EPRI study was to determine, using high-fidelity power system and transformer thermal modeling that was not available at the time of the previous studies, whether or not a significant number (hundreds) of bulk power transformers would experience thermal damage from a single E3 EMP event. More simply, the study sought to answer the question, "if a system were exposed to the nominal E3 EMP environment, would there be enough bulk power transformers available to facilitate system recovery?"

The EPRI study evaluated the potential impacts of the ORNL E3 EMP environment centered over eleven locations within CONUS. Each location was evaluated separately as a single high-

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[7] Electromagnetic Pulse Research on Electric Power Systems: Program Summary and Recommendations. Oak Ridge National Laboratories, Oak Ridge, TN: 1993. ORNL-6708.

[8] Meta-R-321, The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid. Metatech Corporation, January 2010.

altitude detonation event. The study found that although a significant number of transformers (hundreds to thousands depending on target location evaluated) could experience GIC flows greater than the 75 amps/phase screening criteria adopted from North American Electric Reliability Corporation (NERC) TPL-007-1[9], only a small number (3 to 14 depending on the target location evaluated) of these transformers were found to be at potential risk of thermal damage. In addition, the at-risk transformers were found to be geographically dispersed. The principle reason for this finding is the short duration of the E3 EMP event; thus, these findings should not be used to extrapolate potential impacts of GMD events of the same magnitude. The research also found that transformer condition was an important factor indicating that proper transformer maintenance is an important mitigating factor.

The results of this study are in agreement with earlier work performed by ORNL which concluded that direct immediate damage to bulk power transformers from E3 EMP is unlikely. Results from additional analysis using the LANL E3 EMP environment is expected to be made available in the final report.

Voltage Stability Assessment

The EPRI voltage stability assessment was based on the same ORNL E3 EMP environment and evaluated the same 11 target locations across CONUS. As with the previous study, each location was evaluated separately as a single high-altitude detonation event.

The voltage stability assessment was conducted using a time-domain modeling approach (transient stability model) to compute the GIC flows and the response of the bulk power system to those GIC flows. The magnetic response of bulk power transformers to the flow of GICs (that is, the additional reactive power absorption resulting from part-cycle saturation) was included in the power system model as well as dynamics of generators, controls and loads. Generic protection systems for lines and generators were also included. The effects of system topology changes due to protection system operations (lines and generators) were included in both the GIC calculations and dynamics simulations. The effects of harmonics resulting from part-cycle saturation, and the potential damage or disruption to critical electronic systems or other assets caused by the preceding E1 or E2 pulses, were beyond the scope of this initial study.

This initial study found that voltage collapse (or blackout) due to E3 EMP alone was possible for several of the scenarios that were simulated. Although it is difficult to precisely determine the geographic area that would be impacted by voltage collapse it is estimated that the impacts could be regional and on the order of several states or larger, but smaller than either the Eastern or Western Interconnections. None of the scenarios that were evaluated resulted in a nation-wide grid collapse. The results of this study are in agreement with earlier work performed by ORNL which indicated that voltage collapse is possible, but nation-wide blackout is unlikely.

Although study results indicate that regional voltage collapse from E3 EMP is possible, the impact of E3 EMP on the bulk power system can potentially be mitigated by reducing or blocking the flow of GICs in bulk power transformers. Mitigation could potentially be accomplished with neutral grounding resistors, capacitive blocking devices, series capacitors, or a combination of these approaches. Designing protection and control systems so that they are

[9] NERC TPL-007-1 Transmission System Planned Performance for Geomagnetic Disturbance Events

immune to the effects of power system harmonics, and utilizing automatic switching and load shedding schemes, may also help to mitigate the impact of E3 EMP events. Because transmission operators are not currently provided with warning of an impending HEMP attack and voltage collapse due to E3 EMP occurs rather quickly, manual operator actions are not expected to be timely enough to help mitigate voltage collapse.

Because transformer damage is expected to be minimal, recovery times following a E3 EMP induced blackout are expected to be consistent with prior events *if* damage from E1 EMP and E2 EMP is minimal. The ability of E1 EMP to damage communications systems, supervisory control and data acquisition (SCADA) systems, and protection and control systems is a major concern since loss of these functions can adversely affect system recovery efforts. Therefore, hardening of critical electronic systems within transmission control centers, black-start units, and substations included along cranking paths should be considered.

Results from additional E3 EMP analysis using the LANL E3 EMP environment is expected to be made available by April 30, 2019, as part of the final report.

Next Steps

EPRI's EMP research results are being finalized, and are expected to be made available in a final report by April 30, 2019. The final report is expected to include:

- additional unclassified (bounding) HEMP environments provided by DOE and LANL;
- results from extensive E1 EMP testing of substation equipment such as digital protective relays, SCADA and communications equipment;
- results from E1 EMP, E2 EMP, E3 EMP and combined E1 EMP + E3 EMP assessments;
- approaches for mitigating the effects of HEMP (E1 EMP and E3 EMP) on the electric transmission system with focus on substations; and
- considerations for system recovery following a HEMP-induced blackout.

GMD Research

A geomagnetic disturbance (GMD) or solar storm occurs when the magnetic cloud, called a coronal mass ejection, that is emitted from the sun as part of a solar eruption collides with the Earth's shielding magnetic field. This collision generates currents in the magnetosphere and ionosphere of the Earth's outer atmosphere which in turn induces GIC in transmission lines and transformer windings at the Earth's surface.

Because the primary energy source that drives the flow of GIC in the power grid is typically located nearer the geographical poles, power grids in northern latitudes tend to experience greater impacts. Additional considerations include system voltage level and topology, local deep Earth conductivity and proximity to large bodies of salt water.

The potential bulk power system impacts from GIC generated by a severe GMD event are similar to those described previously regarding E3 EMP. However, there are some important distinctions. First, the geoelectric fields associated with severe GMD events, and hence the GIC flows, tend to be considerably less than those generated by a nominal (bounding) E3 EMP environment. For example, the geoelectric field in Quebec during the March 1989 GMD event has been estimated as approximately 2 V/km as compared with the nominal E3 EMP environments of 24 V/km (ORNL) or 35 V/km (LANL). Additionally, GMD events can last for several days as compared to E3 EMP which only last a few minutes. Lastly, severe GMD events can expose continental-scale areas to varying levels of geoelectric fields whereas exposure from a nominal E3 EMP environment is more regional.

The potential impacts of severe GMD events on the bulk power system are real, and have been observed in the past. For example, during the March 1989 geomagnetic storm, Hydro-Quebec experienced a blackout resulting from the effects of GMD-related harmonics, and a generator step-up unit (GSU) at Salem Nuclear Power Plant in New Jersey was damaged from resulting hotspot heating. Damage to several bulk power transformers resulting from voltage transients associated with system collapse (not to be confused with thermal damage from GIC) was also experienced in Canada. A number of other effects were observed in the United States and Canada, for example tripping of capacitor banks, but these did not result in any significant reliability impacts[10].

EPRI recognizes the potential for severe GMD events to impact the bulk power system, and has been involved in GMD-related research for nearly four decades[11]. Some of EPRI's research activities in this area have included:

- prototype development of GIC blocking devices;
- developing sensors and a support network for measuring geomagnetic fields and GIC flows in transformers;
- developing software tools, models and guidelines to assess the impacts of severe GMD events on the bulk power system;
- evaluating and improving the fidelity of existing models (e.g. earth conductivity);
- improving understanding of potential impacts of GMD events on bulk power system components;
- laboratory/field testing of high-voltage transformers to inform the development of magnetic and thermal models for use in assessments;
- evaluating mitigation options and their application; and
- supporting the development of benchmark GMD events (1-in-100 year solar storms) used in assessments.

Because EPRI's research in the GMD area is expansive, only current activities will be addressed.

[10] North American Electric Reliability Corporation (NERC), March 13, 1989 Geomagnetic Disturbance: www.nerc.com/files/1989-quebec-disturbance.pdf

[11] *Investigation of Geomagnetically Induced Currents in the Proposed Winnipeg-Dulluth-Twin Cities 500 kV Transmission Line.* EPRI, Palo Alto, CA: 1981. EL-1949

Monitoring and Sensors

A critical component of GMD research is measurement of geomagnetic fields and GIC flows in the power grid. Measurements can be used to improve understanding of the phenomenology of an event as well as improve and/or validate models that are used in assessments. Thus, one of the important aspects of EPRI's GMD research program is centered around monitoring and development of advanced sensor technologies.

In order to improve geomagnetic field observations throughout the United States, EPRI currently has research underway to locate 13 next-generation magnetometer sensors (sensors that measure the local geomagnetic field) between existing magnetic observatories operated by the U.S. Geological Survey (USGS). Measurement data will be used to improve deep earth conductivity models and understanding of local geological factors that can potentially impact GIC flows in the network.

The EPRI SUNBURST GIC measurement network consists of a consortium of member utilities through which near-real-time continuous monitoring of the GIC flowing in the neutral of large power transformers is performed. Over the last decade, EPRI has accumulated a body of data and experience about correlations between space weather and GIC flows in the grid. While the primary focus of this research is operating the monitoring network, the data collected in this project is being used to inform model validation efforts and prediction models such as the NASA Solar Shield project.

One of the limitations of measuring GICs using more traditional technology (e.g. SUNBURST sensor) is that the monitoring location must be the neutral of the transformer. Depending on the type of transformer, for example an autotransformer, a neutral connected GIC node may not provide the observability necessary to determine the GIC flows that could affect power system operation and performance. To fill this research gap, EPRI developed an advanced sensor capable of measuring GIC flows in energized conductors. Measurement of GIC in energized AC transmission lines and transformer windings improves observability of the behavior and effects of GIC on the bulk power system. In addition, GIC flows to other parts of the network and in some cases remote transformers can be measured directly. The results from this research is expected to lead to developing more effective network boundary models, and closer representation of actual GIC conditions when assessing impact to transformers.

Research in Support of FERC Order 830 and NERC

In response to the R&D gaps identified in FERC Order 830, EPRI initiated a two-year, collaborative research effort in January 2018 to help address the gaps presented in the Order and to inform future revisions of NERC TPL-007. The intent of this research is to help the electric utility industry and stakeholders advance the collective understanding of the potential impact of extreme GMD events on the bulk power system as well as identify options for mitigating effects. The main objectives of this research effort are to:

- advance the science of defining extreme events on bulk power systems to perform GMD vulnerability assessments;
- evaluate the accuracy of ground conductivity models used for geomagnetically induced current (GIC) studies;
- further study the impacts of GIC currents on power system assets; and
- develop software tools and methods needed to assess the potential impacts of extreme GMD events on the bulk power system.

Currently, this research effort is voluntarily financially supported by 26 utilities and the North American Electric Reliability Corporation (NERC).

Research in Support of Executive Order 13744

EPRI is supporting the U.S. Department of Energy (DOE) in fulfilling the directives outlined in Executive Order 13744 "Coordinating Efforts to Prepare the Nation for Space Weather Events." This Executive Order has several directives for the DOE, including developing a plan and implementing a pilot program to field test and evaluate available technologies that mitigate the effects of GMD on the electrical power grid. In phase 1 (completed), EPRI developed a pilot project plan to implement GMD mitigation equipment on the electrical power grid. EPRI has begun Phase 2 of the pilot project, which will include field deployment of mitigation equipment (and associated monitoring systems) and then monitor, evaluate, and report on the performance of the installed GMD mitigation equipment including adverse system impacts (if any) that may be observed.

Concluding Remarks

The potential impacts of GMD and HEMP are real; however, evaluating the effects of such events on existing and future power grid infrastructure is complicated and requires concrete, scientifically-based analysis. Once the true impacts are known, including the potential unintended consequences of some mitigation options, cost effective mitigation and/or recovery options can be developed and employed.

Significant progress has been made over the course of EPRI's three-year HEMP research project. The final report, which will be made available to the public for free, is expected to be delivered by April 30, 2019. The forthcoming final report will provide the technical basis and findings from a broad array of studies including: interconnection-scale E1 EMP and E3 EMP assessments, an assessment that evaluated the synergistic effects of E1 EMP and E3 EMP, and an E2 EMP assessment. The final report will also provide design options for mitigating the potential impacts that were observed during this research effort and discuss considerations for recovering from HEMP-induced blackouts.

GMD research is ongoing to provide a technical basis for informing future revisions of NERC TPL-007-1. Advancements in power system modeling and description of the 1-in-100 year GMD event have been made and will continue over the next year. This research is expected to advance the state-of-the-art in GMD assessments, and improve industry's ability to predict and mitigate the potential impacts of severe GMD events on the bulk power system.

EPRI is committed to developing science-based solutions to these difficult problems, and will continue to offer technical leadership and support to the electricity sector, public policymakers, and other stakeholders to enable safe, reliable, affordable, and environmentally responsible electricity.

Testimony of

David W. Roop, P.E.

Director – Electric Transmission Operations & Reliability

Dominion Energy

Committee on Homeland Security and Governmental Affairs

U.S. Senate

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance"

February 27, 2019

Good afternoon, Mr. Chairman, Ranking Member Peters and Members of the Committee:

My name is David W. Roop, and I am Director of Electric Transmission Operations and Reliability in Dominion Energy's Power Delivery Group.

Thank you for inviting me to appear today to discuss my company's efforts to protect our electric transmission system from naturally recurring Geomagnetic Disturbances (GMD) and the potential for Electromagnetic Pulse (EMP) events. Our company's efforts to protect our system began decades ago, and our response to the threats posed by GMDs and EMPs is an ongoing process. We have taken many steps to protect our electric infrastructure, and we will continue to modify and improve our system as we gain more knowledge of these threats and effective mitigation strategies.

Before offering our testimony, I would like to provide you with some information about Dominion Energy and the Power Delivery Group.

Dominion Energy is headquartered in Richmond, Virginia, and we provide electricity or natural gas to nearly 7.5 million customers – across 18 states – to energize their homes and businesses. We have about $100 billion in assets to provide electric services -- generation, transmission and distribution – as well as natural gas services -- storage, transmission, distribution and import/export.

On January 1 of this year, we were honored to merge with SCANA Corporation. And with that combination came 2.1 million new electric and natural gas customers in the Carolinas and Georgia…most of them served by SCANA's regulated electric and natural gas utilities in North and South Carolina: SCE&G and PSNC Energy.

We are also a leader in clean energy development, with one of the largest solar fleets in the United States. Our electric generating fleet has reduced its carbon intensity – the average amount of carbon dioxide released for each unit of electricity generated – by 50 percent since 2000, and we are committed to a 60 percent reduction by 2030.

Within Dominion Energy, my organization – the Power Delivery Group – is responsible for the safe and reliable delivery of power to the 2.6 million electric customers served by our regulated utility subsidiary in Virginia and northeastern North Carolina. Our system includes about 6,600 miles of electric transmission lines and approximately 250 transmission substations. In 2018 alone we placed into service more than $900 million in additional transmission assets. We expect to add another $700 million in transmission investments this year.

I have served as Director of Electric Transmission Operations and Reliability in the Power Delivery Group since 2001, and in that capacity I lead our company's efforts to provide resiliency to our electric transmission system. I have a 43-year career with Dominion Energy, and I am a Licensed Professional Engineer in the Commonwealth of Virginia. I am also a member of the National Academy of Engineers and serve on the board of directors of the Virginia Academy of Science, Engineering and Medicine.

In addition, I am the U.S. President of CIGRE, a group of power sector professionals from around the world who address the technical challenges facing this industry. I am a senior member of the Institute of Electrical and Electronics Engineers (IEEE) and serve on advisory committees for the Electric Power Research Institute (EPRI), the North American Transmission Forum, and the Electric Sector Coordinating Council R&D Committee.

I can assure you that all of these organizations – including Dominion Energy – recognize the threats posed by the two types of electromagnetic events – naturally occurring GMDs and potentially the high-amplitude EMPs triggered by hostile actions.

Our company is particularly aware of these dangers due to Dominion Energy's service to a vital section of the Eastern Interconnection. The service area for our regulated electric utility, Dominion Energy Virginia, is in close proximity to the District of Columbia and is itself the home of many vital national security and defense operations, including many federal agencies, the Pentagon and the world's largest naval base.

We are also a major supplier of electricity to data centers in Virginia that move more than half of the world's Internet traffic. We understand we have an important role to play in our nation's security and work closely with our federal and state partners.

An important element of maintaining that secure and reliable transmission network is protecting our system from geomagnetic disturbances. We have taken comprehensive steps – including planning and equipment upgrades – to protect our assets and are proud to be a member of the North American Electric Reliability Corporation (NERC) Standard Drafting Team that last year developed a new set of standards dealing with the GMD phenomenon.

But our protective efforts started long before that. In fact they go back three decades, to 1989.

During a major historical GMD event that year, Dominion Energy's electric transmission system was impacted. Multiple infrastructure elements that allow us to maintain voltage within acceptable limits failed – threatening the secure operating state of the electric grid. Immediately after this event, we began work, in cooperation with EPRI, to protect our infrastructure, making it more resilient, with greater immunity to GMD events. This work strengthened our design specifications for transmission capacitors and associated protection systems. Our infrastructure has successfully handled all subsequent events. (Utilities employ capacitors to support system voltage and these devices are critical during GMD and EMP events.)

Given that capacitor banks have a useful service life of approximately 20 years, we made a deliberate transition to the strengthened design. The improvements were components of planned capital upgrade programs. Through this incremental approach, financial impacts were held to a minimum. The protection scheme we deployed was disseminated throughout the electric industry by the IEEE Standards organization and other industry forums. The IEEE has developed several documents that now guide the industry including: IEEE 1036 – *Guide for Application of Shunt Power Capacitors,* IEEE C62.22 G-3, Appendix G, *Arrester energy requirement for shunt capacitor applications,* and IEEE 1531, *Guide for the Application and Specifications of Harmonic Filters.*

Our efforts to protect another vital system component – transformers – from geomagnetic disturbances also began more than a decade and a half ago. GMD can damage large power transformers by causing them to overheat. Dominion Energy worked with Virginia Tech, the University of Tennessee (Knoxville), and our key transformer suppliers to evaluate our existing fleet of in-service power transformers along with new units under construction in our supply chain. This analysis indicated that incremental design changes could improve thermal margins beyond our already generous design margin. Since 2004, we have been replacing the critical units that are approaching end of life with these upgraded designs to ensure their survivability. Our work in this area has also been shared with the industry through the IEEE standards committees, IEEE C57.163 – *IEEE Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances.*

Additionally, we have been working with NERC, as a member of the GIC Task Force/Standard Drafting team, and also with the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, and NASA to improve our real-time situational awareness by deploying sensors across our system. We have also teamed with these government partners to develop, deploy, refine and provide feedback on a broad array of computer modeling capabilities. This research is on-going but is showing significant promise with improved computer models to better define the actions that our system operators should take during a GMD event to prevent a major outage. More research is also scheduled in 2020 to better define our models for transformers subjected to this extreme condition. The research will include testing in-service units at one of our 500kV substations. This would be the first testing of its kind in the U.S., and we are eager to obtain, study, and broadly share the results.

Now let me turn to our efforts and approach relating to EMP. Unlike GMD, EMP is not a recurring event. Their impact is therefore difficult to quantify when attempting to justify spending on mitigation efforts.

These events are not deterministic but more random or stochastic in nature, like terrorist attacks. With that in mind, we have worked with PJM and Oak Ridge National Laboratory to develop a probabilistic methodology to allow us to analyze the spectrum of potential impacts of "N-k" events on the electric grid. ("N-k" is a term of art within our industry used to describe analysis of a large event made up of smaller, multiple events simultaneously challenging the electric grid.)

This novel methodology immediately showed value. The model identified previously unknown vulnerabilities to our system. Legacy planning methodology was simply not capable of identifying the vulnerabilities present in this new normal. Since its development and validation, Dominion Energy has employed the new probabilistic planning approach and has shared it with the industry. It has now been widely adopted. (NERC has discussed this methodology as part of its *September 2018 Reliability Guidelines: Methods for Establishing IROLs.*)

While this probabilistic analysis was being developed, we also began an extensive international research initiative to identify leading practices for addressing EMP system vulnerabilities. We immediately began modifying our substation design standards to improve the resiliency of our designs for withstanding these events. Again, we accomplished this incrementally, by incorporating the improvements into our schedule of capital projects. This approach minimized costs. It also provided collateral benefits for protection against more routine system challenges -- such as lightning, transients, and switching surges, to name a few. Additionally, we standardized an all-metal control enclosure with limited penetrations. These metal enclosures ensure that EMP-radiated waves would be significantly attenuated. We also partnered with utilities across the U.S. to fund EPRI research to provide more specific guidance on other design aspects that would require incremental changes. This research will help us make sure that we are prudently investing in improvements, and ensure the solutions found and implemented do no harm to our equipment and everyday operation of our electric grids.

EPRI's body of work has been extremely valuable in providing data that will inform our future designs. The research has demonstrated the type of damage we could expect from EMP events, and it has improved our ability to specify equipment with greater ability to withstand an electromagnetic pulse. The EPRI work was a critical step in providing us with the technical basis for prudent expenditures. However, their efforts would not have succeeded without significant support from our federal partners such as the Department of Homeland Security, the Department of Defense, and the Department of Energy.

