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The Danger of EMP Requires Innovative and Strategic Action

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Abstract

An electromagnetic pulse (EMP) attack poses a direct threat to the U.S. electric grid—a threat that is poorly understood and lacks the leadership to address it. An EMP—a high-intensity burst of energy caused by a rapid acceleration of charged particles from either solar weather or a nuclear bomb detonated high in the atmosphere—can cause devastating damage to the U.S. electric grid, and severely impede recovery. The U.S. currently has limited protection to address consequences of EMP-like events, which presents a considerable window of opportunity for less-powerful nations to harm this country. At the core of the discussion around EMPs is what is to be done to minimize the threat, and by whom. EMPs represent a high-risk, low-probability situation that, despite over a decade of discussion in Congress and study from the executive branch, fundamentally lacks leadership and understanding. Americans and their Representatives in Congress need to recognize the seriousness of the threat. So far, U.S. efforts to understand and address the threat have been hampered by the dispersion of information and responsibilities among different parts of the government and the private sector. While there is still considerable disagreement about the extent of an EMP threat and how to address its effects, the most immediate contribution Congress or the President could make is to clarify responsibilities. Without clear roles and defined leadership, everyone will continue to view an EMP as someone else's responsibility.

Key Points

- An electromagnetic pulse (EMP)—a high-intensity burst of energy caused by solar weather or a nuclear bomb detonated in the atmosphere above the U.S.—poses a direct threat to the U.S. electric grid and the products, services, and activities that depend on access to electricity.
- An EMP could cause widespread failure of the electric grids of entire regions, grinding the U.S. economy to a halt. Without electricity, almost nothing will work; too many Americans could die as a result; and rioting and looting can quickly create a state of anarchy.
- Congress's most critical task is to increase access to information, and align authority and responsibility in the public and private sectors for preparing for and responding to an EMP attack.

Considered by some to be the stuff of science fiction, an electromagnetic pulse (EMP) attack poses a direct threat to the U.S. electric grid—a threat that is poorly understood and lacks the leadership to address it. An EMP—a high-intensity burst of energy

This paper, in its entirety, can be found at **http://report.heritage.org/bg3299**

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caused by a rapid acceleration of charged particles from either solar weather or a nuclear bomb detonated high in the atmosphere—has the potential to cause devastating damage to the U.S. electric grid and severely impede recovery efforts.

The American public, and their Representatives in Congress, need to recognize the seriousness of the threat. So far, U.S. efforts to address the threat have been hampered by the dispersion of responsibilities among different parts of the government and the private sector. While there is still considerable disagreement about the extent of an EMP threat and how to address its effects, the most immediate contribution Congress or the President could make is to clarify responsibilities for aligning authorities and responsibilities in the public and private sectors for responding to an EMP attack. Without clear roles and defined leadership, the various parties with ostensible responsibility will continue to view preparing for an EMP as someone else's area of responsibility, and it will become increasingly unclear whose recommendations they should follow. The EMP discussion will only progress as far as the next government report. Instead of that outcome, clearly defining roles will help incentivize the various parties to understand their unique risks and vulnerabilities, and to develop the appropriate solutions in a world of competing risks.

The U.S. needs governance structures to ensure that energy transmission is reliable and sustainable, accommodating changes in technology, consumer needs, and national security threats and concerns. The government's first responsibility, its most critical task, is to align authority and responsibility in the public and private sectors for responding to an EMP attack.

What Is an EMP and Why Is It So Dangerous?

An electromagnetic pulse is a high-intensity burst of energy caused by the radiation of air particles—either from naturally occurring geomagnetic disturbances (such as solar flares) or through the detonation of a nuclear weapon.[1] A high-altitude nuclear explosion above the continental United States could easily cause widespread failure of, and permanent damage, to the electric grids of entire regions, grinding the U.S. economy to a halt. With a paralyzed economy come untold deaths—without electricity, almost nothing will work, which means that millions of people will die as a result of not being able to refill medical prescriptions, millions more will be without food, and predictable rioting and looting can quickly create a state of anarchy.

There are three components, or waves, to an EMP event known as E1, E2, and E3, which are differentiated by their wavelength. E1 takes place in a manner of nanoseconds and disrupts electrical systems in general, particularly long-line electrical systems over very large geographical regions, as well as computers, sensors, and electronic-based systems.[2] Electrical appliances and unshielded electronic components could be rendered permanently inoperative.

E2 takes place over milliseconds and enhances the EMP currents on long lines, further exacerbating the damage caused by E1. The E2 is similar to lightning strikes and particularly impacts power lines and tower structures, telecommunications, electronics, controls systems, and transformers.[3]

The E3 component can last minutes and is similar to solar geomagnetic storm effects. The bulk power system, the backbone of the U.S. grid, is particularly vulnerable to this wave. If the bulk power system is compromised, it would cause widespread or cascading outages and irreparable damage to key components, such as transformers and substations.

While protecting long-line systems against an EMP and all its components offers protection from space weather, hardening the systems *only* to withstand space weather does not offer protection from the E1 part of an EMP, which requires different equipment.[4] This means that the United States must go *beyond* hardening its grid against effects of solar weather—both of which it has yet to do.