Given the concerns over security, including EMP, Dominion Energy spent 3½ years designing and constructing a 113,000-square foot facility that cannot be compared to anything else in the energy industry. This new System Operation Center (SOC), which opened its doors in August 2017, is hardened against natural and man-made threats. The center includes a MIL-Spec EMP space for critical operations and employs the latest technologies and practices in physical and cyber security, telecommunications, redundancy, and efficiency.

I believe our record of responding to these threats is impressive. I wish I could tell you that we now have all the answers, but unfortunately, we do not. Additional testing and research is still needed to address the impact of EMP on controls and protective equipment. Further work is needed to ensure we have the communications needed during and after an EMP event to restore service. The industry is also still searching for a cost effective means to shield existing control enclosures.

Despite everything we are doing for EMP protection, we still cannot guarantee that all equipment would remain undamaged. To address this gap, we have purchased spare equipment (including emergency spare relays and EHV transformers) and mobile emergency equipment. We have also entered into equipment sharing agreements like STEP through EEI and RESTORE (a broader equipment sharing agreement with multiple utilities). In addition, we have collaborated with the Department of Energy and Oak Ridge National Laboratory on the Strategic Transformer Reserve analysis as part of the FAST Act. This has helped us to develop a minimal transmission grid recovery methodology.

Additionally, we realize that we are part of a larger, interconnected system. For decades, the strength of our systems has depended on neighbors helping neighbors. We continue to share what we are learning through industry trade associations and professional organizations. In addition, we are working with select utilities to directly share our best practices with them. This sharing will help us quickly improve our understanding and deployment of resiliency measures.

Late in 2018, Dominion Energy began an effort to broaden our focus as an industry on the EMP impacts on generation facilities. We began this process by working with the DOD Defense Threat Reduction Agency, members of DHS, DOE and the Electric Infrastructure Security Council. In addition, our technical staff is working to understand the impacts of renewable energy on our blackstart plans. This analysis will help us determine the measures needed to ensure our vital blackstart resources are available to respond to all events - especially EMP.

Dominion Energy is committed to addressing these issues. We have greatly improved our system's ability to handle these events. We are not finished in this endeavor and will continue our prudent investments, as our research identifies needs for improvement.

I want to again thank this Committee for allowing me to speak and express our appreciation for the invaluable support we have been given by our various federal partners in these areas.

February 22, 2019

STATEMENT FROM
JIM VESPALEC
DIRECTOR OF ASSET PLANNING & ENGINEERING
AMERICAN TRANSMISSION COMPANY

SUBMITTED TO
THE COMMITTEE ON HOMELAND SECURITY AND GOVERNMENTAL AFFAIRS
U.S. SENATE ROUNDTABLE FOR
"PERSPECTIVES ON PROTECTING THE ELECTRIC GRID FROM AN ELECTROMAGNETIC PULSE OR GEOMAGNETIC DISTURBANCE"

Members of the Committee, thank you for the opportunity to share the views of American Transmission Company (ATC) on the important topic of protecting the grid from an electromagnetic pulse (EMP) or geomagnetic disturbance (GMD).

Formed in 2001 as the nation's first multi-state transmission-only utility, ATC owns and operates more than 9,600 miles of high-voltage transmission lines and 560 substations in portions of Wisconsin, Michigan, Minnesota and Illinois. ATC's total assets are nearly $5 billion.

At ATC, steps have been taken to help mitigate the concern of an EMP or GMD event; however, we also recognize, that, as the research concludes, and more industry knowledge is gained, there may be more to do. Today, I would like to highlight some of the steps ATC has taken to prepare and harden its electric grid for an EMP or GMD event.

First, ATC purchased the first commercially available Neutral Insertion Device (NID), known as Solid Ground from ABB/EMPrimus in 2012. In 2015, ATC installed this transformer neutral-insertion device at a substation in the northern part of our service territory. This unique device is meant to automatically protect a transformer from harmful geomagnetic induced current (GIC) during a GMD event or an EMP E_3 pulse. This device was installed as a prototype on ATC's transmission system, and, to my knowledge, it is the only one like it installed and operational in the industry.

ATC learned about the device from the vendor – EMPrimus – at an industry conference. In reviewing the opportunity at the time and the ATC transmission system, it was determined that an ideal location existed on ATC's transmission system to install and test the capability of this device. It was a prudent investment to test the technology and gain experience for our company and the industry.

The unit was received in its most basic form but was, subsequently, modified and enhanced to make it fully automated and fully resilient. To date, the NID has performed according to its design parameters and has not failed. While automated, the setting to activate it is configurable. ATC chose to set the activation level lower than really needed to protect the transformer to garner more operations and operational experience.

The NID has operated automatically to block GIC more than several dozen times and has successfully kept GIC from flowing through the transformer to ground. No adverse operating complications have been experienced on the system due to the NID performing its intended function. In summary, the unit has performed as expected so far.

ATC Operations, Planning and Asset Management will continue to monitor the NID's performance over the next several years to gain confidence and familiarity with this technology should more NIDs be indicated in the future as a result of GMD studies and/or system events.

Second, ATC has installed GIC monitors on dozens of transformers to detect GIC and harmonics. Since GIC may impact each transformer differently, these sensors give our operations centers a broader view of system performance. In the case of an operation of the NID, these sensors also will provide us evidence if it is causing harmful impacts to other transformers.

Third, ATC is an active participant in the research at the Electric Power Research Institute (EPRI) for EMP vulnerabilities and mitigation. This three-year effort has reached some conclusions, but it is not expected to be finalized until April 2019. ATC expects to examine the findings and identify prudent opportunities to implement to mitigate EMP.

Fourth, ATC has taken steps to improve grid resiliency. Through strengthened communications and relationships with the Wisconsin Emergency Management and the Wisconsin National Guard, ATC has put into place improved procedures and secure communication channels to ensure that, should an event occur, ATC is better positioned to respond. ATC has mutual aid agreements with 57 utilities through membership in Edison Electric Institute (EEI) Spare Transformer Equipment Program (STEP) and the 20 utility members of Regional Equipment Sharing for Transmission Outage Restoration (RESTORE). Both provide assurances that ATC will have large power transformers available if a major weather or intentional terror attack should happen.

Thank you for the opportunity to share our information with you, and I look forward to questions you may have.

U.S. Senate Committee on Homeland Security and Government Affairs
Roundtable: Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance
Statement by Dr. Justin Kasper (University of Michigan)

Introduction

Chairman Johnson, Ranking Member Peters, and members of the Committee, thank you for this opportunity to discuss what we know about the solar origin of geomagnetic disturbances (GMD) and how we can improve our ability to predict their occurrence.

The most famous example of a solar GMD began on September 1, 1859, when an intense solar flare produced a visible white flash directly observed by the astronomer Carrington. Just 18 hours later material from the solar atmosphere released after the flare slammed into Earth at about three million miles an hour. Earth was engulfed in a magnetic tsunami from the Sun that sent compasses spinning, brought the Northern lights down into the Caribbean, and set telegraph lines sparking, rendering them inoperable for days. We might not rely on telegraph today but our power lines are equally susceptible. The potential nation-wide and even world-wide loss of power due to a Carrington-level event and the resulting economic and societal impact are why we are here today.

The risk is real and unfortunately the Carrington event was not unique. On July 23, 2012 a spacecraft operating on the other side of the Sun was immersed in a similar eruption that would have hit Earth square on if it had happened nine days sooner. Multiple researchers estimate the probability of a similar event happening in any decade at between 3 and 10 percent. I would like to stress that in addition to these extreme events, smaller but more frequent GMDs are estimated to cause an average of $10 billion in damage each year. Address the major GMDs and we can also protect us from these smaller events.

What can we do about this? Right now telescopes detect an eruption at the Sun and we make a forecast by simulating its expansion into space, but we do not have confirmation of a threat to Earth until it reaches the NOAA DSCOVR spacecraft floating one percent of the way towards the Sun. Any warning is better than none, but an extreme event would get from the spacecraft to Earth in less than ten minutes. This is not enough time to assess the risk and recommend action. We need spacecraft closer to the Sun providing earlier warning of Earth directed events and their properties, better models of these eruptions and regional forecasts of GMD. Most importantly we need leadership with a mandate to coordinate and direct the research and operational components of space weather that are spread over multiple agencies.

Overview

My written testimony is organized to address the following three questions.

1. How do public and private sectors evaluate the likelihood and magnitude of these events?
2. Is there ongoing research to help us better understand the solar phenomena that lead to space weather impacts on Earth?
3. How can current National Oceanic and Atmospheric Administration (NOAA) and/or National Aeronautics and Space Administration (NASA) programs improve GMD forecasting, mitigation, coordination, and response efforts?

1. How do public and private sectors evaluate the likelihood and magnitude of these events?

Evaluating the likelihood and magnitude of the most severe GMDs is challenging because the detailed record of direct observations only extends back half a century to the start of the space age, and because we are still in the early phases of understanding what aspects of a solar eruption and the Earth determine the severity of the resulting GMD. We are also still learning about the impacts of GMDs. For example an extreme space weather event in August 1972 known for its speed and intense particle radiation, did not generate a particularly large global GMD, but did produce a magnetic disturbance in Asia so strong that it spontaneously detonated dozens of sea mines south of Hai Phong, North Vietnam on 4 August 1972.[1] Within the research community the most accepted estimates of the probability of an extreme GMD are based on an analysis of the occurrence rate of historical GMDs as a function of severity, fit to a statistical model, and then evaluated at the extreme.[2] Quoting the Riley et al. (2018) study,

> Based on these results, our best estimate for the probability of another extreme geomagnetic event comparable to the Carrington event occurring within the next 10 years is 10.3% with 95% confidence intervals (CI) in the range [0.9,18.7] for a power-law distribution, but only 3.0% with 95% CI [0.6,9.0] for a log-normal distribution (see also Riley and Love 2017). Our results, however, depend on: (1) how an extreme event is defined; (2) the statistical model used to describe how the events are distributed in intensity; (3) the techniques used to infer the model parameters; and (4) the data and duration used for the analysis.

Thus depending on assumptions about the distribution of events the probability of an extreme Carrington level event within the next ten years ranges from 3% to 10%.

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[1] Knipp, D. J., Fraser, B. J., Shea, M. A., and Smart, D. F. (2018). On the little-known consequences of the 4 August 1972ultra-fast coronal mass ejecta: Facts, commentary, and call to action.SpaceWeather,16, 1635–1643.
[2] Riley, P., Baker, D., Liu, Y.D. et al. Space Sci Rev (2018) 214: 21. https://doi-org.proxy.lib.umich.edu/10.1007/s11214-017-0456-3. P. Riley, J.J. Love, Extreme geomagnetic storms: probabilistic forecasts and their uncertainties. Space Weather 15(1), 53–64 (2017)

In order to test these estimates other researchers are trying to increase the number of large events in the record by either looking at ancient records of activity earlier in Earth's history, or by simultaneously monitoring many other starts like our own Sun for large flares.

Large solar flares and coronal mass ejections can produce elevated levels of high energy particle radiation in space, factors of millions or more above typical levels. This level of particle radiation can cause measurable changes in the isotopic and chemical composition of the atmosphere which then are preserved through snowfall in undisturbed ice or ancient tree rings for millennia. Ice core samples in Greenland and Antarctica have been used to search for extreme events in the more distant past, although signals from other events such as major volcanic eruptions have made them hard to interpret. An isotopic analysis of tree rings has found elevated spikes in the level of the isotope Carbon-14 in the years 774 AD and 993 AD which may have been due to extreme solar events.[3]

In addition to calculating the probability of an extreme GMD, there have also been efforts to estimate the cumulative impact of smaller but more frequency GMDs. For example, Zurich Risk Engineering recently published an examination of over 11,000 insurance claims submitted by North American commercial organizations from 2000 through 2010 for equipment losses and related business interruptions associated with damage to, or malfunction of, electrical and electronic equipment.[4] The claims were then correlated with the level of geomagnetic activity. There is a very clear association, with claims up 20% for the top 5% most geomagnetically active days. This amounted to about $2B in claims over a decade seen by this one insurance company due to GMD induced electrical damage. Given that this insurance company only covers 8% of the market this suggests that GMD could be responsible for $2B a year in commercial property damage in the US.

2. Is there ongoing research to help us better understand the solar phenomena that lead to space weather impacts on Earth?

For reasons we do not yet fully understand the corona or extended atmosphere of our Sun is nearly 1000 times hotter than its surface. This million degree atmosphere is unstable and produces supersonic jets of plasma called the solar wind that expand into space and flood the solar system with particles and magnetic fields. Occasionally a highly magnetized region in the corona will erupt into space. These eruptions as called coronal mass ejections (CMEs) and they can produce the high speeds and magnetic fields that cause the most extreme GMDs. Variation in the solar wind over time and as the Sun rotates every 27 days can cause the Earth to be

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[3] F. Miyake, K. Nagaya, K. Masuda, T. Nakamura, A signature of cosmic-ray increase in AD 774–775 from tree rings in Japan. Nature 486(7402), 240–242 (2012). F. Miyake, K. Masuda, T. Nakamura, Another rapid event in the carbon-14 content of tree rings. Nat. Commun. 4, 1748 (2013). F. Miyake, K.Masuda,M. Hakozaki, T. Nakamura, F. Tokanai, K. Kato, K. Kimura, T. Mitsutani, Verification of the cosmic-ray event in AD 993–994 by using a Japanese Hinoki tree. Radiocarbon 56(3), 1189–1194 (2014)

[4] Dobbins, R. and K. Schriiver, Electrical claims and space weather. Measuring the visible effects of an invisible force, June 2015

bathed in changing speed solar wind, which can also trigger smaller GMDs. The Earth is surrounded by the ionosphere, a region of space that contains charged particles and electric and magnetic fields. The ionosphere is surrounded by a region of space controlled by the magnetic field of the Earth, the magnetosphere. The magnetosphere and ionosphere are continually bathed in large fluxes of radiation, energetic particles and mass from the Sun. The conditions and changes in both these regions of space are referred to as space weather. As with terrestrial weather, space weather can often result in severe dynamic events, storms in space, many of which result in severe operational consequences for satellites and our technological infrastructure on the ground. Some of these events have the potential for catastrophic damage. A recent review of all research into the Sun and space weather can be found in the comprehensive 2013 National Academy of Sciences Decadal Strategy for Solar and Space Physics.[5] For a review of the state of the art in space weather research a recent special collection in Space Science Reviews titled "The Scientific Foundation of Space Weather" has a comprehensive review.[6]

New research capabilities that are posed to transform our understanding of the connection between the Sun and the Earth include the recently launched Parker Solar Probe mission in 2018.[7] This spacecraft will repeatedly plunge into the extended atmosphere of the Sun, collecting the first direct observations of how the corona is heated and the solar wind accelerated, and directly observing coronal mass ejections as they erupt into space.[8] Parker Solar Probe will be joined next year by the Solar Orbiter mission, which will not get as close to the Sun but will image the surface at high resolution. Closer to Earth, the recently launched GOLD mission and the upcoming ICON mission monitor the response of Earth's upper atmosphere to changes in solar input. The community eagerly awaits the completion of the Daniel K. Inouye Solar Telescope (DKIST) solar telescope in 2020 and its unprecedented ability to image activity on the surface of the Sun and in its corona.

3. How can current National Oceanic and Atmospheric Administration (NOAA) and/or National Aeronautics and Space Administration (NASA) programs improve GMD forecasting, mitigation, coordination, and response efforts?

As is often the case, the distribution of work across multiple agencies can hinder progress. In the case of space weather research a major challenge is that it is difficult for NOAA to fund basic research that could translate into operational capability, or to fund the transition of a research product (such as a simulation of a solar eruption, or a model of economic impact) into an operational capability. Similarly NASA and the NSF are well-posed to support cutting edge

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[5] National Research Council. 2013. Solar and Space Physics: A Science for a Technological Society. Washington, DC: The National Academies Press. https://doi.org/10.17226/13060.

[6] The Scientific Foundation of Space Weather, Space Science Reviews (2018), ISSN: 0038-6308 (Print) 1572-9672 (Online).

[7] Fox, N.J., Velli, M.C., Bale, S.D. et al. Space Sci Rev (2016) 204: 7. https://doi.org/10.1007/s11214-015-0211-6

[8] Kasper, J.C., Abiad, R., Austin, G. et al. Space Sci Rev (2016) 204: 131. https://doi.org/10.1007/s11214-015-0206-3

science and technology development, but are generally not in a position to fund the kind of long term monitoring of conditions needed to develop and test forecasting tools. This makes it very difficult for a researcher to develop a new observational capability specifically to improve space weather awareness, or for a modeler or theorist to maintain or extend computer simulations to improve forecasts. One or more agencies must either be given the mandate to foster the transition from research to operations or a managing authority must have the mandate to coordinate this work across agencies.

Our current capability to forecast space weather is decades behind our capability to predict terrestrial weather. This is largely because there are significant aspects of the underlying physics that governs the solar atmosphere and interplanetary space – plasma physics – that we do not sufficiently understand, because our observational view of the connection between the Sun and the Earth is incomplete, and because what we do understand or can predict has not been converted into an operational capability. Over the space age, we have accumulated extensive knowledge of the regions of space surrounding the Earth and the Sun, and the governing physical processes operating in these regions. However, this knowledge, with exceptions, has not fully translated into a systematic operational forecast capability that informs the users of space weather data on timescales sufficient to take appropriate actions, whether for day-to-day operations or to protect against catastrophic events.

What is required is to increase the warning time for when a CME strikes Earth and the probability of it causing a GMD from tens of minutes to at least ten hours for the most extreme events. This would give us time to produce a regional forecast of the resulting GMD and other space weather effects, with sufficient time to make an informed decision whether to take active measures to protect the grid. In order to accomplish this we need (1) new and more capable observations from satellites strategically located to observe the Sun; (2) improved understanding and models that allow us to determine the ambient conditions in the space environment between Sun and Earth and the evolution of CMEs during their transit; (3) improved methods of assimilating the data from the new observations into the models; and (4) improved understanding of the response of the Earth's magnetic field to the impact of a CME to correctly predict the resulting GMD.

Testimony of

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Former Assistant Secretary, Infrastructure Protection,
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Department of Homeland Security

Submitted to the

SENATE HOMELAND SECURITY AND GOVERNMENTAL AFFAIRS COMMITTEE

For the February 27, 2019 Hearing

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance."

Chairman Johnson, Ranking Member Peters, and members of the Committee, thank you for inviting me to testify at the roundtable today, "Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance."

My name is Caitlin Durkovich. I had the honor of serving eight years at the Department of Homeland Security (DHS) from 2009-2017, including as the Assistant Secretary of Infrastructure Protection. I also had the privilege of co-chairing the Space Weather Operations, Research and Mitigation (SWORM) Task Force, which produced *The National Space Weather Strategy* (2016) and corresponding action plan to enhance the preparedness of the Nation to a space weather event.

I now lead the security and resilience practice for Toffler Associates, a future-focused strategic advisory firm, whose clients include critical infrastructure owners and operators and the department and agencies charged with helping them manage risk in increasingly complex and uncertain times.

There is no doubt the risk facing owners and operators of critical infrastructure has increased. We are reliant on aging infrastructures built for a different time that increasingly leverage data and technology to enable more efficient, reliable and distributed operations. This highly interconnected, electrified and digitized ecosystem is not only being used for purposes we could have never imagined when it was built 100 years ago, but it must be resilient to risks we could have never imagined – extreme weather, coordinated cyberattacks, reliance on GPS, electromagnetic pulse (EMP), and severe geomagnetic disturbances (GMD) or space weather, to name a few.

These risks – and our vulnerabilities to them – transcend geographic borders, corporate lines of business, and politics, blurring the lines between public and private accountability and responsibility. It is the private sector, which owns and operates most of our critical infrastructure, that must invest in and manage the risks and often intertwined consequences posed by the threat environment.

The energy sector in particular faces a variety of threats and hazards, largely driven by the increasing sophisticated threat actors with intent and capability as well as the interdependencies of the infrastructure systems, including the increasing reliance on digital infrastructure as the electric grid transitions from an analog system to a digital system to improve efficiency. The bottom line is the risk to digital and physical infrastructures has grown and our critical infrastructure is more vulnerable than it was a few decades ago.

What is encouraging is the partnership between government and industry has matured, providing more visibility into emergent threat vectors and potential consequences – guiding joint action on risk mitigation. We must continue to support and incentivize owners and operators to understand and protect infrastructure not just from the routine, but from the most consequential and disruptive threats – terrestrial and space-based – that pose existential risk.

The challenge we face is sustained focus and engagement on the lower probability, high consequence threats that are overshadowed by high likelihood, real-time threats that require regular, and sometimes 24x7 hour attention, such as cyberattacks.