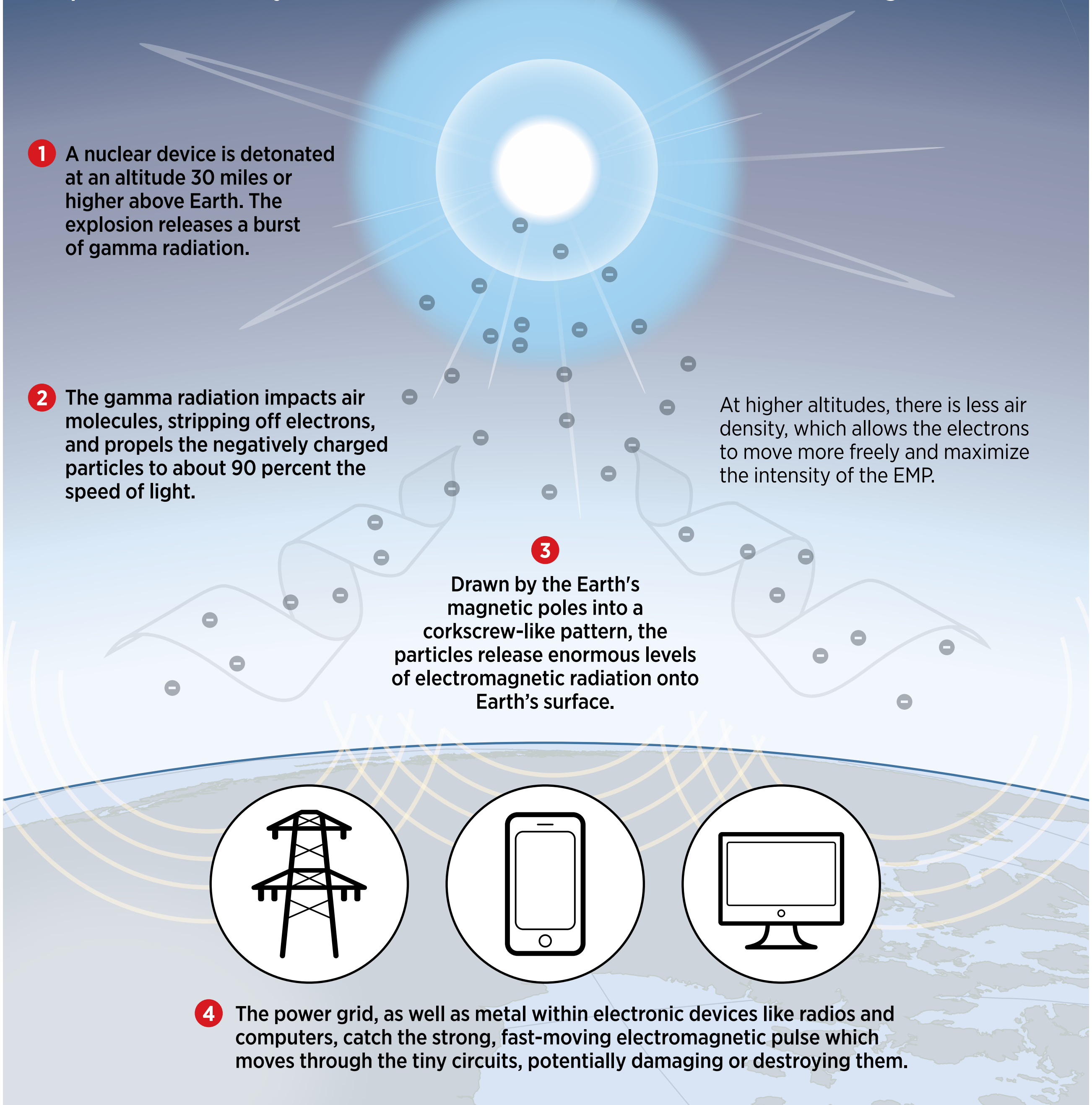
Americans' lives depend entirely on a stable supply of electricity, from using computers and smartphones to paying with a credit card for morning coffee to powering industry, water treatment, hospitals, military institutions, farming, and tens of thousands of other activities. Along with changes in how Americans produce and use electricity, there are ever-challenging threats to maintaining that service. The electricity sector, perhaps more than ever, is evolving to meet the demands for availability and reliability. While weather is still the number one cause of service interruption, the electricity sector is increasingly facing new modes of attack, such as cyber attacks.[5]

The threat of an EMP comes primarily from hostile regimes with access to nuclear and ballistic mis-

FIGURE 1

How an EMP Works

An electromagnetic pulse (EMP) is a rapid discharge of electromagnetic energy. An EMP can occur naturally, such as from a lightning strike, or it can be caused by a nuclear explosion with the potential to destroy electronics across thousands of miles. Here's how it might work:



SOURCE: Heritage Foundation research.

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sile technology. A nuclear bomb detonated at an altitude of just 25 miles above sea level, also known as a high-altitude EMP (HEMP), would have far-reaching consequences, potentially across the continental United States. An endo-atmospheric "source region" EMP (SREMP) occurs if a detonation happens at lower altitudes, which would affect smaller geographic regions than a HEMP.[6]

A nuclear bomb detonated just 25 miles above sea level would have far-reaching consequences, potentially across the entire continental United States.