Potential Impacts to Critical Infrastructure from EMP on GMD

We do not fully understand how an EMP event or space weather event would impact electrical infrastructure, and it is the subject of ongoing analysis. In some of its forms, EMP and

GMD could cause widespread disruption and serious damage to electronic devices and networks, including those upon which many critical infrastructures rely. There is uncertainty over the magnitude and duration of an electric power outage that may result from an EMP event due to ambiguity regarding the actual damage to electric power assets from an event. Any electric power outage resulting from an EMP event would ultimately depend upon several unknown factors and effects to assets that are challenging to accurately model, making it difficult to provide high-specificity information to electric system planners and system operators. These variables include characteristics such as the EMP device type, the location of the blast, the height of the blast, the yield of the blast, and design and operating parameters of the electric power system subject to the blast. Secondary effects of EMP may harm people through induced fires, electric shocks, and disruptions of transportation and critical support systems, such as those at hospitals or sites like nuclear power plants and chemical facilities.

And while space weather phenomena are relatively well understood within the scientific community, the rarity of extreme space weather over the lifespan of our modern-day infrastructure has limited the availability of data useful for predictive analysis. One of the earliest recorded and most infamous geomagnetic storms – the 1859 Carrington Event – caused telegraph systems to fail across North America and Europe. A 1921 extreme GMD, similar to the 1859 Carrington event, also disrupted communication systems in the United States and Europe.

March 1940 is the earliest reported instance of GMD affecting the electric grid. The 1989 Quebec Blackout led to the interruption of power in Québec, Canada for nearly nine hours and demonstrated the potential of GMDs to cascade impacts across geographic regions. In addition to causing the Hydro-Quebec power grid to collapse in less than two minutes, the storm's arrival damaged transformers and caused tripping of protective equipment in the Northeastern United States. The Quebec Blackout is one of four storms that had consequential impacts to the grid: A September 1989 Storm cause thermal damage to North American transformers; a November 2001 storm resulted in transformer failures in New Zealand; and, the October 2003 Halloween event resulted in minor power grid disturbances in North America.

In July of 2012, a major disruptive solar event narrowly missed the earth. It would have been comparable to the 1859 Carrington event and it is believed if the storm had occurred one week earlier, earth would have been in the line of fire. Most newspapers never mentioned the near miss and I would be hard pressed to say most infrastructure operators or Americans know about the phenomena of space weather, much less can name these four modern-day space weather events or the near miss.

In the development of *The National Space Weather Strategy*, the SWORM Task Force also recognized that the growing interdependencies of critical infrastructure systems have increased potential vulnerabilities to EMPs and GMDs and other lower probability, high impact events. Cross sector protection and mitigation efforts to eliminate or reduce EMP and GMD vulnerabilities are essential components of national preparedness. Protection focuses on capabilities and actions to eliminate vulnerabilities to EMP and GMD, and mitigation focuses on long-term vulnerability reduction and enhancing resilience to disasters. Together, these preparedness missions frame a national effort to reduce vulnerabilities and manage risks associated with EMPs, GMDs, and other unbounded events.

Government and Industry Collaboration

More than two decades of critical infrastructure programs and policies has fostered unprecedented collaboration between government and industry to mitigate the consequences of low probability, high consequence events, including EMP and GMD. I want to applaud the Department of Homeland Security for its releasing its strategy for *Protecting and Preparing the Homeland Against Threats of Electromagnetic Pulse and Geomagnetic Disturbances*. The strategy's three goals are practical steps the critical infrastructure enterprise can coalesce around to mitigate the risk of EMP and GMD. They include:

1. Improve risk awareness of electromagnetic threats and hazards.
2. Promote effective electromagnetic-incident response and recovery efforts.
3. Promote effective electromagnetic-incident response and recovery efforts.

I agree with the Department's assessment about the potential severity of both the direct and indirect impacts of an EMP or GMD incident, and that it should compel our sustained national attention. Taking a page from hurricane preparedness, the SWORM Task Force went to great lengths to understand how much advance warning owners and operators need to put effective mitigation measures in place. This information was the basis for improving forecasting lead-time and accuracy and ensuring that products are actionable for decision making. However, if the community is unaware of this environmental hazard, or has not institutionalized it as part of contingency planning and operations, better forecasting will have little effect. One of the biggest challenges I believe EMP and especially GMD risk mitigation faces, is sustained focus on this hard problem. Efforts to to raise critical infrastructure stakeholder understanding of space weather in an increasingly chaotic risk environment are critical. I want to thank the Ranking Member for continuing to advance legislation to improve the understanding and forecasting of space weather events and ensure the homeland security enterprise better understands the vulnerability of critical infrastructure to space weather events. I also believe this is where we can take another page from hurricane preparedness and ensure key stakeholders partake in annual space weather briefings and planning conferences.

Finally, I support the objective of developing effective public risk communication plans to promote consistent messaging and addressing public uncertainty. Many of the EMP and GMD mitigation measures would result in a disruption to the lifeline functions our public takes for granted. However, if the risk is better understood, the public can play an important role in helping us limit the damage and disruption.

Conclusion

EMP and space weather are two of the many threats to the functions, systems, and networks that underpin our national security, economic prosperity, and American way of life. From cyber espionage and sabotage, to the convergence of cyber and physical systems, to insider threats, and to EMPs and GMDs, owners and operators of critical infrastructure have an obligation to manage threats across the risk spectrum – routine, persistent, and existential – but should not have to go it alone. These challenges demand industry and government work together to both develop mitigation strategies and to invest in a modern and secure infrastructure that is resilient to the threats of today and tomorrow.

Chairman Johnson, Ranking Member Peters, and members of the Committee, thank you again for the opportunity to appear before you today. I look forward to your questions.

Department of Energy
Washington, DC 20585

July 24, 2019

The Honorable Ron Johnson
Chairman
Committee on Homeland Security
and Governmental Affairs
United States Senate
Washington, DC 20510

Dear Mr. Chairman:

Thank you for the opportunity to testify and participate in a roundtable discussion on "Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance" before the U.S. Senate Homeland Security and Governmental Affairs Committee on February 27.

To address the risks associated with an electromagnetic pulse (EMP) and geomagnetic disturbance (GMD), the U.S. Department of Energy (Department or DOE) has put in place an EMP Resilience Strategy and associated detailed EMP Action Plan. It is important to note that the Strategy and Plan were developed in close coordination with DOE's National Laboratories, private sector, and academia. Specifically, the National Laboratories are conducting cutting-edge research and the private sector is doing research, development, and demonstration projects on EMP and GMD. Academia, including critics such as Dr. George Baker, provided a series of proposed actions to address this area. All of these constituencies were instrumental in the development of the strategy and action plan.

As a follow-up to the roundtable, you requested additional feedback on Dr. Baker's proposed action items and priorities. We appreciate the opportunity to provide feedback and have enclosed a document that responds to Dr. Baker's proposed action items and recommendations on behalf of the Department.

To address this formidable threat, the Administration requested $30 million to support the Center for EMP/GMD Simulation, Modeling, Analysis, Research and Testing (CE-SMART) in DOE's Fiscal Year 2020 budget. Through CE-SMART, DOE will partner with Federal agencies, DOE laboratories, commercial testing laboratories, and electric power industry operators and equipment manufacturers to better understand EMP/GMD impacts to grid systems. CE-SMART supports identification and acceleration of critical delivery of electric infrastructure most susceptible to EMP/GMD effects. CE-SMART will also assess and validate technologies to mitigate and protect against EMP/GMD.

Thank you again for leading the roundtable on the risk of an EMP and we look forward to continued interactions on this crucial area.

Sincerely,

Karen S. Evans
Assistant Secretary
Office of Cybersecurity, Energy Security,
and Emergency Response

Enclosure

ENCLOSURE

Below is the Department of Energy's (DOE) response to Chairman Ron Johnson's request for feedback on Dr. George Baker's proposed action items during the "Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance" roundtable on February 27, 2019.

Dr. George Baker summarizes his testimony by stating "[d]espite witness arguments to the contrary, the grid, in its current unhardened state, would likely be out of service for long periods following a major solar storm or [electromagnetic pulse] attack."[1] DOE maintains that, although thermal damage of transformers could occur from a long-lasting, severe solar storm (G5+), studies have shown large numbers of transformers are unlikely to be damaged by a man-made EMP because the E3 component is short-lived.[2] In addition, North American Electric Reliability Corporation (NERC) does issue mandatory and enforceable standards to mitigate the risk of instability, uncontrolled separation, and cascading as a result of a geomagnetic disturbance for the electricity sector.

In his testimony, Dr. Baker recommends "'top-down' actions and a set of equally important 'bottom-up' actions" to achieve grid resilience.[3] DOE, in coordination with the energy sector, takes a risk-based approach to address the various threats to the energy sector. A risk-based approach helps identify and prioritize problem areas and drives cost-effective investment decisions. This is consistent with how the U.S. Department of Homeland Security (DHS) and how owners and operators of critical infrastructure evaluate and addresses threats and hazards. Dr. Baker's first "top-down" action proposed that the new EMP Executive Order establish an office of EMP coordination within the National Security Council (NSC) as recommended by the 2018 EMP Commission.[4] DOE defers to the National Security Council and White House on how to organize the work of their offices.

Dr. Baker's second action is to revise the Federal Energy Regulatory Commission's (FERC's) geomagnetic disturbances (GMD) standard (TPL-007-2) because he states that "even if rigorously enforced it will leave the grid dangerously vulnerable to GMD."[5] He adds that "[w]ithout a corresponding FERC EMP directive, the private sector is not doing very much of anything to address the EMP threat. An EMP directive and protection standard are sorely needed."[6] DOE endorses FERC's and NERC's role in the development of standards for the electricity sector.

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[1] *Roundtable - Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance before the S. Comm. On Homeland Security and Governmental Affairs* (Feb. 27, 2019) (Testimony of Dr. George H. Baker, Professor Emeritus, James Madison University; Director, Foundation for Resilient Societies at p. 10) (Dr. Baker Testimony) available at https://www.hsgac.senate.gov/imo/media/doc/Testimony-Baker-2019-02-27-REVISED.pdf.

[2] *Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid: Geomagnetically Induced Current and Transformer Thermal Analysis* report available at: https://www.epri.com/#/pages/product/3002009001/?lang=en-US

[3] Baker, *supra* note 1.

[4] *Id.*

[5] *Id.* at 11.

[6] *Id.*

Since the time of the testimony, the President has signed the referenced *Executive Order on Coordinating National Resilience to Electromagnetic Pulses*, which states that the "Secretary of Energy, in consultation with the heads of other agencies and the private sector, as appropriate, shall review existing standards for EMPs and develop or update, as necessary, quantitative benchmarks that sufficiently describe the physical characteristics of EMPs, including waveform and intensity, in a form that is useful to and can be shared with owners and operators of critical infrastructure."[7]

Dr. Baker's third proposed action is for new legislation to empower FERC to: (1) "write and enforce grid protection standards[;] (2) [i]dentify mechanisms, including cost recovery measures, to incentivize private sector engagement on EMP protection and increase on-site fuel stockpiles[; and] (3) [d]evelop a national blackstart plan."[8] DOE agrees with Dr. Baker's recommendation that mechanisms need to be identified to incentivize private sector engagement on EMP protection. As a starting point, DOE and FERC hosted a technical conference[9] on Thursday, March 28, 2019, to discuss security investments to protect energy infrastructure. The technical conference reviewed all threats, including EMP and GMD, to energy infrastructure. Finally, NERC has developed standards related to system restoration from blackstart resources and, in coordination with FERC, reviews the capability of the nation's power grid operators to blackstart in the event of widespread outages. In the most recent study (May 2018) it was determined that grid operators do have sufficient capability to blackstart in the event of widespread outages.[10] In addition, DOE's Office of Electricity is leading an effort to develop a North American Energy Resilience Model (NAERM) to model the entire energy sector for contingency planning efforts from all threats and hazards, including EMP. This model will help DOE improve preparedness and response efforts from all hazards.

Dr. Baker states that the Department of Homeland Security (DHS) "is to be commended for issuing a coordination [sic] version of a communication/data center protection standard. This document should be expanded to include HV/EHV electric power assets (HV generators and substation transformers/breakers)."[11] For the reasons outlined in response to Dr. Baker's proposal above, DOE maintains that standards should be developed after prioritizing infrastructure, better characterizing and understanding the risks, and ascertaining what level of protection is desirable from a risk-management perspective. Further, DHS does not set energy sector standards, as these would be developed and enforced by NERC and FERC. DOE, DOE National Laboratories, and the Electric Power Research Institute (EPRI) have conducted research to inform FERC and NERC on energy sector standards.

Dr. Baker's sixth proposal is for DHS and DOE EMP/GMD protection programs to emulate the Department of Defense's (DoD's) efforts in protecting "high priority military command, control, communication, and computer assets for nuclear deterrence and response."[12] However, DoD

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[7] *Coordinating National Resilience to Electromagnetic Pulses*, 26 March 2019.
[8] *Id.*
[9] FERC Technical Conference notice located at https://www.ferc.gov/media/news-releases/2019/2019-1/02-04-19.asp#.XK4b1CFKjRY
[10] Report on the FERC-NERC-Regional Entity Joint Review of Restoration and Recovery Plans (May 2018) available at https://www.ferc.gov/legal/staff-reports/2018/bsr-report.pdf?csrt=17363026875705090851.
[11] Dr. Baker Testimony at 11.
[12] *Id.*

utilizes military standards (MIL-STD) that are developed for mission critical national security functions, and hence are unnecessarily high, and likely impractical, for the entirety of the electric grid. Further, they are also not specifically designed for electric grid equipment and control systems. Therefore, DOE believes standards for the grid should be based on a solid characterization and understanding of EMP threats and associated risks.

Dr. Baker states that DHS and DOE should be given full access to DoD standards and databases. In particular, Dr. Baker states that "[t]here is no need to recalculate a standard EMP waveform. Note that current EPRI grid vulnerability assessment models are using low-bound recalculated E3 waveforms. Existing IEC and EMPC EMP waveforms are more than adequate. Use of the unclassified MIL-STD-188-125 test regimen will assure power grid survivability to both EMP and 100-year solar storms."[13] DOE is evaluating and validating the appropriate E1 and E3 waveforms that should be used as standard waveforms for grid modeling and testing purposes. In addition, the available waveforms today vary widely, which is why standard development is difficult without further research and analysis by DOE and its National Laboratories.

Dr. Baker states that "[a] prioritized list of EMP-susceptible infrastructure is needed. System protection and reconstitution prioritization requires improved grid modeling. Integrated system test beds will be important for model validation. Top priority is HV generation plants and HV/EHV transformers, heretofore untested. The [Idaho National Laboratory] and the [Tennessee Valley Authority] test beds look promising." DOE will support DHS in identifying priority energy critical infrastructure and national critical functions as identified in the Executive Order and then, as a follow-on activity, consider which assets, functions, and nodes are most susceptible/vulnerable to an EMP.

Dr. Baker points out that "[t]he most current EMP Intelligence report is technically flawed and misleading in a manner that downplays the need for action – a new assessment is needed."[14] DOE stands by the Intelligence Community (IC) assessment, which is grounded in intelligence, has been coordinated throughout the IC and peer-reviewed by subject matter experts with relevant technical expertise.

Dr. Baker estimates the "cost of EMP protection for the bulk power system to be in the $50B range. The investment strategy is based on identifying a top-down 'thin-line' of grid assets. More rigorous cost estimates are needed by DOE & industry."[15] DOE recommends a structured approach to reviewing critical assets and nodes. The current testing and analysis program to characterize and understand the vulnerable elements and risks to the grid must first be completed as a basis for decisions.

From a bottom-up perspective, Dr. Baker recommends "EMP protection programs must be pursued at the local and State levels since communities would be on their own for extended periods in a wide-area blackout." DOE agrees that local and state governments do play a role in addition to the Federal Government and owners and operators. DOE, FERC, and State regulators work closely in addressing risks to the energy sector from all hazards. DOE's Office

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[13] *Id.*
[14] *Id.*
[15] *Id.*

of Cybersecurity, Energy Security, and Emergency Response (CESER) manages a State, Local, Tribal, and Territorial (SLTT) program that engages with Governors' offices, State energy offices, State regulators, and other officials on energy security.

He also recommends pilot demonstration programs of selected grid sectors to address the feasibility and cost of local EMP protection. DOE supports pilot demonstration programs. For example, DOE is currently field-testing commercially available technologies to mitigate the adverse impacts of ground-induced currents on the electric grid. This pilot demonstration program is part of DOE's Center for EMP/GMD Simulation, Modeling, Analysis, Research, and Testing (CE-SMART) that is a national program that DOE is hoping to advance in 2019 and 2020. Through pilot programs and other initiatives, DOE will partner with Federal agencies, DOE laboratories, commercial testing laboratories, and electric power industry operators and equipment manufacturers to close the gaps in our understanding of EMP/GMD impacts to grid systems.

Dr. Baker goes on to state that "[b]ottom-up protection should address a thin-line of essential life-support infrastructures including distribution substations, backup power generation systems, emergency services, water supply and treatment, hospitals, and the necessary logistics tail."[16] DOE agrees with this action item and is working closely with DHS's National Risk Management Center (NRMC) to address interdependencies and cross-sector risks, including identification of national critical functions.

Dr. Baker contends that "[l]ow cost, stop-gap measures will be important, including hardened microgrid installations as a near-term solution for life-line infrastructures...Federal requirements and standards are important to ensure that microgrids will survive and not increase the EMP vulnerability of the rest of the grid. Microgrid EMP protection is only a small incremental cost if included in initial system design."[17] DOE is committed to supporting the private sector in better understanding, mitigating, and responding/recovering from risks whether they are natural or man-made. Ensuring the resiliency of microgrids and other energy infrastructure takes a holistic approach which is precisely why CESER is working across the Department—with the Office of Electricity, Office of Fossil Energy, and Office of Energy Efficiency and Renewable Energy—to prepare for and mitigate EMP risks to the energy sector.

Additionally, Dr. Baker recommends that "[t]he federal government must coordinate the interface between the top-down and bottom-up efforts. A useful interface demark occurs where the high voltage transmission grid (bulk power) meets the distribution grid (lower voltage electric network supplying local infrastructure services."[18] DOE works closely with all aspects of the energy sector, whether it is generation and transmission owners and operators or distribution utilities to support their risk management activities. DOE primarily does this through close collaboration with ESCC, which includes representatives from the investor-owned, cooperative, and municipally-owned electric utilities, FERC, NERC, independent system operators, and regional transmission owners to ensure that we are able to address issues across the electricity supply chain.

[16] *Id.*
[17] *Id.*
[18] *Id.* at 12.

Finally, Dr. Baker notes that “several commercial enterprises have developed turn-key EMP protection services and product lines and stand ready to harden critical infrastructure facilities and systems on[c]e directives and programs are in place.”[19] DOE agrees and supports private sector innovation in this space.

[19] *Id.*

Post-Roundtable Questions for the Record
Submitted to Brian Harrell
From Senator Ron Johnson

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance"

February 27, 2019

Question#:	1
Topic:	Priorities and Action Items
Hearing:	Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance
Primary:	The Honorable Ron Johnson
Committee:	HOMELAND SECURITY (SENATE)

Question: In the written testimony provided by Dr. George Baker, he outlined several priorities and action items for addressing the impacts of electromagnetic pulses (EMPs) and geomagnetic disturbances (GMDs). Please review Dr. Baker's written testimony and provide your perspective on his priorities and action items. Specifically, please identify the action items you agree with, disagree with, and those that you believe can and should be implemented to better protect the U.S. electric grid from an EMP and GMD event.

Response:
From a Top Down perspective:

- "The Federal Energy Regulatory Commission (FERC) GMD standard (TPL-007-2), though its specified environments and system thresholds are not defense-conservative, has at least brought industry attention to GMD effects. This standard, even if rigorously enforced will leave the grid dangerously vulnerable to GMD and needs to be revised."
  - DHS Position: DHS defers to DOE as the sector specific agency and to FERC on regulatory action. DHS, along with its interagency partners, are developing the implementation plan and specific actions for the recent update to the National Space Weather Strategy, which will likely involve projects that will provide input to FERC's deliberations.

- "Without a corresponding FERC EMP directive, the private sector is not doing very much of anything to address the EMP threat. An EMP directive and protection standard are sorely needed."

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- DHS Position: DHS defers to DOE as the sector specific agency and FERC as the regulatory agency on regulatory action and to the private sector on their individual efforts

- "New legislation is needed to empower FERC, specifically to

(1) Enable FERC to write and enforce grid protection standards.
(2) Identify mechanisms, including cost recovery measures, to incentivize private sector engagement on EMP protection and increase on-site fuel stockpiles.
(3) Develop a national blackstart plan."

- DHS Position: DHS defers to DOE as the sector specific agency and to FERC on regulatory action.

- "A national EMP protection standard is needed. DHS is to be commended for issuing a coordination version of a communication/data center protection guideline. DHS should expand this to include HV electric generator stations and electric substations."
  - DHS Position: DHS is currently working with The National Security Council (NSC), assisting in the coordination of EMP and geomagnetic GMD security policy. As Dr. Baker is currently serving as a consultant to the NSC on this topic, DHS is working in close coordination to address this issue as a part of the ongoing work in coordinating EMP and GMD activity, with DOE as the sector specific agency, across the Federal Government.

- "For more than a half□century, DoD has protected high priority military command, control, communication, and computer assets for nuclear deterrence and response. DHS and The Department of Energy (DOE) EMP/GMD protection programs should emulate DoD's efforts."
  - DHS Position: DHS is currently working with the National Security Council, assisting in the coordination of EMP/GMD security policy. As Dr. Baker is currently serving as a consultant to the NSC on this topic, DHS is working in close coordination to address this issue as a part of the ongoing work in coordinating EMP and GMD activity across the Federal Government. DHS is working in collaboration with DOE, as the sector specific agency, and with interagency partners to review and potentially

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revise the EMP and GMD hardening or protection levels to be applied to civilian infrastructure systems.

- "We must preclude the temptation to re-invent the wheel by giving DHS and DOE full access to DoD standards and databases. There is no need to recalculate a standard EMP waveform. Note that current EPRI grid vulnerability assessment models are using low bound recalculated E3 waveforms. Existing IEC and EMPC EMP waveforms are more than adequate. Use of the unclassified MIL-STD-188-125 test regimen will assure power grid survivability to both EMP and 100-year solar storms."
  - DHS Position: DHS is currently working with the NSC, assisting in the coordination of EMP and GMD security policy. As Dr. Baker is currently serving as a consultant to the NSC on this topic, DHS is working in close coordination to address this issue as a part of the ongoing work in coordinating EMP and GMD activity across the Federal Government. The lack of consistent use of EMP threat waveforms and the lack of interagency agreement on the data, models, and simulation tools used to generate EMP waveforms has created confusion within the interagency, which has led to inaction. DHS is working in close collaboration with our DOE, Defense Threat Reduction Agency (DTRA), and NSC partners to define a process to reach interagency consensus on this issue, which will necessitate generation of new and consistent EMP waveforms.

- "A prioritized list of EMP-susceptible infrastructure is needed. System protection and reconstitution prioritization requires improved grid modeling. Integrated system test beds will be important for model validation. Top priority is HV generation plants and HV/EHV transformers, heretofore untested. The INL and TVA test beds look promising."
  - DHS Position: As part of the Executive Order on Coordinating National Resilience to Electromagnetic Pulses, the Secretary of Homeland Security will, among other things, in coordination with the heads of any relevant SSAs, use the results of risk assessments to better understand and enhance resilience to the effects of EMPs across all critical infrastructure sectors, including coordinating the identification of national critical functions and the prioritization of associated critical infrastructure at greatest risk to the effects of EMPs.

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DHS defers to DOE and industry regarding the specifics of grid modeling However, in carrying out its role in the interagency; DHS confers and collaborates frequently with experts in advanced grid modeling, especially with respect to EMP and GMD. The Electric Power Research Institute in this area has made significant advancements. DHS has initiated peer reviews of this recent grid modeling work for EMP and GMD impacts and has included DOE in these activities.

- "The most current EMP Intelligence report is technically flawed and misleading in a manner that downplays the need for action – a new assessment is needed."
  - DHS Position: DHS defers to the Intelligence Community (IC) regarding the development of raw and finished intelligence in this area. DHS is currently working closely with DOE to review the technical requirements for defining EMP waveform fields for potentially updating these joint intelligence assessments.
- "I estimate cost of EMP protection for the bulk power system to be in the $50B range. The investment strategy is based on identifying a top-down "thin-line" of grid assets. DOE & industry need more rigorous cost estimates."
  - DHS Position: DHS defers to DOE and industry

From a Bottom-Up perspective:

- "EMP protection programs must be pursued at the local and State levels since communities would be on their own for extended periods in a wide-area blackout."
  - DHS Position: As part of the Executive Order on Coordinating National Resilience to Electromagnetic Pulses, the Secretary of Homeland Security will provide timely distribution of information on EMPs and credible associated threats to Federal, State, and local governments, critical infrastructure owners and operators, and other stakeholders. DHS is currently working with the NSC, assisting in the coordination of electromagnetic pulse EMP and GMD security policy. As Dr. Baker is currently serving as a consultant to the NSC on this topic, DHS is working in close coordination to address this issue as a part of the ongoing work in

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coordinating EMP and GMD activity, with DOE as the sector specific agency, across the Federal Government.

- "Pilot demonstration programs of selected grid sectors are all-important to address the feasibility and cost of local EMP protection. The ongoing Lake Wylie Demonstration Project and the San Antonio Joint-Based micro grid development program are good examples and should be expanded and funded."
    - DHS Position: DHS defers to DOE and industry
- "Bottom-up protection should address a thin-line of essential life-support infrastructures including distribution substations, backup power generation systems, emergency services, water supply and treatment, hospitals, and the necessary logistics tail."
    - DHS Position: CISA leads the national effort to secure and protect critical infrastructure from all threats and hazards, to include EMP and GMD. CISA's primary role in managing EMP and GMD risks is through cross-sector coordination and information sharing, to ensure stakeholders have access to current information on risks and any resources to assist with mitigation efforts.
- "Low cost, stopgap measures will be important, including hardened micro grid installations as a near-term solution for lifeline infrastructures. We are presently at a watershed moment due to the recent onset and rapid acceleration of micro grid installations. Federal requirements and standards are important to ensure that micro grids will survive and not increase the EMP vulnerability of the rest of the grid. Micro grid EMP protection is only a small incremental cost if included in initial system design."
    - DHS Position: DOE has the lead role in development of micro grid technology and demonstration projects. DHS is working closely with DOE on developing EMP impact analyses and protection requirements; however, this process is dependent upon completion of analyses described earlier in this response.
- "The federal government must coordinate the interface between the top-down and bottom-up efforts. A useful interface demark occurs where the high voltage

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transmission grid (bulk power) meets the distribution grid (lower voltage electric network supplying local infrastructure services."

- DHS Position: Regarding coordination, CISA leads the national effort to secure and protect critical infrastructure from all threats and hazards, to include EMP and GMD. CISA's primary role in managing EMP and GMD risks is through cross-sector coordination and information sharing, to ensure stakeholders have access to current information on risks and any resources to assist with mitigation efforts.

Post-Roundtable Questions for the Record
Submitted to Brian Harrell
From Senator Gary Peters

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance"

February 27, 2019

Question#:	2
Topic:	Cross-Sector Assets Update
Hearing:	Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance
Primary:	The Honorable Gary C. Peters
Committee:	HOMELAND SECURITY (SENATE)

Question: The Department of Homeland Security's Strategy for Protecting and Preparing the Homeland Against Threats of EMP and GMD reference the need to prioritize the protection of the most important components of our critical infrastructure, that if disrupted could cause catastrophic effects on our nation. Please give an update on your Department's efforts around determining what cross-sector assets are the most critical.

Response: The Department of Homeland Security (DHS) through the Cybersecurity and Infrastructure Security Agency (CISA) has developed a list of National Critical Functions (NCF) and a framework for mapping the dependencies between the NCFs and between the NCFs and the critical infrastructure networks that support the NCF. DHS/CISA has developed a flexible framework to enable the SSA and other agencies with responsibilities for these critical infrastructure networks to catalog and document this information. This information will be used to identify and catalog critical component of the infrastructure networks vulnerable to EMP. We look forward to briefing the committee on these efforts in depth.

Question#:	3
Topic:	EMP Recovery and Response
Hearing:	Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance
Primary:	The Honorable Gary C. Peters
Committee:	HOMELAND SECURITY (SENATE)

Question: In the event of a significant EMP or GMD event, please describe DHS's role during the response and recovery operations.

Response: Due to the wide range of possible scenarios that could be caused by a significant EMP or GMD event, response would be dependent on the specific effects. These decision points are captured in the National Response and Disaster Recovery Framework and the National Incident Management System produced by The Federal Emergency Management (FEMA), which is publicly available. CISA, as lead for Emergency Support Function 2: Communications, under the National Response Framework, would support communications service providers in response, recovery, and restoration. Per the Executive Order, these response and recovery plans are currently under review and potential update. DOE, as the sector specific agency, has the primary role for response and recovery of the energy sector.

Question#:	4
Topic:	National Risk Management Center
Hearing:	Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance
Primary:	The Honorable Gary C. Peters
Committee:	HOMELAND SECURITY (SENATE)

Question: The newly established National Risk Management Center (NRMC) within DHS's Cybersecurity and Infrastructure Security Agency (CISA) is charged with examining cross-sector risks that threaten critical infrastructure. Please describe how the NRMC and its analysis informs the work of DHS to coordinate critical infrastructure protection.

Response: The Cybersecurity and Infrastructure Security Agency's (CISA) National Risk Management Center (NRMC) is a planning, analysis, and collaboration center that was established to manage reducing strategic risks to our Nation's critical infrastructure. The NRMC promotes effective risk management by unifying people and processes to identify, analyze, prioritize, and manage these risks. This includes developing modeling, simulation, and risk analysis capabilities through the National Infrastructure Simulation and Analysis Center (NISAC) that can be leveraged to analyze infrastructure system impacts and interdependencies during crises and steady state operations.

As an example of this, the NRMC is leveraging NISAC capabilities to support the energy sector and our national defense in identifying infrastructure dependencies necessary to enable continued Department of Defense (DOD) operational activities from critical military bases. This work connects civilian critical infrastructure with national security needs and will lead to additional electric grid resilience for DOD missions.

NRMC has also worked closely with the critical infrastructure community to develop a set of national critical functions (NCFs) - those functions of government and the private sector so vital to the United States that their disruption, corruption, or dysfunction would have a debilitating impact on either the Nation's security, economic security, public health or safety, or any combination thereof. The NCF enables a risk management approach based on the functions that an entity enables or to which it contributes, rather than focusing on a static sector-specific or asset approach. This more holistic approach better captures crosscutting risks and associated dependencies that may have cascading impact within and across sectors. We are now in the process of analyzing and prioritizing these NCFs.

Prioritization will drive a community-oriented risk mitigation approach, with public and private sector representatives collaborating to reduce risk. CISA will lead or fulfill portions of the risk management plans, but other federal agencies and the private sector will also play significant roles as appropriate for the identified risk.

Question#:	4
Topic:	National Risk Management Center
Hearing:	Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance
Primary:	The Honorable Gary C. Peters
Committee:	HOMELAND SECURITY (SENATE)

The NRMC is currently focused on developing the prioritized NCF set and building the longer-term framework for organizing critical risks. At the same time, NRMC activities are focused around known high-priority risk areas such as information and communications technology (ICT) supply chain; position, navigation, and timing (PNT) resilience; pipeline cybersecurity; and election security. These initial activities will be complemented with other priority areas of risk management collaboration identified through the NCF process.

The NRMC anticipates the completion of the prioritized list of NCFs and potential scenarios of degradation, referred to as a Risk Register, by the end of calendar year 2019. This will be the next substantive step toward unifying the critical infrastructure community, both public and private, around needed national response to urgent national risks.

GAO response to question for roundtable participants in *Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance, held by the U.S. Senate Committee on Homeland Security & Governmental Affairs, February 27, 2019.*

Question: Please provide additional feedback on Dr. George Baker's proposed action items and priorities.

GAO response: Dr. Baker provided the Committee with a written statement that included proposed action items to address electromagnetic events. These included 10 actions directed toward federal activity and 6 actions directed to state and local governments and the private sector. The actions provide Dr. Baker's perspective on how best to defend against both electromagnetic pulse (EMP) and geomagnetic disturbance (GMD) events.

Recent GAO work also provides areas of action needed to address EMP and GMD threats.[1] Specifically, one unaddressed recommendation and additional areas of understanding GAO identified would assist the nation in better preparing and responding to both EMPs and GMDs. GAO's unaddressed recommendation is similar to an action item provided by Dr. Baker, as noted below.

GAO's open recommendation regarding EMPs and GMDs:

- GAO recommended that DHS and DOE direct responsible officials to review the Federal Energy Regulatory Commission's electrical infrastructure analysis and collaborate to determine whether further assessment is needed to adequately identify critical electric infrastructure assets.[2] Among Dr. Baker's action items is a prioritized list of EMP-susceptible infrastructure. As of March 2019, GAO was awaiting additional information about DHS's plans to implement actions identified in its EMP/GMD Strategic Plan regarding DHS's determination of critical utilities and national security assets at risk from EMP and GMD events. GAO is also monitoring DOE efforts to develop a North American Energy Model that DOE officials reported would also help identify critical electric infrastructure assets.

Specific to GMD, GAO recently reported how determining appropriate actions to protect against GMD would be better informed with answers to the three questions below:[3]

- What is the likelihood of a large-scale GMD?

As GAO has reported, despite ongoing efforts to better understand large GMDs, it is not currently possible to offer a definitive view on the likelihood of a large GMD, based on GAO's review of the available evidence and input from experts. In part, this is because these events occur so rarely. Since 1933, there have been 22 extreme GMDs and GAO found that four

[1] GAO, *Critical Infrastructure Protection: Federal Agencies Have Taken Actions to Address Electromagnetic Risks, but Opportunities Exist to Further Assess Risks and Strengthen Collaboration,* GAO-16-243 (Washington, D.C.: March 24, 2016) and GAO, *Critical Infrastructure Protection: Protecting the Grid from Geomagnetic Disturbances,* GAO-19-98 (Washington, D.C.: Dec. 19, 2018).

[2] GAO-16-243.

[3] GAO-19-98.

severe or extreme GMDs led to transformer damage or large-scale electric power outage, and none of the power outages were long-duration. The largest recorded GMD, the Carrington event in 1859, predated the existence of the electric grid as well as detailed measurements of solar, space, and Earth conditions relevant to GMDs. Ongoing federally-funded research into solar physics, such as NASA's recently launched Parker Space Probe, may improve our understanding of the sun and how it causes space weather, and lead to improved assessments of the likelihood of large GMDs. As GAO has also reported, the uncertainties surrounding GMDs, including the likelihood of a GMD large enough to potentially damage the electric grid, limit decision-making on whether additional efforts, beyond those that are ongoing, are needed.

- What is the risk such storms pose to the electricity grid?

The extent to which a large GMD could cause a large-scale, long-duration electricity service outage in the United States is not fully understood, but work is underway that could increase understanding. The most persuasive studies GAO reviewed concluded that the most likely effects of a large GMD would be service interruptions that are neither long-term nor large-scale. However, in the event of a significantly larger GMD, on the order of magnitude of the 1859 Carrington event, there remains some uncertainty about the potential level of impact. As GAO reported, the disruption or damage the most extreme GMDs can cause on the grid is the result of geomagnetically induced current (GIC) flow in transformers. A NERC GMD reliability standard provides a benchmark to estimate the impact on the electric transmission system from a large GMD. Conducting such estimates is challenging because the wide variety in transformers—including model, age, and power capacity—could lead to significant variability in the effects on GIC on specific transformers. It is also challenging to incorporate the effects of harmonics on electric grid equipment, which are important because harmonics caused by GIC led to the only two known electric service outages to result from GMDs in 1989 and 2003. NERC's GMD research work plan, in part, proposes to develop guidelines and tools to perform system-wide assessment of GIC-induced harmonics which, when completed and implemented, should improve the understanding of the effects that large GMDs and its resulting GIC flow could have on grid performance.

- What are potentially effective solutions to mitigate the effects of a large scale GMD?

Potential solutions to prevent or mitigate the effects of GMDs on the electric grid could include operational procedures or, eventually, the integration of new technologies.

As GAO reported, levels of GIC are not widely used in the real-time operation of the power grid, but the industry could monitor and use this information to mitigate its effects during an event. In FERC Order 830 approving TPL-007-1, FERC concluded that "additional collection and disclosure of GIC monitoring and magnetometer data is necessary to improve our understanding of the threats posed by GMD events." As part of approving the standard, FERC directed NERC to require the collection of GIC monitoring and magnetometer data, to collect such data, and make that information available. The ability to monitor the levels of GIC that are actually occurring on the system, in particular, could improve situational awareness, according to industry sources.

The recently implemented NERC GMD reliability standard (EOP-010-1) directs certain grid operators to document and implement operational changes when a GMD occurs, but NERC recognizes that the use of technologies may also be beneficial. Unfortunately, there is little operational data on the effectiveness of currently available technology solutions to mitigate the effects of a large-scale GMD. Obtaining such operational data would require high-voltage transmission lines and transformers that could be exposed to simulated GIC at potentially damaging levels and configured to measure impacts on the equipment being tested, the other equipment on the system, and overall power flows. In response to a 2016 executive order, DOE is developing a pilot program to test and evaluate technology solutions on an operational electric power grid.[4] This work, when completed, may help validate the operational viability of the most promising technologies for integration into the operational grid.

As GAO concludes in its Technology Assessment, without better information on these three broad questions—(1) whether a large GMD is likely, (2) the extent to which a large GMD could cause a large-scale, long-duration outage, and (3) whether specific procedures or technologies are effective—it will be difficult for federal decision-makers to determine whether the risk posed by GMDs warrants specific federal actions to address it or to determine the appropriate solutions to prevent or mitigate the effects of such GMDs on the U.S. electric grid.

[4] Coordinating Efforts to Prepare the Nation for Space Weather Events, Exec. Order No. 13744, 81 Fed. Reg. 71,573 (Oct. 13, 2016).

Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance Response from Joseph McClelland to post-hearing questions for the record from Senator Ron Johnson.

Question:

In the written testimony provided by Dr. George Baker, he outlined several priorities and action items for addressing the impacts of electromagnetic pulses (EMPs) and geomagnetic disturbances (GMDs). Please review Dr. Baker's written testimony and provide your perspective on his priorities and action items. Specifically, please identify the action items you agree with, disagree with, and those that you believe can and should be implemented to better protect the U.S.

Thank you for the opportunity to appear before the Homeland Security & Governmental Affairs Committee's Roundtable of 2/27/19 entitled "Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance." As requested, the following is my perspective to his "Summary and Action Items":

- From a <u>Top Down</u> perspective:
  - The most important recommendation of the 2018 EMP Commission was to establish an office of EMP coordination within the National Security Council (NSC). The new EMP executive order does this.

    Response: I agree with this action item.

  - The FERC GMD standard (TPL-007-2), though its specified environments and system thresholds are not defense-conservative, has at least brought industry attention to GMD effects. This standard, even if rigorously enforced will leave the grid dangerously vulnerable to GMD and needs to be revised.

    Response: Under section 215 of the Federal Power Act, FERC cannot directly change the reliability standards, including those that address GMD. While FERC can direct the development or modification of a reliability standard to address a specific issue, it must depend upon the North American Electric Reliability Corporation (NERC) in its role as the Electric Reliability Organization (ERO) to develop or modify standards. NERC uses a deliberative and inclusive stakeholder process drawing upon the subject matter expertise of volunteers from the users, owners and operators of the Bulk Power System to develop draft reliability and security standards that are voted on by its members and then submitted to FERC. Upon receiving the draft standards, FERC can either approve them or remand them back to NERC for further work, but FERC cannot make direct changes to the standards.

- Reliability standards establish foundational, or baseline requirements that are applicable to broad sections of the Bulk Power System. In the case of GMD, the standard establishes a threshold level that when met, requires the applicable entities to assess the vulnerability of their systems to GMD events and take corrective action when necessary. The standard therefore requires all entities to consider GMD events and take baseline action to evaluate and protect their systems.
- Considering the nature of space weather events that can cause GMDs however, it is inevitable that any threshold established by a standard will eventually be exceeded. In addition, certain equipment may have unique characteristics that cause it to be more susceptible to GMD events than has been established by the standard. These factors should be considered by the applicable entities when conducting protective actions. Although not required, the GMD standard does not prevent entities from taking further action to protect their systems and such measures may be eligible for cost recovery from FERC.

- Without a corresponding FERC EMP directive, the private sector is not doing very much of anything to address the EMP threat. An EMP directive and protection standard are sorely needed.

Response: The nature of a national security threat by entities intent on attacking the U.S. through vulnerabilities in its electric grid stands in stark contrast to other major reliability vulnerabilities that have caused regional blackouts and reliability failures in the past, such as vegetation management and protective relay maintenance practices that can be addressed by routine reliability standards. Reliability and security standards establish baseline requirements that are applicable to broad sections of the Bulk Power System. These standards typically take years to develop and implement as they are established in a deliberative, open, and iterative process by NERC, its stakeholders, and interested outside parties. Such a process produces common foundational Standards and was not designed for the purpose of protecting national security against attacks by foreign nations.

- New legislation is needed to empower FERC, specifically to
  - Enable FERC to write and enforce grid protection standards.
  - Identify mechanisms, including cost recovery measures, to incentivize private sector engagement on EMP protection and increase on-site fuel stockpiles.
  - Develop a national blackstart plan.

  Response: As noted above, FERC does not currently have the authority to author or directly modify standards. I defer to Congress on whether new authority is warranted. FERC does have the ability to grant cost recovery for prudent investments in reliability and security including EMP protection and on-site fuel stockpiles.