Radio-frequency weapons also can be used to generate more localized EMP effects. The components used to build these devices are commercially available, more covert and more easily transportable than nuclear weapons, and require much less sophistication and far fewer resources than nuclear weapons. They must be detonated close to the target and cause much more localized damage. Their output and damage vary based on their size and design, but generally speaking, radio-frequency weapons are very portable and can fit in the bed of a truck or even a suitcase. An adversary could choose to use multiple devices at different locations to increase damage to the target.[7] The U.S. military is exploring these effects in a Counter-electronics High-power Microwave Advanced Missile Project (CHAMP) designed as a non-kinetic alternative to rendering electronic targets useless with little to no collateral damage.[8] Adversaries are likely doing the same because the ability to "blind" the United States in a conflict could put them at a decisive advantage.

Attractive Threat: Consequences of an EMP

The U.S. has had some limited experience with an EMP. In 1859, a nascent electric system was first exposed to an EMP-like event. Telegraph operators were shocked unconscious and their machines caught on fire as energy from a particularly large solar flare reached the earth.[9] The world today is much more electrified than it was in 1859 (a commercially available light bulb was not invented until 1879) and is overdue for another large solar storm.[10]

In 1962, the United States detonated a hydrogen bomb at a high altitude off Johnston Island in the Pacific Ocean in an operation known as Starfish Prime. The effects were felt in Hawaii, almost a thousand miles away, where the bomb's effects blew out streetlights and caused telephone outages.[11] The test also damaged U.S., British, and Russian satellites.[12] The Soviet Union tested its own nuclear weapons in Kazakhstan quickly thereafter, reportedly causing damage to power and communications lines hundreds of miles away.[13]

Due to difficulties related to modeling EMP events, as well as assessing adversarial capabilities to cause them, there is some uncertainty about how grave the damage to U.S. systems would be, and what an appropriate level of hardening, or protection, would entail. Hardening the grid through special grounding and other technologies could ensure that equipment, particularly high-value assets like transformers or generator control systems, continue to work after being hit by an EMP.[14] Decisions about hardening the grid also require a particular emphasis on assets that are relevant for the recovery of the electrical system.[15]

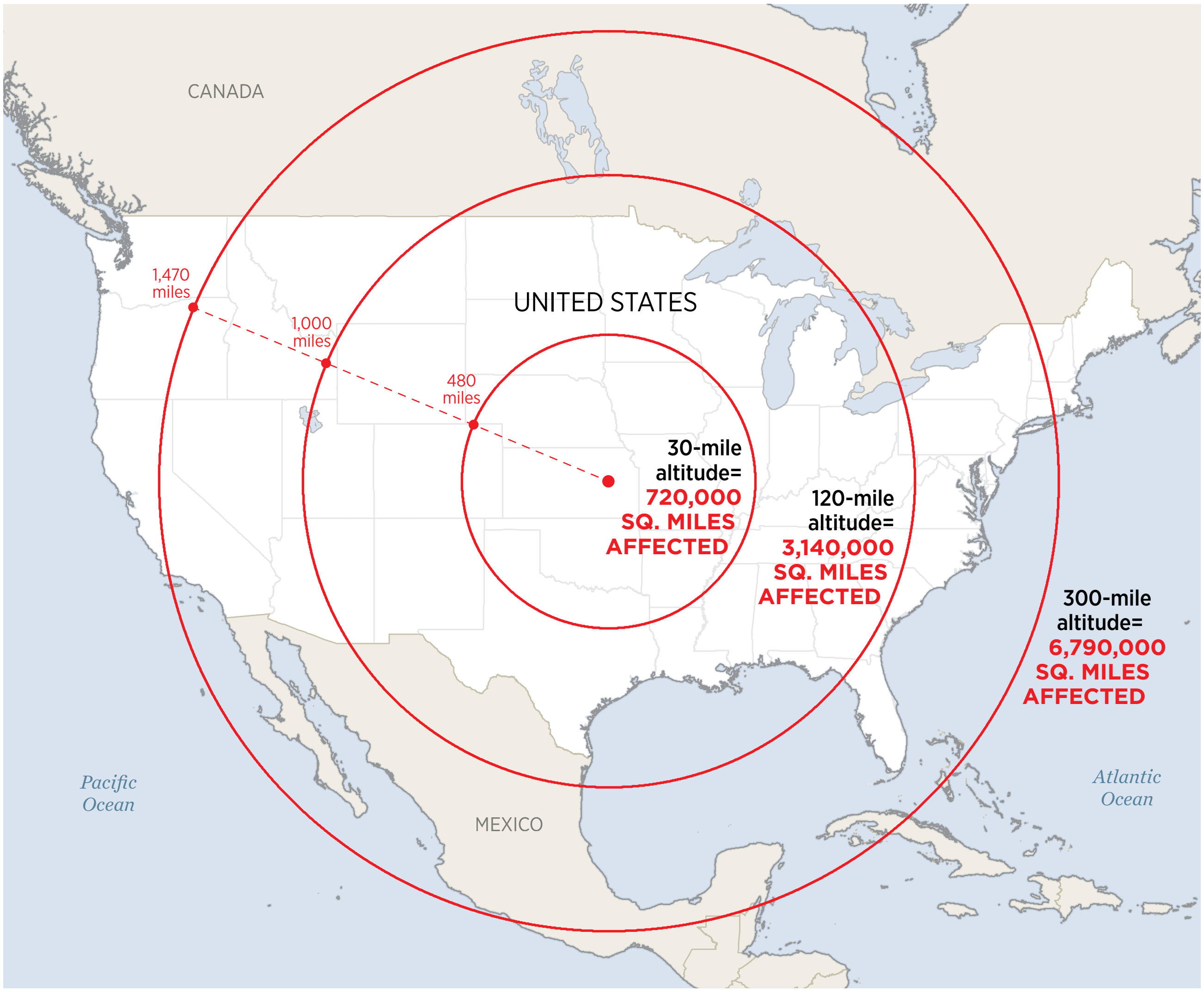
While satellites today are hardened to address the harsh space environment, for the most part, they are not hardened to withstand the effects of a HEMP attack. A successful HEMP detonation could permanently or temporarily damage satellites in a low-earth orbit (LEO), and also deny human access to that region of space since the debris from the detonation can make the orbit unusable for a long time. It could also cause an early demise of satellites in a medium-earth orbit (MEO) and geosynchronous orbit (GEO). The Defense Threat Reduction Agency warned in 2010: "Any nation with missile lift capability and sufficient technology in the requisite number of disciplines can directly attack and destroy a satellite, but significant damage to satellites in MEO or GEO cannot easily be accomplished with detonations at high latitudes."[16]

The U.S. military also tests its equipment to withstand EMP-like environments. Waivers to the protection standards are common. Such tests, however, are limited in the civilian sector and standards for hardening equipment tend to be appreciably lower. On some level, a significant difference in hardening standards for military equipment and critical infrastructures makes little sense given that, in the long term, the military ultimately depends on civilian critical infrastructure, such as the electric grid.

MAP 1

As EMP Burst Altitudes Increase, So Do Affected Areas

A nuclear device detonated at an altitude of 30 miles above the earth could generate an electromagnetic pulse (EMP) strong enough to damage or destroy electronics within an area of about 720,000 square miles. At higher altitudes the damage would affect even larger areas.



SOURCE: "Threat Posed by Electromagnetic Pulse (EMP) to U.S. Military Systems and Civil Infrastructure," testimony before the House of Representatives, Committee on National Security, July 16, 1997, http://commdocs.house.gov/committees/security/has197010.000/has197010_1.htm (accessed March 6, 2018).

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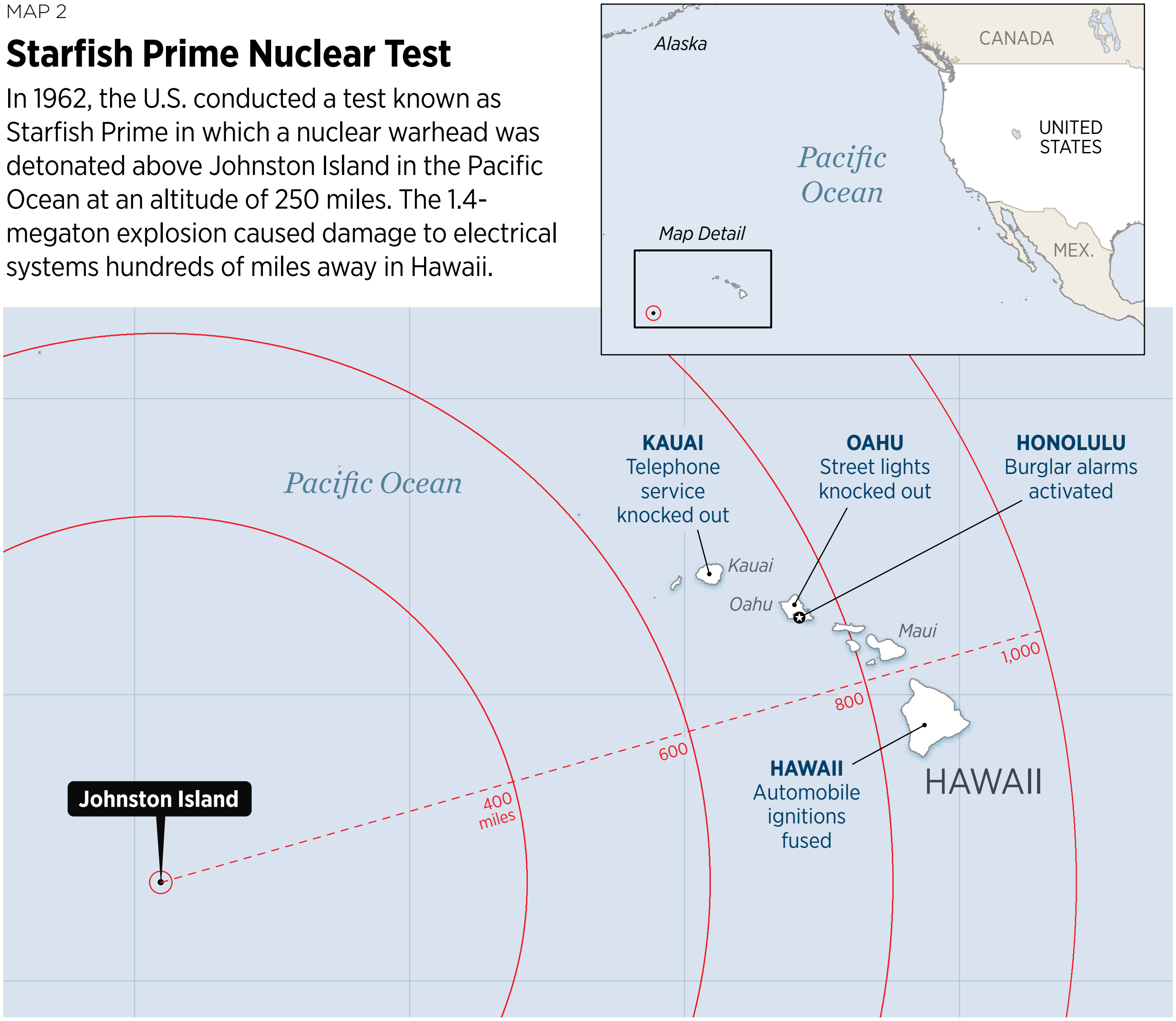
Electronic systems, communications, and components of the grid—transformers, substations, transmission lines, perhaps even generation stations—are vulnerable. Industry collaborative groups exist to stockpile and share critical equipment in the case of damage. For example, because critical equipment, such as transformers, are of various designs, expensive, difficult to transport, and take months to replace, industry has addressed this vulnerability to date through programs like SpareConnect and the Spare Transformer Equipment Program (STEP).[17] However, these programs would probably be insuf-