- A national EMP protection standard is needed. DHS is to be commended for issuing a coordination version of a communication/data center protection guidelines. DHS should expand this to include HV electric generator stations and electric substations.

  Response: In order to ensure that all applicable entities develop and implement consistent and effective EMP protections, mandatory requirements may need to be established if guidelines and incentives fail to be persuasive. The addition of HV electric generator stations and electric substations to DHS protection guidelines may provide certainty and consistency of effort by the electric industry.

- For more than a half-century, DoD has protected high priority military command, control, communication, and computer assets for nuclear deterrence and response. DHS and DOE EMP/GMD protection programs should emulate DoD's efforts.

  Response: My understanding is that the use of DOD protection measures represents best practices when protecting against EMP effects and could be used by DHS and DOE as appropriate for critical energy infrastructure.

- We must preclude the temptation to re-invent the wheel by giving DHS and DOE full access to DoD standards and data bases. There is no need to recalculate a standard EMP waveform. Note that current EPRI grid vulnerability assessment models are using low- bound recalculated E3 waveforms. Existing IEC and EMPC EMP waveforms are more than adequate. Use of the unclassified MIL-STD-188-125 test regimen will assure power grid survivability to both EMP and 100-year solar storms.

Response: My understanding is that the use of DOD standards to protect against the effects of EMP including the MIL-STD-188-125 represents best practices and could be used in the private sector where appropriate such as for energy facilities that serve critical loads or provide important system stability or recovery functions.

- A prioritized list of EMP-susceptible infrastructure is needed. System protection and reconstitution prioritization requires improved grid modeling. Integrated system test beds will be important for model validation. Top priority is HV generation plants and HV/EHV transformers, heretofore untested. The INL and TVA test beds look promising.

    Response: Emphasis should be placed on protecting critical facilities from significant EMP and GMD events including those that represent worst case scenarios. Activities could encompass system reconstitution and recovery although emphasis should be based on protection and prevention strategies since wide-spread GMD or EMP events may deplete system spares and overwhelm recovery efforts. Special attention should be paid to the criticality of facilities that protect system stability and that serve critical load, such as Defense Critical Electric Infrastructure facilities. Testing, including laboratory test beds and at actual facilities, should be conducted as necessary to validate system models and assumptions.

- The most current EMP Intelligence report is technically flawed and misleading in a manner that downplays the need for action – a new assessment is needed.

    Response: It is important to provide comprehensive peer review for any EMP intelligence reports and their subsequent findings of effects and proposed mitigation actions. Subject matter experts representing differing views should be involved in these reviews in order to fully identify both points of agreement and disagreement. In this way, any differences between findings (for example the EMP Commission findings versus the above-cited report) can be clearly identified and explained for subsequent policy deliberations.

- I estimate cost of EMP protection for the bulk power system to be in the $50B range. The investment strategy is based on identifying a top-down "thin-line" of grid assets. More rigorous cost estimates are needed by DOE & industry.

Response: I am unable to comment on this this statement because I do not have the details supporting this cost estimate.

- From a Bottom-Up perspective:
  - EMP protection programs must be pursued at the local and State levels since communities would be on their own for extended periods in a wide-area blackout.

    Response: It seems prudent to pursue solutions and mitigations to the threat of EMP from both a federal and state level.

  - Pilot demonstration programs of selected grid sectors are all-important to address the feasibility and cost of local EMP protection. The ongoing Lake Wylie Demonstration Project and the San Antonio Joint-Base microgrid development program are good examples and should be expanded and funded.

    Response: Pilot and testing projects are an important part of evaluating the effectiveness of proposed EMP mitigation plans.

  - Bottom-up protection should address a thin-line of essential life-support infrastructures including distribution substations, backup power generation systems, emergency services, water supply and treatment, hospitals, and the necessary logistics tail.

    Response: Skeletal services necessary to ensure continuity of critical services including those for public safety and national defense must be identified and protected in the event of an EMP attack or GMD event.

  - Low cost, stop-gap measures will be important, including hardened microgrid installations as a near-term solution for life-line infrastructures. We are presently at a watershed moment due to the recent onset and rapid acceleration of microgrid installations. Federal requirements and standards are important to ensure that microgrids will survive and not increase the EMP vulnerability of the rest of the grid. Microgrid EMP protection is only a small incremental cost if included in initial system design.

    Response: Existing energy infrastructure should be studied to identify critical locations for EMP mitigation. In the event that microgrids proliferate to any significant degree, appropriate protections for these facilities should be considered.

- The federal government must coordinate the interface between the top-down and bottom-up efforts. A useful interface demark occurs where the high voltage transmission grid (bulk power) meets the distribution grid (lower voltage electric network supplying local infrastructure services.

  Response: I agree that it is important for the federal government to coordinate with other authorities such as the states, to effectuate a top-down and bottom-up approach to address threats, such as EMP, that affect both transmission and distribution networks.

- On a positive note, several commercial enterprises have developed turn-key EMP protection services and product lines and stand ready to harden critical infrastructure facilities and systems one directives and programs are in place.

  Response: Commercial products that have been tested and prove to be effective, will likely play an important role in hardening critical infrastructure facilities.

Post-Hearing Questions for the Record
Submitted to George H. Baker. Ph.D.
From Senator Rick Scott

Regarding February 27, 2019 Senate Roundtable: "Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance"

Question 1. We need to protect our nation's critical infrastructure against a potentially catastrophic event. That being said, there was a lot of uncertainty on how and what those protective steps would look like. Mr. Baker, in your testimony you reference that this protection is urgently needed to assure electric power grid reliability.

Can you explain what steps government and industry must take in order to assure electric power grid reliability?

Answer: Both "top-down" (Federal and 'Bulk Power Grid' Industry-level) steps and "bottom-up" (Local, State and 'Distribution Grid' Industry-level) steps are needed to provide comprehensive assurance that our electric power grid will survive nuclear electromagnetic pulse (EMP) and solar storm geomagnetic disturbance (GMD) effects.

I. Top-down level.
  a. Federal Government.
    i. Establish an office of EMP coordination within the National Security Council (NSC). This was the most important recommendation of the 2018 Congressional EMP Commission executive report. The new EMP executive order, recently signed, helps in this regard by designating the Assistant to the President for National Security Affairs (APNSA), through the NSC and in consultation with the Director of the Office of Science and Technology Policy (OSTP), as responsible for coordinating the development, and implementation of executive branch activities related to national EMP preparedness.

    ii. Enact legislation to empower the Federal Energy Regulatory Commission (FERC):

      1. Provide FERC with the authority to modify NERC-proposed reliability standards, or to promulgate new standards directly. Consistent with Section 215 of the Federal Power Act, FERC currently lacks the authority to modify electric reliability standards. This duty has been delegated to an industry-dominated nonprofit, viz. the North American Electric Reliability Corporation (NERC). Note that the DOE Quadrennial Energy Review released in January 2017 recognized this shortfall and recommended, "... in the area of cybersecurity, Congress should provide FERC with authority to modify NERC-proposed reliability standards—or to promulgate new

standards directly..." EMP could be included under the cybersecurity rubric since it debilitates electronic cyber system networks, causing denial-of-service over multi-state regions.

2. Ask FERC to order modifications to the NERC GMD benchmarks standard, TPL-007-2, to be consistent with observed threats and equipment malfunctions and set defense-conservative threat levels and equipment threshold levels. The NERC GMD standard has set geoelectric field benchmark stress levels lower than those measured during past solar storms and set transformer failure thresholds higher than observed malfunction levels. Even with enforced utility compliance with the present GMD standard, our grid will remain highly vulnerable to 100-year solar storms.[1] Government officials and utility executives must transition to a "defense-conservative" mindset in protecting our power grid and other lifeline infrastructures – just as the military does in protecting our strategic systems. "Defense-conservative" means using reasonable upper bound threat stress level envelopes in assessments and testing, and reasonable lower bounds for equipment vulnerability threshold levels.

3. Ask FERC to direct a *sua sponte* rulemaking for a reliability standard to protect against nuclear EMP, analogous to the FERC benchmark rulemaking for the solar storm GMD protection directive (TPL-007-2). Without a corresponding EMP directive (or combined GMD-EMP directive), the electric power industry, in general, will not take actions to protect the grid against EMP. This is because they cannot reliably achieve cost recovery for voluntary measures. Furthermore, industry members have stated they will not protect their systems against benchmark levels that could change in the future. A FERC EMP or combined GMD-EMP directive will enable a uniform national protection approach to preclude cascading grid collapse from failures of "weaker protection" grid sectors, as occurred during the 2003 Northeast blackout. There is no need to research and recalculate a standard EMP benchmark threat waveform. Existing unclassified industry standard and EMP Commission waveforms can be used to set reasonable benchmark EMP threat environment levels for the protection of national infrastructure.

4. Ask FERC to identify mechanisms, including cost recovery measures to incentivize private sector engagement on EMP protection and increase on-site generator fuel stockpiles. Under deregulation, electricity market competition has had a countervailing effect on reliability and resilience of the electric power grid. The adage,

[1] Electric Power Research Institute, Magnetohydrodynamic Electromagnetic Pulse Assessment of the Continental U.S. Electric Grid. Palo Alto, CA, February 2017.

"private efficiency leads to public vulnerability," applies here.[2] Better designed electricity markets with incentives to reduce multi-hazard risk of catastrophe would lead to major improvements in grid resiliency.

iii. To enable implementation of the FERC directive under subparagraph I.a.ii.3., direct Department of Homeland Security (DHS) to issue an official EMP/GMD grid protection engineering/test standard that provides protection engineering and test certification guidance governing electric power grid generation, transmission, and distribution systems. DHS, to its credit, has issued a coordination version of an EMP protection standard that should be reviewed, modified as necessary, and officially endorsed. The standard should emulate DoD's MIL-STD-188-125-1. DHS' adoption of the military standard's test regimen to certify electric power grid systems' EMP hardness will achieve power grid survivability to both EMP and 100-year solar storm GMD.

iv. Give DHS and Department of Energy (DOE) full access to Department of Defense (DoD) standards and data bases. DoD data bases have information on equipment test failure thresholds. DoD has been protecting high priority command, control, communication and computer assets for more than a half-century and has learned many valuable lessons on *how* and *how not* to protect systems. DHS and DOE EMP/GMD protection and testing efforts should emulate the DoD EMP approach. Lengthy research and development programs are not needed to begin the protection implementation.

v. DHS should develop a prioritized list of EMP-susceptible infrastructure. Because we can't protect everything, progress will be spurred by developing a prioritized list of EMP-susceptible infrastructure from DHS. Developing of criteria for rank ordering infrastructure would benefit from coordination with Assistant Secretary of Defense (Homeland Defense and Americas' Security Affairs) on their criteria for assembling the Defense Critical Asset (DCA) and Defense Critical Infrastructure Protection (DCIP) lists. An important criterion for infrastructure systems' priority assignment is how rapidly critical systems need to be restored. A "recovery time objective (RTO)" criterion is recommended for critical infrastructure systems.

vi. DOE should work with DHS and DoD to develop improved grid models. Models are important to the prioritization process to determine regional and community life-line systems that need to continue to operate or be rapidly restored following a major blackout. Effective modeling will enable the identification of the most critical system and network failure points requiring protection, allowing the most effective application of scarce resources. The National Infrastructure Simulation and Modeling Center (NISAC) is a likely

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[2] P. Auerswald et al, Seeds of Disaster, Roots of Response: How Private Action Can Reduce Public Vulnerability, Cambridge University Press, 2006.

lead for this effort.

vii. DOE should work with DHS and DoD to develop integrated system test beds for grid system vulnerabilities/thresholds identification, hardness certification, and model validation. Top test priorities are bulk power system generation plants and high voltage/extra high voltage (HV/EHV) transformer substations, heretofore untested at threat levels.

viii. DOE should work together with DHS and DoD to provide cost estimates for protecting the bulk power system against EMP. Existing rough order of magnitude estimates range in the tens of billions of dollars. Estimates should be based on the "thin-line" list of priority grid assets developed under subparagraph I.a.v.

ix. The DCI should conduct a new EMP intelligence assessment to replace the technically-flawed and preparedness-impeding 2014 Joint Atomic Energy Intelligence Committee (JAEIC) EMP report.

b. NERC/Industry

i. NERC's role re. EMP/GMD grid resilience assurance should be redefined to be responsible for coordinating and assuring industry compliance with EMP/GMD standards set by FERC.

ii. NERC and Industry should pursue a defense-conservative approach that emphasizes and implements pre-event protection engineering to enable as much of the grid as possible to operate through or rapidly recover from an EMP attack. The present NERC/electric industry EMP protection approach appears to be to allow the three major interconnections of the grid to fail during attack and instead concentrate attention, investments and preparedness on elaborate recovery plans to rebuild the grid in the aftermath of an EMP-caused grid collapse.

iii. NERC, in coordination with FERC should report to NSC and Congress on a regular basis on the status of the overall resilience, security, and protection status of the U.S. electric power grid.

II. Bottom-up, State-Local actions

a. EMP protection programs must be pursued at the local and State levels since communities would be on their own for extended periods in a wide-area blackout.

b. Bottom-up protection should address a thin-line of essential life-support infrastructures including distribution substations, backup power generation systems, emergency services, water supply and treatment, hospitals, and the necessary logistics tails.

c. Pilot demonstration programs in selected grid sectors are all-important to answer questions on the feasibility and cost of local and regional infrastructure EMP protection. The cost of grid EMP protection is the biggest question out there. The ongoing Lake Wylie Protection Project and the San Antonio Joint-Base microgrid development programs are good examples and should be encouraged, expanded, and funded. Protection and cost experience and lessons learned from the pilot demonstration programs can then be scaled to other localities and regions.

d. Implementation of low cost, stop-gap measures will be important, including hardened microgrid installations as a near-term solution for life-line infrastructures. A major national concern is the rapid growth of microgrid installations around the U.S. with no attention to EMP protection. Microgrids are being justified and installed at highly-critical infrastructure sites that cannot tolerate even short-term electric power grid outages. Thus, failure in an EMP event would terminate these essential microgrid-powered services. Compounding the concern about microgrid proliferation is that the failure of unprotected microgrids can cascade to bring down the rest of the grid (ROG) due to interconnected microgrid-ROG power feeds and control systems. We are presently at a watershed moment due to the rapid increase of microgrid implementation. Federal requirements and standards are important to ensure that microgrids will survive themselves, and not increase the EMP vulnerability of the larger, surrounding electric power grid. Microgrid EMP protection is a relatively small incremental cost if incorporated in the initial system design.

III. General Considerations

a. The federal government must coordinate the interface between the top-down and bottom-up grid protection efforts. A useful demark occurs where the high voltage transmission grid or "bulk power" FERC-regulated system governed by FERC meets the lower voltage, State-regulated distribution grid that supplies electricity to local critical infrastructure services.

b. On a positive note, several commercial enterprises have developed turn-key EMP protection services and product lines and stand ready to harden critical infrastructure facilities and systems once directives and programs are in place.

Question 2. Mr. Baker, in your testimony you mentioned that the private sector is not doing enough to address the threats posed by electromagnetic pulses (EMPs).

2.a. Do you believe that applying a corresponding federal directive to address an EMP threat would have an impact to help industry prepare and know the potential effects from an electromagnetic pulse?

Answer: Yes, definitely. Per my answer to your Question 1 (see subparagraph I.a.ii.3.), ask FERC to initiate a FERC EMP benchmarks directive, analogous to the FERC GMD directive (TPL-007-2). If possible, a combined EMP/GMD benchmark directive would be the best outcome, because protection against nuclear EMP will also protect against the most severe solar storms. Threat levels (electric field strengths and waveforms) for EMP/GMD standards should be developed by DHS, not industry trade groups such as the Electric Power Research Institute (EPRI).

2.b. If so, what are reasonable standards you think industry could comply with?

Answer: Contrary to the position of the Edison Electric Institute and other trade groups that "one size does not fit all," unified compliance with MIL-STD-188-125-1 protection guidance and validation testing pass/fail requirements will enable the grid to survive both EMP and 100-year solar storm GMD effects. DHS adaption of the Military Standard's pulsed current injection test and pass/fail criteria as the benchmark will enable uniform survivability of the U.S. electric grid. The Lake Wylie EMP Project cost studies indicate that protecting the electric grid and minimum-essential life support infrastructures to the levels in the Military Standard can be both practical and affordable. The only recommended update is to evaluate the need for a possible increase in the current MIL-STD-188-125-1 'E1' injection levels. We do not need a major R&D program to redefine current EMP environment, protection and testing standards.

EEI's Scott Aaronson's responses to Dr. George Baker's testimony

March 18, 2019

<u>From a Top Down perspective:</u>

- **The most important recommendation of the 2018 EMP Commission was to establish an office of EMP coordination within the National Security Council (NSC). The new EMP executive order does this.**

  I am not aware of the specific details of a potential EMP Executive Order. That said, EEI appreciates the continued focus the Administration has placed on inter-agency and industry coordination to help address the potential threat of an EMP event.

- **The FERC GMD standard (TPL-007-2), though its specified environments and system thresholds are not defense-conservative, has at least brought industry attention to GMD effects. This standard, even if rigorously enforced will leave the grid dangerously vulnerable to GMD and needs to be revised.**

  The GMD planning standard sets a conservative, high benchmark for reliability against the high-impact, low-probability risk of a severe GMD event. The 1-in-100-year storm threshold was developed through collaborative work with the electric power industry, space weather researchers at the National Aeronautics and Space Administration (NASA), National Oceanic and Atmosphere Administration (NOAA), the U.S. Geological Survey (USGS), and their counterparts in Canada. As noted in testimony, this benchmark is substantially stronger than the historical storms that have demonstrated their ability to affect modern electric power systems (e.g., the March 1989 Quebec blackout and the 2003 Halloween storm). The GMD planning standard will require entities across North America to mitigate the risks of a Bulk Power System (BPS) blackout and protect EHV/HV transformers from thermal effects from a 1-in-100-year GMD event.

  The newest version of the GMD planning standard (TPL-007-2) enhances the original GMD planning standard through an additional threshold (e.g., the supplemental GMD event) that exceeds the 100-year benchmark in strength. The supplemental GMD event is used to assess localized impacts from space weather, adding even greater conservatism to the wide-area protections afforded by the original GMD planning standard.

The industry takes high-impact low-frequency (HILF) risks seriously and continues to devote extensive resources to maintain the state-of-the-art capabilities for mitigating risks to the BPS from severe space weather. This includes an active NERC-Industry GMD Research Work Plan with collaborators from the U.S. DOE National Labs, the Electric Power Research Institute (EPRI), and other research organizations. Through this effort, key elements of the GMD planning standard continue to be investigated and advanced, including the GMD event thresholds, transformer vulnerability assessment requirements, and tools and models for industry to mitigate space weather impacts to the BPS. The research work plan began in 2017 and will run through early-2020, addressing:

- Continued analysis and sensitivity testing of the standard's GMD event thresholds and modeling approaches to support accurate GMD Vulnerability Assessments;
- Further development of earth models available to BPS owners and operators to improve their usability and applicability for calculating geomagnetically-induced currents (GIC); and
- Development of additional complex analysis guidelines and tools for BPS owners and operators to use in performing system-wide assessment of GMD-related harmonics, which can enhance capabilities to prevent certain types of protection system misoperations that directly contributed to the 1989 Quebec blackout.

Finally, it is important to note that the standards process should not be set to a defense conservative standard. Standards, by definition, are developed as a set of best practices that all entities of the BPS follow to ensure the reliability and security of the grid. In addition to standards, electric companies take a risk-based approach to identify additional mitigation solutions and hardening measures to protect its most critical assets from all hazards.

- **Without a corresponding FERC EMP directive, the private sector is not doing very much of anything to address the EMP threat. An EMP directive and protection standard are sorely needed.**

The industry takes exception with the premise of this statement. As was outlined in great detail during the Committee Roundtable discussion, the industry has made EMP protection a priority. Efforts include better understanding of the threat and potential impacts to the sector of a high-altitude EMP caused by the detonation of a nuclear weapon in the atmosphere, along with the pursuit of effective mitigation strategies.

Specifically, the industry has invested significantly to better understand the EMP threat, assess vulnerabilities, impacts and risks, and identify mitigation strategies to protect critical assets. As recommendations and solutions are identified, the industry is prepared to take a series of risk-based actions to harden its systems. It is paramount we allow the researchers complete their work as sound science will lead us to sound policy.

Also, individual companies are making significant greenfield investments to harden their systems against EMPs. For example, Dominion's System Operation Center that took 3.5 years to design and construct includes a MIL-spec EMP space for critical operations and employs the latest technologies and practices in physical and cyber security, telecommunications, redundancy, and efficiency. Other companies have made similar investments in control centers, substation housing, spare equipment, and blocking technology pilots as described by the American Transmission Company (ATC) during the Committee Roundtable.

Protection of the energy grid and its most critical assets remains a top priority independent of a legislative or regulatory mandate.

- **New legislation is needed to empower FERC, specifically to**

(1) Enable FERC to write and enforce grid protection standards.