MAP 2

Starfish Prime Nuclear Test

In 1962, the U.S. conducted a test known as Starfish Prime in which a nuclear warhead was detonated above Johnston Island in the Pacific Ocean at an altitude of 250 miles. The 1.4-megaton explosion caused damage to electrical systems hundreds of miles away in Hawaii.



SOURCE: Heritage Foundation research.

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ficient in an event that wipes out vast regions of the national grid. Further, in the case of extended electric outages on the order of months, extensive casualties are possible since the very fabric of U.S. society depends on highly complex and interdependent electrical systems.

Defining the Threat

Nation-States. Given that a successful EMP strike requires ballistic missile capabilities and nuclear technology to create a bomb, potential adversaries are generally known. As a congressionally designated commission noted in 2004, the threat of an EMP attack is nothing new: Russia and China both have the capability to generate an EMP and are known to have incorporated them into military planning.[18] Russia and China are reportedly working on new weapon designs that strengthen some of these effects.[19]

An EMP's devastating effects make it a useful asymmetrical weapon for weaker U.S. adversaries, particularly those who are not as technologically advanced and as dependent on electricity as the United States, who would thus not be similarly affected by a U.S. "response in kind." Allegedly, EMP technology has been transferred by Russia to North Korea, and Iran has also incorporated the option of using an EMP in official policy.[20]

North Korea, for example, has been working for decades to advance its ballistic missile and nuclear weapons program. North Korea's ballistic missiles are now capable of reaching the United States as well as allies in Japan, South Korea, and the Northern Hemisphere.[21] In September 2017, North Korea reportedly tested a hydrogen bomb, much more destructive than a nuclear bomb, and claimed the device can be mounted on a ballistic missile.[22] From there, it is just a matter of time before North Korea learns how to fuse the weapon properly so that it could detonate in a high altitude to maximize the weapon's EMP effect. Reportedly, North Korea stated in conjunction with the September 2017 launch that it has "a multifunctional thermonuclear nuke with great destructive power which can be detonated even at high altitudes for super-powerful EMP attack."[23] The Department of Defense is due to brief Congress on the potential damage North Korea could inflict using an EMP as directed in the most recent National Defense Authorization Act.[24]

Terrorists. Terrorist organizations may also have an interest in EMPs for the significant disruption they could cause to advanced economies. The avenues for a terrorist to acquire an EMP-style weapon, are limited however, negating much of the EMP threat from such organizations.

> Given that a successful EMP strike requires ballistic missile capabilities and nuclear technology to create a bomb, potential adversaries are generally known.... An EMP attack would be an act of war.

The first avenue for a terrorist EMP attack is a nuclear missile HEMP attack. If terrorists manage to acquire a nuclear weapon, they will have overcome a significant hurdle. But beyond merely acquiring a working nuclear weapon, a terrorist group must also be able to launch it as a missile to a sufficient altitude in the atmosphere. So a terrorist must not only acquire a nuclear weapon, but also possess missile technology capable of reaching an altitude of dozens or hundreds of miles above the earth. Together with the difficulty that terrorist organizations face in acquiring a nuclear weapon in the first place, it is highly unlikely that the U.S. will face a terrorist-launched nuclear EMP attack in the foreseeable future.

The second avenue for a terrorist EMP attack is a high-power microwave (HPM). Rather than an EMP blast created by a nuclear weapon, an HPM can be created from various electronics and a source of energy ranging from an explosion to powerful batteries. U.S. government scientists were able to construct two HPMs from commercial electronics in 2001, and it is estimated that a terrorist could construct a small, crude HPM for less than $2,000.[25] An HPM can be very effective in disrupting electronic devices but has a very short range, likely less than one mile. As such an HPM will have a small local impact, but the greater concern would be that such a geographically limited attack could have cascading effects beyond the area initially struck.

Mitigating an EMP Event: Can the U.S. Know an EMP Is Coming?

The challenge with mounting a defense against an EMP is that the tactical warning time is inherently limited, no more than 45 minutes in the case of solar-weather-created events.[26]

In the case of monitoring solar storms, the Advance Composition Explorer (ACE) and Deep Space Climate Observatory (DSCOVR) satellites provide anywhere from 15 minutes to 45 minutes of warning.[27] The National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center uses the ACE and DSCOVR satellites to provide timely warning of geomagnetic storms that may affect the electric power grid, satellites, or aircraft.[28] There are no common standard operating procedures through which all the main stakeholders would be notified and able to communicate with each other, making it even more difficult to determine the best possible actions to minimize effects of solar-weather-created EMPs.

The National Aeronautics and Space Administration (NASA) operates a Heliophysics System Observatory (HSO), which is a system of satellites designed to understand the dynamics of the solar system, including detecting solar threats and sending the information back to Earth.[29] Additionally, NASA operates Solar Terrestrial Relations Observatory (STEREO) spacecraft designed to observe the structure and evolution of solar storms.[30] One of these spacecraft, STEREO-A, was directly hit by a large coronal mass ejection (CME)—a huge explosion of magnetic field and plasma from the sun's corona—that barely missed Earth in July 2012. The spacecraft itself did not sustain any damage—but it was specifically designed to operate in harsh environments outside the Earth's magnetosphere. Had Earth been hit by this particular CME, catastrophic power blackouts would have occurred.[31] STEREO-A was able to collect data on an unprecedented scale furthering scientists' understanding of solar storms. Some of these assets are operated in coordination with international partners, including France, Switzerland, the U.K., Germany, and Belgium. The U.S. Geological Survey supplements the information about effects of space weather by terrestrial monitoring variations in the Earth's geomagnetic field.[32]

The Air Force operates the Solar Observing Optical Network, a global network of ground-based solar optical observatories monitoring visible solar phenomena, such as solar flares, sun spots, and magnetic fields. The Air Force provides that information to the Department of Defense as well as to NOAA.[33] The Air Force also runs the Radio Solar Telescope Network (RSTN) that monitors solar activity with potential impact on radio transmissions.[34] Information gathered by RSTN helps mission planning and environmental situational awareness of various parts of the U.S. government.

The U.S. would have a roughly 30-minute warning after an adversary-launched ballistic missile.[35] The U.S. military operates a sophisticated sensor network designed to monitor incoming ballistic missiles in all stages of the flight. Coverage varies based on the direction in which ground-based radars are facing and their individual capabilities. Sea-based and air-based radars' coverage depends on the deployment of assets as well as their capabilities. Their advantage is that assets can move depending on the level of threat. The disadvantage is a risk that they will not be at their most optimal locations when needed due to competing missions.

Space-based assets are the least vulnerable and, in relative terms, the most capable way to monitor ballistic missile trajectories.[36] The Defense Support Program satellites use infrared sensors to identify heat from missile plumes. They are set to be replaced by the Space-Based Infrared Radar System.[37] The Space Tracking and Surveillance System-Demonstrators satellite system tracks ballistic missiles that exit and re-enter the Earth's atmosphere during the midcourse phase of flight.[38] They have the advantage of a variable waveband infrared system to maximize their detection capabilities.

The problem with both ways of detecting either HEMP or space weather is that technical means to monitor them depend on and are connected to on-the-ground infrastructure that is usually not hardened to withstand large-scale events. The warning time would therefore be extremely short, minutes to a few hours at best, and the United States may not initially have a good idea of how big the event is, which parts of the infrastructure are impacted, or how severely. The United States may have a longer warning time leading up to an adversarial HEMP attack since that information would be supplemented with information from other intelligence sources.

In the event of a non-EMP event, such as a terrorist attack or a natural disaster, the U.S. has robust emergency communication systems and protocols. These communication channels are routinely tested. For example, the Army regularly coordinates communication exercises with the amateur radio community in a communications exercise. The most recent exercise simulated an EMP event and was "designed to improve readiness, build cooperation and public awareness, and better prepare to defend the nation" by testing communications links and local emergency reporting.[39] Existing telephone and cellular networks can be useful but can often be degraded or overloaded during a disaster.