Under Section 215 of the Federal Power Act, FERC has authority to order NERC to develop specific mandatory reliability standards, which FERC has exercised to address GMD risk, supply chain risk management, and physical security. The model under Section 215 works effectively because it leverages industry expertise – a necessity when it comes to the vast and complex bulk electric system – to inform development of Reliability Standards. Before a standard becomes effective, it must be approved by NERC's independent Board of Trustees and by FERC.

(2) Identify mechanisms, including cost recovery measures, to incentivize private sector engagement on EMP protection and increase on-site fuel stockpiles.

As demonstrated by the steps industry is taking and the resources it has dedicated to this effort, the industry is willing to make the necessary cost-effective investments to appropriately and successfully protect the grid without unintended consequences.

(3) Develop a national blackstart plan.

The industry plans for all types of contingencies to respond to power disturbances, which includes ensuring there are sufficient blackstart capabilities and resources to restore service following a widespread outage.

FERC approved three NERC emergency operations (EOP) standards, including System Restoration from Blackstart Resources (EOP-005-2) in 2011. These standards are mandatory and enforceable under Section 215 of the Federal Power Act.

The purpose of EOP-005-2 is to ensure plans, facilities, and personnel are prepared to enable system restoration from blackstart resources to assure reliability is maintained during restoration and priority is placed on restoring the interconnection. Requirements include:

- Each transmission operator must have a restoration plan approved by its reliability coordinator. The restoration plan must allow for restoring the transmission operator's system following a disturbance in which one or more areas of the Bulk Electric System (BES) shuts down and the use of blackstart resources is required to restore the shutdown area to service.
- Each transmission operator must review its restoration plan and submit it to its reliability coordinator annually.
- Each transmission operator must update its restoration plan within 90 days after identifying any unplanned permanent system modifications, or prior to implementing a planned BES modification, that would change the implementation of its restoration plan.
- Each transmission operator must verify through analysis of actual events, steady state and dynamic simulations, or testing that its restoration plan accomplishes its intended function. This must be completed every five years at a minimum.
- Each transmission operator must have blackstart resource testing requirements to verify that each blackstart resource is capable of meeting the requirements of its restoration plan.
- Blackstart resources are tested at least once every three years.
- Each transmission operator must include within its operations training program, annual system restoration training for its system operators to assure the proper execution of its restoration plan.

- **A national EMP protection standard is needed. DHS is to be commended for issuing a coordination version of a communication/data center protection guidelines. DHS should expand this to include HV electric generator stations and electric substations.**

  EPRI's research is ongoing and will provide recommendations and solutions that industry can take to harden their systems through a risk-based and prioritized approach. Additional guidelines from government on how critical infrastructure can better protect their systems is welcome and will inform existing research, future pilot programs, and industry investments.

- **For more than a half-century, DoD has protected high priority military command, control, communication, and computer assets for nuclear deterrence and response. DHS and DOE EMP/GMD protection programs should emulate DoD's efforts.**

  As was discussed at the Committee Roundtable, EPRI set out to determine whether the unclassified MIL-spec standard could be applied to the electric grid. Since MIL-spec was not designed to harden electric grid assets, the EPRI report – due out on April 29 – will examine whether MIL-spec would be effective, as well as whether there would be unintended consequences or to determine if further testing is required. Once these findings are released, asset owners and operators can make informed decisions about the appropriate course of actions.

  DOD has been a great partner in working with DOE and EPRI to provide their information and subject matter expertise on this issue. The electric grid is unique, but industry continuing to learn and benefit from DOD's perspective will improve the industry's preparedness.

- **We must preclude the temptation to re-invent the wheel by giving DHS and DOE full access to DoD standards and databases. There is no need to recalculate a standard EMP waveform. Note that current EPRI grid vulnerability assessment models are using low-bound recalculated E3 waveforms. Existing IEC and EMPC EMP waveforms are more than adequate. Use of the unclassified MIL-STD-188-125 test regimen will assure power grid survivability to both EMP and 100-year solar storms.**

  As referenced earlier, understanding effectiveness and unintended consequences of unclassified MIL-spec on the transmission system is a major focus of the EPRI report.

To clarify the above statement, any mitigation for solar storms (E3) would likely protect components of the grid, like transformers, that are susceptible to EMP E3. However, GMD protections would not protect equipment from EMP E1.

- **A prioritized list of EMP-susceptible infrastructure is needed. System protection and reconstitution prioritization requires improved grid modeling. Integrated system test beds will be important for model validation. Top priority is HV generation plants and HV/EHV transformers, heretofore untested. The INL and TVA test beds look promising.**

The industry already takes a risk-based approach to prioritize its most critical assets. That said, improved grid modeling, specially making DOE's North American Energy Resilience Model (NARM) dynamic would be something the industry would support. The NARM is providing great value and situational awareness to the industry in understanding DOD's Defense Critical Electric Infrastructure (DCEI) as was mandated by the FAST Act of 2015.

- **The most current EMP Intelligence report is technically flawed and misleading in a manner that downplays the need for action – a new assessment is needed.**

It is not clear what intelligence report Dr. Baker is referencing. EEI welcomes the opportunity to continue working with government partners to better understand the EMP threat and mitigation solutions to harden our systems.

- **I estimate cost of EMP protection for the bulk power system to be in the $50B range. The investment strategy is based on identifying a top-down "thin-line" of grid assets. More rigorous cost estimates are needed by DOE & industry.**

We can't estimate mitigation costs, until we better under the suite of mitigation solutions. Once those mitigation solutions are formalized, the industry will undergo a cost benefit analysis based on risk to harden the energy grid. Further, it is important to note that mitigation will not be as simple as purchasing a device to protect the system, certain aspects of re-engineering, as well as ongoing operation and maintenance costs need to be factored into any estimate.

<u>From a Bottom-Up perspective:</u>

- **EMP protection programs must be pursued at the local and State levels since communities would be on their own for extended periods in a wide-area blackout.**

  I agree that state response is a key component. The ESCC has launched a state coordination initiative and works in close collaboration with the DOE and DHS, and national organizations representing key state stakeholders, including the National Governors Association (NGA), the National Association of Regulatory Utility Commissioners (NARUC), the National Association of State Energy Officials (NASEO), and the National Emergency Managers Association (NEMA). These are key stakeholders in preparing for and responding to incidents of all kinds that affect the energy grid.

- **Pilot demonstration programs of selected grid sectors are all-important to address the feasibility and cost of local EMP protection. The ongoing Lake Wylie Demonstration Project and the San Antonio Joint-Base microgrid development program are good examples and should be expanded and funded.**

  The electric power industry agrees and would welcome additional funding and collaboration on pilot programs. EEI's understanding is there is electric company participation in the San Antonio Joint-Base microgrid development program. Following the release of the report, EPRI will be leading a pilot program to test mitigation solutions.

- **Bottom-up protection should address a thin-line of essential life-support infrastructures including distribution substations, backup power generation systems, emergency services, water supply and treatment, hospitals, and the necessary logistics tail.**

  At the national, state, and local level the electric power industry is actively engaged in working with other critical infrastructure sectors (communications, transportation, financial services, water, downstream natural gas, and life, healthy, and safety providers) to plan for, and respond to, major incidents, understand mutual dependences, and share information more effectively.

  Also, individual companies work within the communities they serve to identify priority critical customers based on economic and national security, as well as life, healthy, and safety of their customers.

- **Low cost, stop-gap measures will be important, including hardened microgrid installations as a near-term solution for life-line infrastructures. We are presently at a watershed moment due to the recent onset and rapid acceleration of microgrid installations. Federal requirements and standards are important to ensure that microgrids will survive and not increase the EMP vulnerability of the rest of the grid. Microgrid EMP protection is only a small incremental cost if included in initial system design.**

  As noted in my testimony, microgrids are not a silver bullet for resiliency. However, they can be an effective tool. We are seeing greater deployment of microgrids now, but they are not for every situation. I would add, the existing grid effectively serves as a grid of grids.

  Added hardening or setting a standard for microgrids would have it's challenges. Many third-party providers are building out microgrids at a very low margin to be cost competitive, so 2 to 5 percent additional hardening costs would be a lot for those providers. However, if the federal government would consider funds to provide additional hardening for microgrids that support military installations that is probably a good place to start. This is an area electric companies are actively working with DOE. The goal is to allow the base to have priority power if needed, but added resiliency for the base and surrounding community when necessary.

- **The federal government must coordinate the interface between the top-down and bottom-up efforts. A useful interface demark occurs where the high voltage transmission grid (bulk power) meets the distribution grid (lower voltage electric network supplying local infrastructure services.**

  The area where the BES meets the distribution grid is an area of discussion in a number of areas. I think this critical intersection would benefit from better communication and coordination between the federal government, including FERC that regulates the BES, and the states, including the public service commissions that regulate the grid at the distribution level. At the state-level, we need to ensure officials and commissioners have all the tools available to them to make informed decisions.

- **On a positive note, several commercial enterprises have developed turn-key EMP protection services and product lines and stand ready to harden critical infrastructure facilities and systems one directives and programs are in place.**

The electric power industry looks at a variety of mitigation solutions from venders. Many of them were examined and tested during EPRI's EMP project and will likely be deployed in future pilot programs.

Homework Assignment Following the Hearing of the U.S. Senate Homeland Security and Governmental Affairs Committee

Randy Horton, Ph.D., P.E.
Senior Program Manager
Electric Power Research Institute

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance"

March 15, 2019

Dear Chairman Johnson,

Per your request of me and other witnesses during the hearing on February 27, 2019, I have reviewed Dr. George Baker's Committee testimony dated February 27, 2019 and have provided comments below. Because EPRI does not engage in policy-related issues I have limited my response to the technical aspects of Dr. Baker's testimony for which I can provide public comment. My comments are as follows.

1. **On page 1, Dr. Baker states that "well-known, effective, and practical engineering solutions are available to counter these threats. We have the engineering know-how and tools to protect ourselves. What is lacking is resolve."**

From a high-altitude electromagnetic pulse (HEMP) perspective one must be careful to not take these comments out of context. While there are known unclassified and classified military standards for hardening defense-related systems against the HEMP threat, additional research and testing is required before one can conclude that these same techniques can be used to protect all electric power grid assets. For example, while the unclassified MIL-STD-188-125-1 has been used by several U.S. utilities to harden Transmission Control Centers against the potential effects of HEMP, additional research and testing has shown that one of the mitigations required by the standard could be detrimental to the normal operation of protective relays that are used to protect and control the electric power grid. As such, other options for protecting these assets were evaluated and tested as part of the EPRI EMP research. In summary, it is of paramount importance that any HEMP mitigation measures that are to be used in an electric power grid be thoroughly tested and evaluated in the context of their proposed application so that unintended consequences can be minimized or avoided altogether.

2. **On page 2, Dr. Baker describes the E1 EMP damage mechanism and alludes to damage that would be caused to high-voltage lines or the "overhead line[s] that you see as you drive down major highways."**

Dr. Baker is correct in that E1 EMP can induce surges of thousands of amps into overhead lines, but it is also important to understand that high-voltage lines are designed to withstand these stress levels. As such, E1 EMP damage to high-voltage lines or equipment rated 69 kV and above, is not expected to occur[1].

3. On page 3, Dr. Baker states that "the private sector is not doing very much of anything to address the EMP threat."

To the contrary, EPRI launched a three-year research project in April 2016 to: 1) provide a technical basis for making more informed decisions regarding the potential impacts of HEMP on the electric transmission system and 2) to identify possible options for mitigating the potential impacts that were identified. The research project is currently voluntarily supported by more than 60 U.S. utilities. EPRI has also recently launched collaborative projects with utilities to perform field evaluations of some of the E1 EMP hardening options that were identified in the first phase of the research[2] and evaluate the potential impacts of E1 EMP on generation assets[3].

4. On page 3, while discussing GMD impacts, Dr. Baker incorrectly cites an EPRI report that found that only 14 transformers would be potentially damaged by a severe GMD event.

EPRI did not study the effects of a severe GMD event on the U.S. transformer fleet. The report that Dr. Baker cites describes an assessment that evaluated the potential impacts of E3 EMP on bulk power transformers in the U.S. The results should not be used to extrapolate potential effects from a severe GMD event, and, in the discussion that follows, we provide an example of why E3 EMP should never be used as a proxy for extrapolating GMD impacts on bulk power transformers.

5. On page 9, Dr. Baker states that "systems complying with MIL-STD-188-125 E3 PCI acceptance test will also survive 100-year solar storm GMD-induced current."

Extensive research has shown that this statement may be incorrect for E3 EMP and in particular for the late-time pulse defined in MIL-STD-188-125-1. Because the MIL-STD-188-125-1 waveform is of such short duration and the thermal response of bulk power transformers is sufficiently slow, extreme hotspot heating in transformers from these short-duration GIC events is not expected to occur. A crude analogy is holding your hand over a candle. Running your hand through the flame (response to E3 EMP) does not cause burning, but if you hold your hand over the flame for a longer period (response to GMD) burning can occur. To illustrate this point further, computer simulations were performed to compute transformer heating that could occur from an E3 EMP pulse defined in MIL-STD-188-125-1 and a severe GMD event (March 1989 storm). In both scenarios, the initial top oil temperature of the transformer was assumed to be 80°C which is a conservative approximation. The peak amplitude of the MIL-STD-188-125-1 pulse was set at 1,000 Amps/phase per the requirements of standard. The current pulse and the

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[1] Oak Ridge National Laboratory, Electromagnetic Pulse Research on Electric Power Systems: Program Summary and Recommendations, ORNL-6708, January 1993. https://www.osti.gov/servlets/purl/10131917
[2] E1 Electromagnetic Pulse Hardening of Substations: Design and Implementation Support, https://www.epri.com/#/pages/product/3002014867/
[3] Electromagnetic Pulse (EMP) Effects on Generation Assets https://www.epri.com/#/pages/product/3002015354/

hotspot temperatures that were calculated along with the IEEE recommended temperature limits[4] are shown in Figure 1.

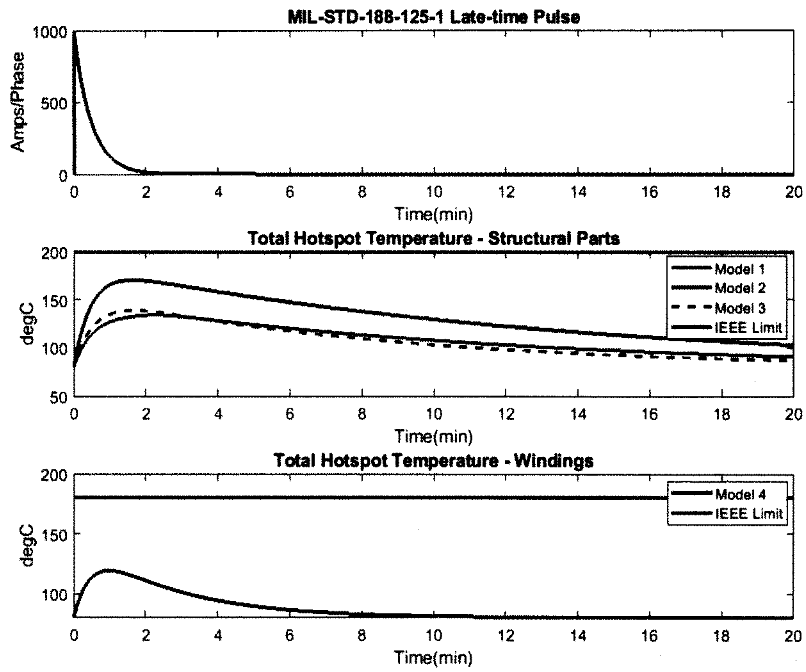

Figure 1
Simulation of transformer hotspot temperatures using the GIC waveform defined in MIL-STD-188-125-1

Figure 2 illustrates the thermal response of the same transformer models when they are subjected to GIC flows with waveform signature that is representative of a severe GMD event. In this scenario, the GIC was scaled such that the peak GIC was 150 Amps/phase as opposed to 1,000 Amps/phase used in the previous example.

[4] IEEE Std. C57.163-2015 IEEE Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances

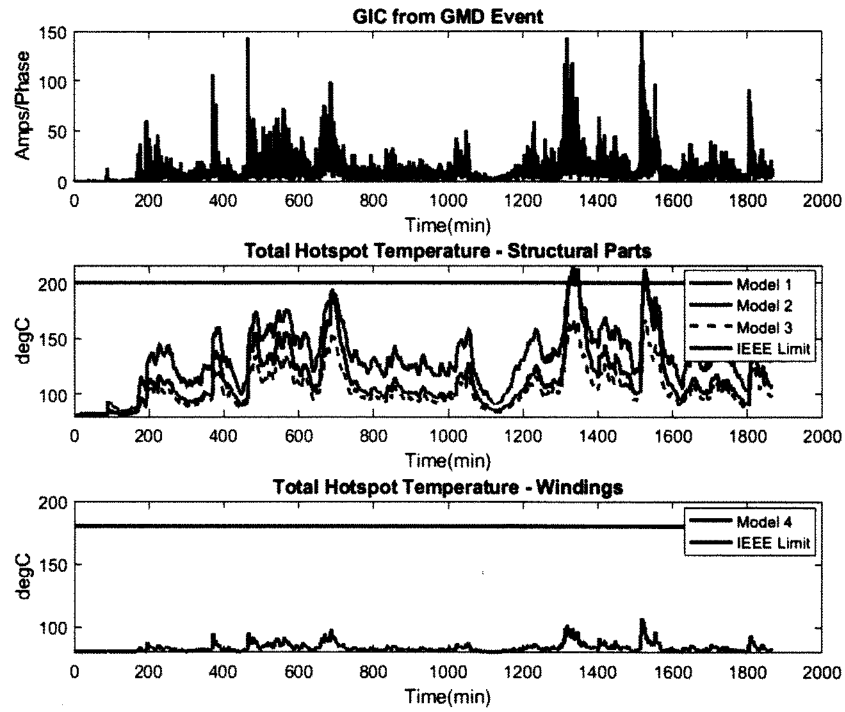

Figure 2
Simulation of transformer hotspot temperatures using a GIC waveform representative of the March 1989 GMD Event

Comparing the results from Figure 1 and Figure 2 provides two important insights. First, the time duration of the pulse defined by MIL-STD-188-125-1 only lasts approximately 2 minutes whereas the GIC waveform from the GMD event lasts approximately 1800 minutes (30 hours). Secondly, the maximum transformer temperature of ~215°C caused by the GIC of 150A/phase from the severe GMD event was significantly higher than the maximum temperature of ~170°C caused by the 1000 A/phase E3 EMP waveform defined in MIL-STD-188-125-1. Additionally, the maximum hotspot temperature resulting from the GMD event actually exceeded the IEEE recommended temperature limit whereas they did not in the case of E3 EMP. Thus, transformers that able to withstand the 1000 A/phase pulse defined in MIL-STD-188-125-1 may not have adequate resilience to GIC flows from severe GMD events.

These examples illustrate that not only is the amplitude of the GIC important, but of most importance, is the *duration* or *shape* of the GIC waveform. E3 EMP and GMD impacts should be evaluated separately using the most accurate data available to describe these events. As illustrated by the previous examples, using MIL-STD-188-125-1 as a guide to infer resilience of bulk power transformers to GMD events may not be appropriate.

6. On page 10, Dr. Baker states "Of most concern, we have not yet tested ... HV/EHV transformers" and "Duke Energy has recently provided a large transformer for the first U.S. HV transformer test."

We agree that additional testing of HV/EHV transformers is needed, and is of paramount important to improving understanding of the phenomena, but we would also like to make the Committee aware that HV/EHV transformer testing to assess response to the flow of GIC began in the United States decades ago. EPRI in collaboration with Minnesota Power and Light Company in the early 1980's performed three separate transformer tests (six transformers in total) by directly injecting energized transformers with various levels of dc current, up to 100 Amps. The three tests included:

- Two 500/230 kV autotransformers
- Two 230/115 kV autotransformers
- Two 230/115 kV autotransformers

Details of these tests are provided in the publicly-available EPRI report *Mitigation of Geomagnetically Induced and DC Stray Currents.*[5]

EPRI also investigated the possible effects of dc current on transformer by using scaled models built by transformer manufacturers. The results of this extensive research effort are documented in the publicly-available EPRI report *High-Voltage Direct-Current Converter Transformer Magnetics.*[6]

Additional testing of bulk power transformers that are currently used in the U.S. was performed at Siemens' transformer factory in Weiz, Austria in 2013[7]. The results of these tests were used to validate computer simulations that are the basis of one of the thermal models used in NERC TPL-007 and EPRI's E3 EMP assessments.

Additional transformer testing by Idaho National Laboratory (INL) in the U.S. and others abroad[8,9] has also been performed.