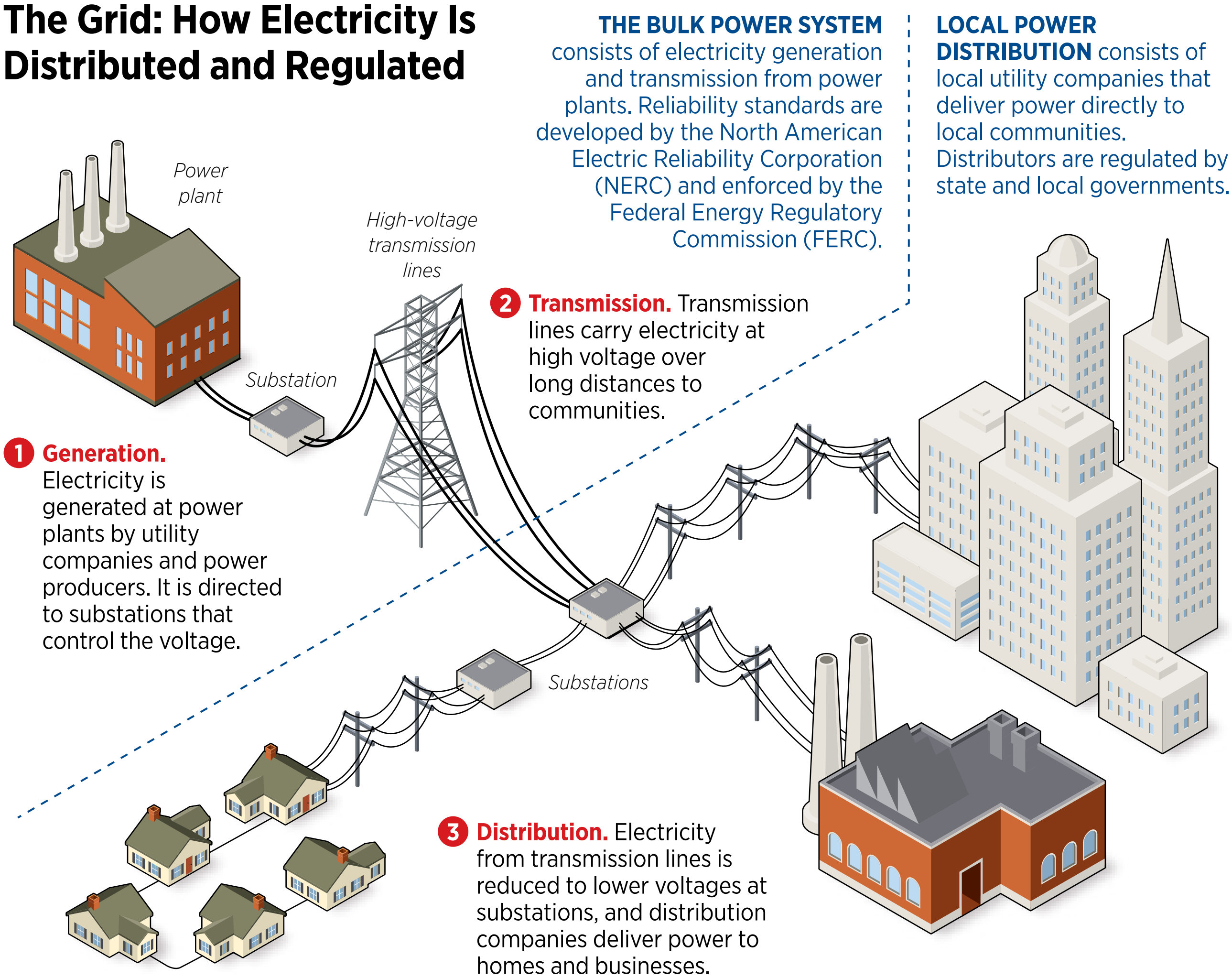
In the event of an EMP, however, many of these capabilities will be disrupted. One study found that an EMP attack on the greater Washington, DC, area could significantly damage as much as 50 percent of communication systems.[40] As such, communications between various stakeholders will be much more difficult but not impossible. Certain types of communications systems and electronics are also more resilient or protected from harm than others. Radios, for example, do not require a vast infrastructure to function, but merely require two working devices and there is some evidence that smaller, isolated electronic devices may be less likely to be impacted by an EMP. [41]

Addressing the Challenge to Protect the Electric Grid

The U.S. currently has limited protection to address consequences of EMP-like events, which presents a considerable window of opportunity for less-powerful nations to harm this country.[42] At the

FIGURE 2

The Grid: How Electricity Is Distributed and Regulated



NOTE: FERC regulation does not include Texas.
SOURCE: Heritage Foundation research.

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core of the discussion around EMPs is what is to be done to minimize the threat, and by whom. EMPs represent a high-risk, low-probability situation that, despite over a decade of discussion in Congress and study from the executive branch, fundamentally lacks leadership and understanding. There are several main areas of disagreement, including over basic information like what the expanse of impact would be, which assets need to be prioritized and protected, how much will that cost, and who among the many involved parties is responsible.

No Center of Excellence on Grid Vulnerabilities. Interested parties across the federal government and industry each possess information and experience that are relevant to the EMP discussion. Such information has not been easily shared amongst the many interested parties, hampering progress toward understanding the scope of a potential attack and adequate solutions.

Industry has valuable data and experience regarding previous threats (such as cybersecurity threats) and what possible points in the grid are vulnerable. Some utilities have begun working with academia to better understand their own risks and develop solutions.[43]

The Department of Energy (DOE) houses vast knowledge and research capabilities in the national labs, the origins of which were nuclear research and development during World War II and the Cold War. The independent government agency that shares responsibility for regulating the electricity sector, the Federal Energy Regulatory Commission (FERC), is also part of the DOE.