[5] *Mitigation of Geomagnetically Induced and DC Stray Currents*, Electric Power Research Institute, Palo Alto, CA. EL-3295, December 1983. https://www.epri.com/#/pages/product/EL-3295/

[6] *High-Voltage Direct-Current Converter Transformer Magnetics*, Electric Power Research Institute, Palo Alto, CA. EL-4340, December 1985

[7] https://www.nerc.com/comm/PC/Geomagnetic%20Disturbance%20Task%20Force%20GMDTF%202013/Transformer%20GIC%20testing.pdf

[8] J. E. M. Lahtinen, "GIC Occurrences and GIC Test for 400 kV System Transformer," *IEEE Transactions on Power Delivery,* vol. 17, no. 2, pp. 555-561, 2002.

[9] L. Marti, "Simulation of Transformer Hotspot Heating Due to Geomagnetically Induced Currents," *IEEE Transactions on Power Delivery,* vol. 28, no. January, pp. 320-327, 2013.

7. On page 11, "EPRI grid vulnerability assessment models are using low-bound recalculated E3 waveforms."

Per my previous testimony, EPRI collaborated with the Department of Energy, Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory and the Defense Threat Reduction Agency to improve our understanding of HEMP phenomenology and to identify/develop additional bounding environments that can be used to perform HEMP assessments. EPRI's latest E3 EMP assessments, which have yet to be published, are based on the E3 EMP environment provided by LANL. EPRI's E1 EMP assessments, also yet to be published, are based on the threat level provided in IEC 61000-2-9 as well as a bounding E1 EMP environment provided by LANL. Research has shown that HEMP environments like the ones provided by LANL, which include full spatio-temporal characteristics[10] of the environment, are necessary for more accurate prediction of HEMP impacts. Additional work in this area is needed so that the U.S. government can provide similar unclassified environments for broader use in civilian applications.

<u>Closing</u>

In closing, I would like to thank you and the Committee for this opportunity to provide additional feedback, and would ask that you not interpret lack of comment or feedback on some aspects of Dr. Baker's testimony as agreement. In some cases, information or data were not available to base a response, and in other cases providing a response in a classified setting would be more appropriate. We look forward to continuing the dialogue with you and other Committee members on these important topics.

Sincerely,

Randy Horton, Ph.D., P.E.

[10] These characteristics refer to the time-varying electric fields on the ground over a large geographic area.

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March 27, 2019

The Honorable Ron Johnson
Chairman
Committee on Homeland Security and Governmental Affairs
United States Senate
Washington, D. C. 20510

Dear Mr. Chairman:

In response to your letter dated March 19, 2019, regarding questions for the record from the hearing titled "Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance," I have enclosed our responses.

Thank you again for holding the hearing and for considering Dominion Energy's views.

Sincerely,

David W. Roop, PE
Director, Electric Transmission Operations & Reliability

Dominion Energy Response to

Testimony of Dr. George H. Baker, Professor Emeritus, James Madison University

To Committee on Homeland Security and Governmental Affairs

U.S. Senate

February 27, 2019

Submitted by David W. Roop, P.E.

Director – Electric Transmission Operations & Reliability

Dominion Energy

March 15, 2019

As requested by the Committee, Dominion Energy submits these comments on the testimony of Dr. George H. Baker, Professor Emeritus – James Madison University and Director – Foundation for Resilient Studies, presented to the Committee on February 27, 2019. Dominion Energy appreciates the opportunity to comment on Dr. Baker's testimony and recommendation.

We commend Dr. Baker on his many contributions to the citizens of the United States through his efforts to protect U.S. military facilities from the effects of electromagnetic pulse (EMP). His efforts to develop and implement methods to protect this vital infrastructure are very much appreciated. However, these comments regarding his testimony are intended to provide clarity to EMP's relation to the electric power industry, since Dr. Baker's considerable expertise in this field lies outside the electric industry.

Our nation's electrical system is one of the most complex machines ever developed by man. It has been built by many years of experience and by sound engineering disciplines. The transmission system constantly changes every millisecond, balancing to provide the reliability that we have all come to expect in this country. The protection and control systems must sense events that may cause harm to this network, and to the general public, and isolate the event to the smallest area possible within cycles (1 cycle = $1/60^{th}$ of a second) of the disturbance's initiation. Events must be cleared rapidly to ensure the overall system remains stable and affected areas are kept to a minimum.

The ever-changing state of this complex system requires our Operating Centers to constantly analyze contingencies (i.e. "what-if" scenarios) and take pre-contingency actions if the real-time data suggest something has or could create a vulnerability. This local understanding of load, generation, grid topology, and real-time contingency analysis is critically important. It ensures reliable operations and is also needed should restoration efforts, including blackstart efforts, be required. We have taken this same approach regarding geomagnetic disturbance (GMD) events. Our Operating Centers' tools provide situational awareness and actions to operators during GMD-related events. This capability was made possible through collaborative research conducted with the U.S. government and other entities.

These facts are important as we review Dr. Baker's testimony. It is important to understand how our system operates before we modify it so that we do not cause harm or potential negative consequences during the daily events that occur on the power grid. With that fundamental principle in mind, we offer the following comments on specific statements in Dr. Baker's testimony (highlighted below).

Dr. Baker's Statement***: "The FERC GMD Standard (TPL-007-2), though its specified environments and system thresholds are not defense-conservative, has at least brought industry attention to GMD effects. This standard, even if rigorously enforced will leave the grid dangerously vulnerable to GMD and needs to be revised."***

Comment: We respectfully disagree with Dr. Baker's statements regarding the standard. The NERC TPL-007-1 Reliability standard included a 100-year GMD benchmark case based on statistical analysis of historical GMD events and 30 years of observational data. Furthermore, the TPL-007-2 standard included a supplemental benchmark case which has considered local enhancement phenomena during a solar storm. It is worth emphasizing that the study of solar storms and local enhancement phenomena is an evolving science. The peak values of the storm are scientifically derived based on credible measurement data and information using statistical methods with 95% likelihood. The conclusion is comprehensive and trustful. The

TPL-007 standard therefore provides extremely sound guidelines for planning and reliability assessment. Additionally, the standards consider a wide-area power system, not a small subset area. The peak values provided in the benchmark case are geospatially averaged values with a distance span of 100 kilometers. Due to irregular earth conductivity characteristics, it is possible that local geo-electric field measurements would be higher than the average peak, with the latter representing the statistical maximum of a one-hundred-year event on a large distance scale.

Dr. Baker's Statement: ***"Without corresponding FERC EMP directive, the private sector is not doing very much of anything to address the EMP threat. An EMP directive and protection standard is sorely needed."***

Comment: The electric power industry is doing all it can reasonably do to protect itself and its customers from EMP, given our limited knowledge of the impact of potential EMP threats on equipment or systems. Our efforts in this area are not publicized for obvious reasons: we do not want to provide someone with information that could be used to thwart our defenses.

However, we are taking action. In many cases these actions can be classified as "no regrets hardening" which also improves overall day-to-day operations. ("No regrets hardening" include measures such as metal control enclosures, continuously shielded protection and control cable, etc.).

While Dominion Energy and multiple utilities across the U.S. have taken this approach, we know more needs to be done after adequate research, testing, and study to ensure the measures do not severely disrupt vital day-to-day operations. As discussed during oral testimony presented to the Committee, the research activities taken thus far, with significant assistance from our federal partners, have provided much-needed guidance to reduce the vulnerability of our equipment to damage or disturbance during an EMP event, while at the same time ensuring that the mitigation and hardening steps identified and installed do not cause harm or disruption to daily grid operations and existing grid equipment. The research is not complete; further research is needed before we can take the final steps to harden our systems. But doing something without sufficient guidance would not be prudent and would place undue burden on utilities with little benefit for our customers. It would also add to the possibility of significant risk, damage, and harm to daily grid operations and grid equipment.

Dr. Baker's Statement: ***"New legislation is needed to empower FERC, specifically to***

(1) Enable FERC to write and enforce grid protection standards.

Comment: Great care should be taken in efforts to develop a "one size fits all" standard. Electric systems were built across the nation over many decades with varying voltages, configurations and designs, as operating experiences and conditions dictated. Input is needed from the various stakeholders due to the complexity and variances across the U.S. in the design of the bulk power system. NERC has a thorough process to do this as is evidenced by their cyber protection work and other electric grid standards.

For many issues, the stakeholder process has helped us improve and enhance this system. These challenges are no different. They warrant a similar approach. I submit that this does add time to this process but the negative impact potential warrants careful deliberation. If FERC becomes aware of a potential resiliency issue(s), then FERC should have the authority to confidentially provide guidance regarding the threat and authorize the financial recovery required for utilities to resolve the vulnerability, without public disclosure of the issues that would compromise national security or reveal the resiliency issue.

(2) Identify mechanisms, including cost recovery measures, to incentivize private sector engagement on EMP protection and increase on-site fuel stockpiles.

Comment: Once ongoing research establishes an understanding of the minimum requirements for action, then a cost recovery or incentive mechanism would be beneficial to ensure rapid deployment. The impact of EMP on renewable generation resources, such as solar facilities, is only one of the areas that should be the focus of research. We must note, however, that as we move more and more towards heavy penetration of renewable generation, our need for on-site fuel supplies will continue to diminish, due in large part to the closure of coal-burning facilities.

(3) ***Develop a national blackstart plan."***

Comment: Blackstart must be done regionally due to the complexity of the load/ generation balance and the understanding of the state of the electric network prior to the black out. (This knowledge is built on the "what-if" scenarios previously discussed and cannot be replicated in a national plan.) It is important to note that blackstart is <u>NOT</u> starting the system by leaning on a neighboring utility. Rather, the transmission owner must restart its own grid using its own equipment, with no help from any neighboring utilities. This is the definition of blackstart restoration for Transmission Owners and Operators, and all have in place blackstart plans, strategies, and equipment. There has never been a true blackstart event in the continental U.S. but all transmission owners must be prepared to restart their own system should this occur. Once one utility is restarted it will aid its neighboring utilities. This already happens with major restoration efforts. A national blackstart plan would provide no benefits except to emphasize federal priorities; however, those priorities are currently being provided by the Department of Homeland Security (DHS).

Dr. Baker's Statement: "A national EMP protection standard is needed. DHS is to be commended for issuing a coordination version of a communication / data center protection guidelines. DHS should expand this to include HV electric generator stations and electric substations."

Comment: As noted above, it is highly problematic to develop and implement a standard without a thorough understanding of its impact on daily operations. The industry still has open questions regarding the most cost effective way to protect digital equipment from an EMP (E1) conductively coupled waveform. Currently available solutions may be hard to install and worse yet, could cause significant unintended consequences during daily grid events.

The lessons learned from our transmission research can also be readily applied to our generation assets. For example, the use of MIL spec standards is not only cost prohibitive but can reduce the speed of operations of some equipment, which could create wide-area events and outages during normal grid operations.

As noted in my testimony, productive work can be done by the U.S. government such as:

- Testing of vehicles to make sure they will work if exposed to an EMP event so that we can be assured that response will not be impaired.
- Testing of distribution insulators to provide guidance as to good, better, and best voltage classifications. This would allow the industry to begin installing the correct voltage class insulators to mitigate the EMP waveform effects seen in the 1962 Starfish Prime nuclear testing or in the Russian atmospheric nuclear tests.
- Providing guidance to the industry on leveraging the hardened Federal Emergency Alert System to respond to EMP and other large-scale events. The system could provide

notification to our personnel that the outage they are experiencing is not a "normal" outage, but rather an EMP or other large scale event requiring that they report to their preassigned work locations.

- Testing of an *E1 EMP Surge device.* This will occur in 2019 and may demonstrate that there is not currently an available adequate product on the market. This may require engagement and research by the DOE and the National Labs to develop such a product.
- Further research and guidance for developers of renewable generation, as they become more predominant, on what is required to harden these assets to EMP.
- Assessment of the potential extent of damage to microgrid installations that are not in-service but react only after an EMP event. This would help resolve the question of whether full EMP hardening is needed in the case of not-in-service (i.e. not energized) equipment.
- Development of a national communication system that is robust enough to support restoration and response efforts during an EMP event. The utility industry is currently working to pilot a system to determine functionality and the cost to deploy.

Dr. Baker's Statement: "For more than half a century, DoD has protected high priority military command, control, communication, and computer assets for nuclear deterrence and response. DHS and DOE EMP/GMD protection programs should emulate DoD's efforts."

Comment*:* As noted by Dr. Randy Horton of EPRI, the use of MIL Spec standards creates issues for daily transmission system operations; we cannot use MIL Spec without negatively impacting normal grid operations. Although the Mil Spec standard is needed to protect DOD facilities, for the electric industry, the cost of using the standard is not justified if we can develop alternative ways to effectively reduce the impact on operations without going to this extreme. The U.S. electric system has built-in redundancy, so the loss of some components does not necessarily lead to a widespread, unrecoverable blackout. However, MIL Spec designs are prudent for new primary Operating Control Centers and many utilities are moving in this direction, as has Dominion Energy, without a regulatory requirement.

Dr. Baker's Statement: "We must preclude the temptation to re-invent the wheel by giving DHS and DOE full access to DoD standards and data bases. There is no need to recalculate a standard EMP waveform. Note that current EPRI grid vulnerability assessment models are using low-bound recalculated E3 waveforms. Existing IEC and EMPC EMP waveforms are more than adequate. Use of unclassified MIL_STD_188-125 test regimen will assure power grid survivability to both EMP and 100-year solar storms."

Comment: The guidance from the federal government is very much appreciated but we also understand the national sensitivity with some of their data. Regarding the Mil Spec standard, we believe it is an excellent standard for primary control centers of our electric grids, but, as previously noted, is not suitable for other protective measures, notably substation control enclosures.

The electric grid is extremely important to this nation's vitality. Whatever we do with regard to EMP cannot impact this system's daily function. As stated, additional research is needed before we can offer industry-wide guidance on the best approach to mitigate these threats while not negatively impacting daily grid operations.

We acknowledged that GMD and EMP (E3) waveforms are significantly different in duration; thus their impact on electrical equipment is very much different. The GMD waveform can last from hours to days with several peaks during this period where the EMP (E3) event will be of a very short duration. However, the efforts underway to harden equipment for GMD should provide improved protection for the short EMP (E3) event.

Our industry is committed to serving our customers and making prudent investments. I can assure this Committee that many in our industry are working hard in both of these areas with the knowledge that we have today. We recognize the risk, but work is still needed if we are to harden our systems in a manner that is reasonable and justified.

On behalf of Dominion Energy, I greatly appreciate the opportunity to testify on this topic and comment on Dr. Baker's work and concerns. I hope this information will be helpful in your deliberations.

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April 8, 2019

Chairman Ron Johnson
Homeland Security and Governmental Affairs Committee
United States Senate
Washington, D.C. 20510-6250

Dear Mr. Chairman,

Thank you for the opportunity to participate in the roundtable discussion on "Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance" on February 27th, 2019.

As you requested, I have prepared comments to address Dr. Baker's testimony. Please see the included document. If you have any further questions, I would be happy to address them.

Sincerely,

Jim Vespalec

James J. Vespalec, P.E.
Director of Asset Planning & Engineering

April 8, 2019

RESPONSE FROM
JIM VESPALEC
DIRECTOR OF ASSET PLANNING & ENGINEERING
AMERICAN TRANSMISSION COMPANY
SUBMITTED TO
THE COMMITTEE ON HOMELAND SECURITY AND GOVERNMENTAL AFFAIRS
REGARDING DR. BAKER'S PROPOSED ACTION ITEMS

I am responding to Chairman Johnson's post-hearing question for the record submitted to me after the roundtable discussion "Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance." Specifically, the request was stated as follows:

> "In the written testimony provided by Dr. George Baker, he outlined several priorities and action items for addressing the impacts of electromagnetic pulses (EMPs) and geomagnetic disturbances (GMDs). Please review Dr. Baker's written testimony and provide your perspective on his priorities and action items. Specifically, please identify the action items you agree with, disagree with, and those that you believe can and should be implemented to better protect the U.S. electric grid from an EMP and GMD event."

Dr. Baker's characterization of the electric utility sector as being unconcerned and unresponsive to these threats is inaccurate. Both the industry, as a whole, and ATC, in particular, take these threats very seriously.

To date, we have had no sound, scientific basis for evaluating the full range of these threats and their effects on the grid. Since we have not been able to model the threats and their effects, we have been conservative by adopting prudent measures to protect our systems against them as best we understand. We are hopeful that Electric Power Research Institute (EPRI) EMP studies and tests will inform us of the severity of the threats and prudent hardening solutions. Since this is a national security issue, the federal government has an important role in setting standards to protect our country and its citizens against these threats. We look forward to a measured and scientifically disciplined approach to protect the grid and other critical sector infrastructures against these existential threats.

Dr. Baker describes many steps to take to address this issue. Of those addressed, I will comment of them in the order presented.

1. ***New legislation needed to empower FERC, specifically to enable the Commission to write and enforce grid protection standards.***
   FERC is already addressing these concerns through its regulatory process, and new enabling legislation is unlikely to reach a quicker result. While I recognize the development of regulations can be a slow-moving process at times, given the complexity of the power system, the process develops feasible, effective standards. Legislation to give FERC more power over the standards is not likely to result in standards that can be effectively applied across the power system.

2. ***FERC should also be asked to identify regulatory and non-regulatory mechanisms, including cost recovery measures, to incentivize private sector engagement to address the effects of EMP.***

   Cost recovery mechanisms that incentivize private sector engagement will help move mitigation implementation forward. For instance, FERC could promulgate incentive transmission rates to encourage public utilities to harden the grid against EMPs. FERC could also affirmatively implement broad "grid resilience" planning requirements that would include, among other things, a requirement for public utilities and RTOs to engage in local and regional planning to mitigate EMP issues.

3. ***In legislation, FERC should also be asked to develop a national-level blackstart plan.***

   The premise of Dr. Baker's comment is faulty. Specifically, he states that utilities assume that they will be able to restart the electrical system from an adjacent part of the grid that has been unaffected. Some utilities make this assumption, but many others, such as ATC, do not assume this and have contracted Blackstart Resource Units within their own footprint. So, by starting from a faulty assumption, Dr. Baker draws a potentially unsupported conclusion.

   Here are some of the challenges I see with a FERC level plan:

   - In general, the closer an entity is to the front lines, the more awareness that entity has into what measures must be taken to operate its system resiliently. The Transmission Operator (TOP) is closer to the actual system than a higher-level regulator and is the best entity to build, maintain and operate the plan. Being closer matters for understanding what works, what is needed, how it can be tested, and what is actually happening on the day the plan needs to be executed.
   - The TOP's plan currently has to be approved by the Reliability Coordinator (RC). The RC maintains a wide-area view and has neither the staff nor the expertise to create and maintain all the details of each TOP's plan. The RC can and does set the primary strategies and philosophies that all plans need to incorporate and/or reflect. The RC is able to keep the area on a similar footing and aid the reconnection of islands and transition back to normal operation.
   - FERC is at a higher level than the RC so we should expect they would have even less capability as compared to the RC in terms of knowledge of the local system in terms of how it actually runs, the relationships of the various parties, the requirements of the various customers and the real time conditions should an event occur.

   That said, could FERC play some role? I believe the answer is "Yes" and they would best serve the industry by maintaining a framework for development of plans (i.e., the current reliability standards), a framework for paying for services (i.e., approved tariffs and contracts) and investigations of events and compliance findings (e.g., FERC-NERC Southwest Blackout recommendations or FERC-NERC review of blackstart plans). FERC exercises its power best through these existing avenues, and not by taking federal control over an area it is neither staffed to address nor has the expertise to oversee effectively.

4. ***The U.S. military already has EMP protection approaches that are practical, affordable, tested and well understood that can be translated directly to electric power grid control facilities and supervisory control and data acquisition electronics and networks.***
   While I will defer to Dr. Baker's knowledge of military technology, before declaring military technology translatable to electric power technology, given the potential impact and the complexity of the power grid, it is best to have the industry research the topic prior to implementing anything. ATC has been participating with EPRI for the last three years to research EMP and potential mitigation techniques. The final report is due at the end of April 2019, and we expect to review and consider the conclusions of that research.

   As a part of the EMP research project, EPRI worked with the Department of Energy and the national labs to obtain additional unclassified HEMP environments that can be used to assess potential impacts of HEMP on the electric power grid. These additional unclassified environments included information on electric field amplitudes, waveforms and other details that are important for simulating the effects of HEMP on the power grid and allows industry to test mitigation strategies against a "design basis" event. This is a great start. Government can do more to help the industry understand the threat and vulnerabilities to allow industry to cost effectively mitigate for this risk. There are basic questions with answers that could perhaps be declassified. For example, will service vehicles withstand a HEMP attack and remain operational? Is the threat considered "low" by DHS today because our adversaries do not have the capability? If they have the capability do they only lack desire, which could change quickly? Answers are needed to provide a comprehensive strategy.

5. ***Threat level testing will be required to determine EMP/GMD vulnerabilities, develop and validate models, and verify protection methods. To this end, new and upgraded EMP/GMD integrated system test beds are needed.***
   If the research can be shared, this is something that would provide benefit to the electric power industry.

U.S. Senate Committee on Homeland Security and Government Affairs
Roundtable: Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance
Responses to Questions for the Record
by Dr. Justin Kasper (University of Michigan)

Post-Hearing Questions for the Record
Submitted to Justin Kasper, Ph.D.
From Senator Ron Johnson

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance"

February 27, 2019

1. In the written testimony provided by Dr. George Baker, he outlined several priorities and action items for addressing the impacts of electromagnetic pulses (EMPs) and geomagnetic disturbances (GMDs). Please review Dr. Baker's written testimony and provide your perspective on his priorities and action items. Specifically, please identify the action items you agree with, disagree with, and those that you believe can and should be implemented to better protect the U.S. electric grid from an EMP and GMD event.

I was present for Dr. George Baker's testimony and have reviewed his written testimony, including his Summary and Action Items section. Here I will comment on the bulleted action items I judge within my expertise.

- The FERC GMD standard (TPL-007-2), though its specified environments and system thresholds are not defense-conservative, has at least brought industry attention to GMD effects. This standard, even if rigorously enforced will leave the grid dangerously vulnerable to GMD and needs to be revised.

Kasper: I agree with this statement. It is commendable that a FERC GMD standard has been developed but examination of the specifics of the standard suggest to me that it does not reflect the real worst-case events of the last century. I think FERC recognizes this as there are plans for a more detailed standard to be developed but this process should be encouraged.

- Without a corresponding FERC EMP directive, the private sector is not doing very much of anything to address the EMP threat. An EMP directive and protection standard are sorely needed.

Kasper: I agree with this statement. It was very clear from the testimony that EMP is viewed as a national security issue and the Federal government is obliged to take the needed actions to prevent it from happening. There is a useful middle ground here, where it may be overkill to design the entire infrastructure to be resilient to a highly unlikely nation-wide EMP event, but there could be great value to developing an EMP directive and standard that safeguards against a more probable localized EMP event. In order to be successful it will be necessary to assess the state of the art in localized EMP generation.

- New legislation is needed to empower FERC, specifically to (1) Enable FERC to write and enforce grid protection standards.
    - (2) Identify mechanisms, including cost recovery measures, to incentivize private sector engagement on EMP protection and increase on-site fuel stockpiles.
    - (3) Develop a national blackstart plan.

Kasper: I agree with this statement. GMD and EMP are unlikely but high impact events that we should prepare for on a national level but are difficult to justify or explain on the local level. By writing clear protection standards we can give the utilities and private sector the basis for implementing protective measures that will come with a cost. There absolutely needs to be a national blackstart plan given the chaos and poor communication expected from a national event. As a private citizen I sincerely hope such a plan exists and just is not circulated, but if everyone reading this is making the same assumption...

- A national EMP protection standard is needed. DHS is to be commended for issuing a coordination version of a communication/data center protection guidelines. DHS should expand this to include HV electric generator stations and electric substations.

Kasper: Agreed in general, but a detailed analysis would be needed to determine the fraction of HV electric generator stations and electric substations that should be required to meet this standard.

- For more than a half-century, DoD has protected high priority military command, control, communication, and computer assets for nuclear deterrence and response. DHS and DOE EMP/GMD protection programs should emulate DoD's efforts.

Kasper: I do not think the entire national grid needs to be safeguarded at the same level as high priority military assets used for nuclear deterrence to strike the correct balance between cost and risk reduction. A study should be able to identify an optimum point or at least a broad middle ground for the level of protection and the fraction of the power infrastructure covered that has significantly less cost.

- We must preclude the temptation to re-invent the wheel by giving DHS and DOE full access to DoD standards and data bases. There is no need to recalculate a standard EMP waveform. Note that current EPRI grid vulnerability assessment models are using low-bound recalculated E3 waveforms. Existing IEC and EMPC EMP waveforms are more than adequate. Use of the unclassified MIL-STD-188-125 test regimen will assure power grid survivability to both EMP and 100-year solar storms.

Kasper: I have two concerns about this. MIL-STD-188-125 is in response specifically to a high altitude EMP from a nuclear detonation. If a localized EMP device is far more likely to be employed then I would suggest a different standard. I am also worried that the late phase of an EMP, lasting for minutes, really doesn't capture the days of geomagnetic disturbances that can develop as part of a large solar storm. It is one think to survive a steady current for minutes, but does that directly translate into being able to survive similar levels for hours and days, even if they are intermittent?

- A prioritized list of EMP-susceptible infrastructure is needed. System protection and reconstitution prioritization requires improved grid modeling. Integrated system test beds will be important for model validation. Top priority is HV generation plants and HV/EHV transformers, heretofore untested. The INL and TVA test beds look promising.

Kasper: I agree with this statement. A lot of the uncertainty in the dangers of EMP or GMD come from us not understanding how the whole system will interact with itself. For example, we do not think that turning on an active protection device on one transformer will stress other nearby transformers, but what would the interaction between systems of protective devices actually look like? This is difficult to simulate. We have also discussed scenarios where a GMD disables or knocks out a subset of transformers. What happens to the other transformers? Are they equally likely to fail or does the failure of other transformers increase their failure rates? I am reminded of the subprime mortgage collapse, fueled in large part by everyone assuming that one homeowners chances of defaulting would never be impacted by external factors such as other people defaulting. Let's not relearn that lesion.

- The most current EMP Intelligence report is technically flawed and misleading in a manner that downplays the need for action – a new assessment is needed.

Kasper: I have not reviewed it.

- I estimate cost of EMP protection for the bulk power system to be in the $50B range. The investment strategy is based on identifying a top-down "thin-line" of grid assets. More rigorous cost estimates are needed by DOE & industry.

Kasper: I agree with the basic assumption that we do not upgrade all assets. I strongly support the suggestion of a more rigorous cost estimate. The more clarity and definition we have in the EMP and GMD requirements the more accurate this cost assessment will be.

From a Bottom-Up perspective:

• EMP protection programs must be pursued at the local and State levels since communities would be on their own for extended periods in a wide-area blackout.

Kasper: I agree, but Federal requirements and regulations will make it much easier for local and state officials and utilities to explain the costs to their customers.

- Pilot demonstration programs of selected grid sectors are all-important to address the feasibility and cost of local EMP protection. The ongoing Lake Wylie Demonstration Project and the San Antonio Joint-Base microgrid development program are good examples and should be expanded and funded.

Kasper: Agreed.

- Bottom-up protection should address a thin-line of essential life-support infrastructures including distribution substations, backup power generation systems, emergency services, water supply and treatment, hospitals, and the necessary logistics tail.

Kasper: Agreed.

Post-Roundtable Questions for the Record
Submitted to Dr. Justin Kasper
From Senator Gary Peters

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse (EMP) or Geomagnetic Disturbance (GMD)"

February 27, 2019

1. Please describe how the National Oceanic and Atmospheric Administration (NOAA) forecasts space weather events and how sophisticated our ability is to predict such events?

A NOAA forecast of space weather events begins with an analysis of real-time images of the surface of the Sun and its extended atmosphere (also known as the corona) in visible, ultra-violet (uv), and x-ray light. High resolution imaging of the visible surface of the Sun is possible from the ground, but to avoid blurring from turbulence in our atmosphere and to see the very faint light from the corona we need to observe from space. UV and x-ray light has to be observed from space because it is immediately absorbed by our atmosphere.

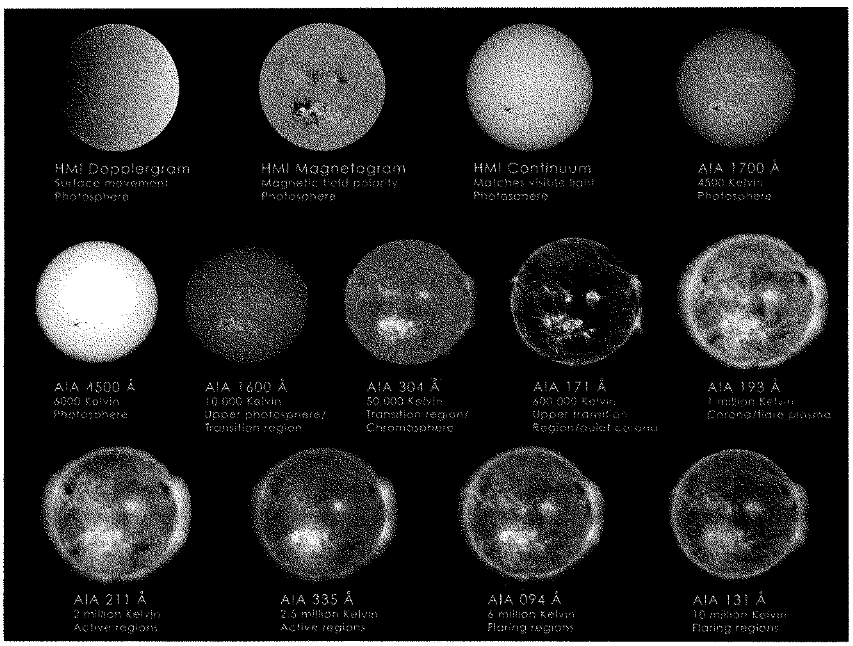

Figure 1: How NASA Solar Dynamics Observatory (SDO) sees the Sun.

By looking at the polarization of light in special wavelengths, forecasters can measure the magnetic field on the surface of the Sun, as illustrated by the solar images at various wavelengths in Figure 1 that were taken by the NASA Solar Dynamics Observatory (SDO) spacecraft. Sunspots are dark regions on the Sun where strong magnetic field pops up through surface. Once a sunspot emerges two things can happen. The sunspot may dissipate, and the magnetic field ebbs away or returns below the surface, or the magnetic field can float in the corona, twisting into a tightly wound rope as the surface of the Sun boils and churns. The uv image in Figure 2 captures both an intense solar flare (the bright saturated white light in the upper left) and the release of a filament of magnetic plasma into space. For scale this filament is hundreds of times larger than Earth even close to the Sun. It will expand substantially as it flies away from the Sun.

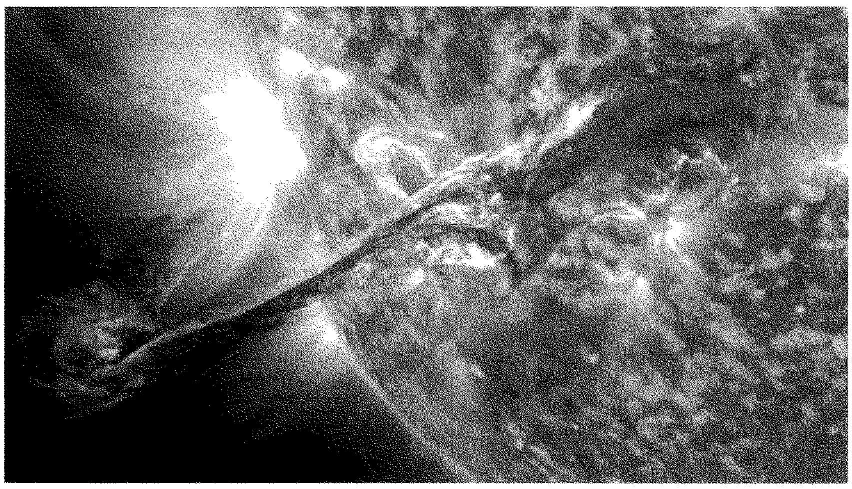

Figure 2: A flare and a filament erupt! An enormous coronal mass ejection that occurred on 31 August 2012 as captured by SDO in ultraviolet light.

Once a filament lift off from the Sun it expands and accelerates, moving into interplanetary space at higher and higher speeds and turning into what we call a coronal mass ejection (CME). A fast CME may be move through the coronal into space at 3,000 km/s or more than a million miles an hour. The last glimpse we currently have of the CME is a faint image from sunlight scattering off electrons within the eruption seen by sensitive visible light telescopes like on the NASA STEREO or ESA SOHO spacecraft shown in Figure 3. Once the CME leaves the field of view of these visible light telescopes we have no operational way of following its expansion until it reaches the DSCOVR, ACE, and Wind spacecraft at the first Lagrange point, or L1. L1 is about one percent of the way towards the Sun from Earth, and is a special location where the Sun and Earth's gravity compete to keep the spacecraft essentially hovering on the line between the Earth and the Sun. From L1 we have between 20 minutes and an hour of warning before a storm hits Earth, less so for a fast event like the Carrington CME. Currently we rely on simulations to forecast the direction of the ejection and to estimate its severity like hurricane landfall simulations, but with no daily observations from spacecraft to update the models as the CME erupts through space.

Figure 3: Zooming out on a CME as it erupts from the Sun we are able to follow it until it is tens of solar radii from the Sun (about 1/20 of the way to Earth). After that we have no operational way of tracking the CME until it strikes the DSCOVR, ACE and Wind spacecraft near Earth.

2. In your written testimony, you stated that the space weather community needs leadership with a mandate to coordinate and direct research for space weather. Please elaborate on that as well as any solutions that could address this problem.

There are disconnects between the different federal agencies responsible for aspects of space weather that make it very difficult to plan or improve our ability to forecast or monitor space weather. For example consider what happens if someone has an idea for a new way to monitor a space weather event. NOAA does not have funding to support basic research and development to test a new technique that could eventually become an operational data product. NASA judges proposals on their scientific merit or the value of the basic technology being developed, and it is very unlikely that a long term observation or study that develops a new space weather capability will have the same level of scientific or technical value as mainstream proposals. NOAA requires long term extended observations to establish that a data product is useful operationally. NASA shuts down science missions once the data they are returning is no longer novel or useful for science. This makes it very difficult to establish the value of new observations. Most of the current observations in deep space that we are dependent upon for space weather forecasts were scientific missions that had a real time capability added on but that wasn't a primary driver of the mission. The NSF is able to fund groundbreaking research but has difficulty supporting activities that need to go into space. As a result potentially valuable advances fall through the cracks.

Several solutions are possible. NOAA could run a research and development program for space-based and ground based space weather observations and models with competed funding for Universities, industry, non-profits, national laboratories – wherever the talent resides. They could take additional funding to add extra instruments to operational missions that may not be required today but demonstrate the potential of becoming valuable operational data products today. NASA could be given additional funding to support a line of missions, or instruments of opportunity flying on planned spacecraft, that have long term monitoring as their primary goal as opposed to short term scientific yield. The NSF could fund space-based research. Each of these comes with a challenge as the work is not necessarily the specialty of the organization I named, so an empowered coordination group might be needed.

3. As you stated during the roundtable, for major GMD events, timeliness from observing the event to notifying the power sector is very important. However, NOAA cannot forecast with great fidelity the severity or vicinity that may be affected by the event until it is less than an hour away. Please discuss how we can improve our monitoring and forecasting capabilities to more quickly understand the likely impacts of an impending GMD event.

First, regional forecast capability (predicting GMD on the local level) is being developed and that work should continue. Second, we need better observations to feed into these improved models. There are two separate activities that could be equally valuable. We should place one or more spacecraft closer to the Sun to provide real time information on the speed, magnetic field, and other critical properties of CMEs headed towards the Earth. This could be accomplished in a few ways and the best approach should be studied. A single spacecraft with a solar sail could station itself directly on the Sun Earth line. Multiple simple spacecraft could be placed into orbit around the Sun so that at least one of them was near the Sun Earth line at any time. Finally, a ring of spacecraft could be placed into a very large circular orbit about the Earth so that any one of them was along the Earth-Sun line at any time. We should also have observations by multiple spacecraft of the changes in the solar wind around Earth in three dimensions, so we are not asking too much of a single measurement at L1. Small spacecraft around Earth looking for 3D disruptions to the magnetic field may be sufficient.

4. What additional benefits would come from having more advanced warning about a Carrington-like space weather event headed for earth?

We talk about the Carrington event and other major events because the threat to society is very stark and easier to imagine. However it is very important to realize that for every century storm there are hundreds of minor storms occurring over a solar cycle, each of which does some economic damage, the sum of which can be substantial. In my testimony I pointed out that insurance claims in the US and Europe for damaged industrial electronics jump up on days with elevated geomagnetic disturbances. Adding up all of those jumps over the last two decades suggests that industry in the US suffers $2-3B in equipment damage every year on average. If utility operators knew to provide backup power, or industry knew to run at lower capacity during these periods there would be substantial cost savings.

Beyond damage to power grids and electrical and industrial equipment advanced warning of major events headed to Earth has many other commercial, civilian, and military benefits. A day warning of potential issues with radar, shortwave radio communication, satellite navigation and communication due to a major storm would be used by airlines to reroute polar flights and plan for degradation of wide area augmentation (WAA) aircraft navigation assistance and by the military to plan for communication and navigation error or loss. Industries that rely on precision navigation, such as deep sea oil drilling could avoid operating on a day where they could lose control of their rig.

5. Do you have suggestions on how the U.S. government should improve how it allocates or prioritizes investments in space weather detection technology?

I think for electrical utilities to be willing to take advance warning of an impending storm seriously enough to shut down all or part of the grid we need to move from minutes warning to a day warning at least. This would give decision makes time to evaluate the risk and make decisions. Developing spacecraft that can observe closer to the Sun near the Earth Sun line should be a priority. More broadly there needs to be a path for new detection technology to be developed that is not yet operational and possibly not cutting edge science, so currently falls between NOAA and NASA purvue.

6. Please describe the challenges with defining a '100 year solar storm'. What can the U.S. government do from a science and research perspective to help improve this analysis?

If we were designing part of a city to be resilient to a '100 year storm' we would simply look at historical weather observations and identify either the single worst storm in terms of overall impact in the last 100 years, or we could identify several storms in the last 100 years that individually led to the worst flooding, the worst soil erosion, the worst damage to structures, etc. Defining the '100 year solar storm' is more difficult because we only have observations from space over the last 50 years, and much of the equipment that is susceptible to a solar storm has only been around for 50 years. Much like a rain storm, different solar storms may produce different one in 100 year levels of damage. Different solar storms could produce, for example: the strongest single change in magnetic field, the longest disturbed period of magnetic field, different locations of intense geomagnetic disturbances. Along with the GMD we have discussed today other storms could produce the highest dose levels of radiation in space, or the largest disruptions of GPS, radar, or radio communications.

There are two things the US government can do to improve this analysis.

First, identify the aspects of solar storms we are most concerned with and then separately identify the once in a century level for each of those key aspects. That would include: highest total radiation dose, highest radiation dose rate, highest impact to ionosphere, largest induced geomagnetic currents, longest geomagnetically disturbed interval, and fastest changing geomagnetic currents.

Second, when historical events are not available or observed completely, develop alternative analysis to estimate their impact, including numerical simulations of the response of the Earth as a whole to simulated solar storms. Also investigate historical records at Earth like tree rings or external analogs. A recently published paper https://iopscience.iop.org/article/10.3847/1538-4357/ab14e6 looked at how often stars with the same mass and composition as our Sun produce super flares. Essentially, by looking at hundreds of stars for a decade, we can start to draw conclusions about century level events without waiting one hundred years. The NASA Kepler mission is supposed to hunt for exoplanets, and it does this by staring at hundreds of thousands of other stars waiting for the light to momentarily twinkle as a planet rotating the distant star passes between us and the star. The spacecraft is also excellent at detecting visible light from massive solar flares. Kepler might only operate for 10 years, but if it looks at 100 stars like our Sun it can substantially improve our knowledge of the probabilities of a major event. However, are all stars the size of our Sun really like our Sun in every way? This recent study showed that the size and occurrence of superflares depends on how quickly the stars rotate. A young version of our Sun may produce flares that are 100 times stronger and more frequent than our relatively older Sun. This recent study was able to use the rotation rate of the stars to identify the stars that are most like our own Sun. By then following dozens of the stars over the mission we are able to piece together that superflares larger than the Carrington event may happen every thousand years in a star like our Sun. We can also say with more confidence that a major event like the Carrington event is likely to occur more than once a century. This kind of creative use of other stars, ancient records, and simulations of major events can allow us to piece together he properties of real century level events.

Post-Hearing Questions for the Record
Submitted to Caitlin Durkovich
From Senator Ron Johnson

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse (EMP) or Geomagnetic Disturbance (GMD)"

February 27, 2019

1. In the written testimony provided by Dr. George Baker, he outlined several priorities and action items for addressing the impacts of electromagnetic pulses (EMPs) and geomagnetic disturbances (GMDs). Please review Dr. Baker's written testimony and provide your perspective on his priorities and action items. Specifically, please identify the action items you agree with, disagree with, and those that you believe can and should be implemented to better protect the U.S. electric grid from an EMP and GMD event.

Witness responses to questions submitted for the record were not received by time of printing.

Post-Roundtable Questions for the Record
Submitted to Caitlin Durkovich
From Senator Gary Peters

"Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse (EMP) or Geomagnetic Disturbance (GMD)"

February 27, 2019

1. What additional steps should the U.S. government take to assist in the process of securing our critical infrastructure from a GMD event? Do agencies, specifically DHS, need more authorities in your opinion?

2. Because critical infrastructure sectors are in many way interdependent, do you think we need to reexamine or update the U.S. government's approach to critical infrastructure risk and mitigation, or do we currently have the right structures in place? Please explain.

Witness responses to questions submitted for the record were not received by time of printing.