The Department of Defense (DOD), unlike any other party, has had direct experience over the past 50 years with EMPs. It has long since developed standards and technologies, and to a degree hardened its own critical infrastructure. Unfortunately, much of the DOD's experiences, information, and modeling capabilities are classified. Helpfully, retired members of the military have since participated in the EMP conversation through venues like Congress's Commission to Assess the Threat to the United States from EMP Attack, created in 2001 and responsible for the publishing of two major reports to Congress in 2004 and 2008. The commission was disbanded and reformed in 2015, and reorganized under the Senate Armed Services Committee through the 2018 National Defense Authorization Act (NDAA).

In addition, there are a variety of government–private sector collaborative organizations each focused on different aspects of the EMP issue. Each of these groups has different perspectives on the problem and possible solutions. For example, the DOE and Electric Power Research Institute (EPRI) began a joint project in 2015 to "establish a common framework with consistent goals and objectives that will guide both government and industry efforts to increase grid resilience to EMP threats."[44] The collaboration is problematic to some who see it as a symptom of, rather than a solution to, the problem of dispersed information maintained across the various parties, further "confus[ing] the playing field."[45]

A promising organization that entered the conversation in 2012 is the Electricity Subsector Coordinating Council (ESCC) under the auspices of the DOE and in coordination with the Department of Homeland Security (DHS). The ESCC brings together American and Canadian electric companies, the North American Energy Reliability Corporation (NERC), and grid operators with federal agencies "with the mission of coordinating efforts to prepare for, and respond to, national-level disasters or threats to critical infrastructure."[46] The ESCC has been used as a forum for classified briefings and information sharing; it has already proved a useful intersection between the electricity sector and government in navigating cybersecurity threats and coordinated physical attacks on transformers;[47] and it has formed an EMP task force.[48]

Because knowledge and experience are disbursed, there are gaps in knowledge. The DOE identified multiple areas where more research is necessary to understand the nature and scope of the EMP threat. For example, the DOE noted that impact on high-voltage systems is uncertain, a critical piece of information to determine adequate solutions. Attempts to model aspects of an EMP event also suffer from a lack of complete information and have not been validated for their ability to predict the impact of EMP attacks and the suitability of technology to protect the grid.[49]

Beyond the general recognition that a successful EMP attack would be catastrophic, there is a robust disagreement on basic information, including what the extent of an event would be, what assets need to be prioritized and protected, and how much that would cost.

Dispersed knowledge and experience have also led to an apparent lack of agreement on the probability, nature, or extent of damage caused by an EMP. For example, as part of its own action plan under the joint project with the DOE, EPRI published initial research in February 2017 to reconcile the broad spectrum of projected impacts on transformers determined by national lab and private-sector studies. These models have not been validated. EPRI concluded that the risk might not be as widespread as some believe: Of the tens of thousands of transformers across the U.S., they postulate that only between three and 14 would be at risk when exposed to E3.[50] EPRI argues this "provides the technical basis that is needed before an effective strategy to mitigate the effects of HEMP can be developed," although its estimates are considered conservative since it was unable to model the impact of E1 and E2.[51] A subsequent study examining the impact of E3 to the bulk power system was recently published using the same model parameters. EPRI concluded that an E3 event like the one modeled could cause localized and regional voltage instability and collapse.[52]

Members of the EMP Commission, among others, have found this approach unrealistic and believe it should not become the basis for what they deem would be "both illogical and imprudent" protection standards.[53] EPRI, they argue, lacks any real experience. EPRI maintains that "there is no credible testing" that proves the grid could be wiped out, making "risk-informed decisions" impossible.[54]

Given the disagreement on the extent of an EMP's effects, it is no surprise that cost projections for hardening the civilian grid range widely from $2 billion to over $1 trillion,[55] or that there is disagreement on whether specific technologies to mitigate EMP impacts would work or would instead be counterproductive to addressing other threats like cybersecurity.[56]

With so many interested parties pulling in a variety of ways and with wide-ranging opinions about the nature of the problem, it is not surprising that little has been done. Beyond the general recognition that a successful EMP attack would be catastrophic, there is a robust disagreement on basic information, including what the extent of an event would be, what assets need to be prioritized and protected, and how much that will cost. If the problem is not more clearly defined and information remains stove-piped among the different parties, coherent and useful action will remain out of reach.

Unclear Prioritization

An EMP attack is a low-probability, high-consequence prospect. This presents challenges for how to prioritize it amongst the many other risks facing grid operators and the national security threats facing the federal government. While some believe a gradual, piecemeal approach is sufficient, others believe no time should be lost to make comprehensive changes.

Because there are unclear roles of responsibility and the prospect of an EMP attack seems remote, there are some who believe the electric sector should continue to focus efforts on addressing more immediate threats like cybersecurity issues, solar weather, and aggressive regulatory changes (such as the Environmental Protection Agency's New Source Performance Standards). Addressing these threats is more important, they argue, being more frequent and near-term challenges to providing reliable power. They suggest following this course would also provide some protection against EMPs and that over time, utilities will become more secure as older systems are retired and newer, more secure systems take their place. This school of thought would propose that it is important to mitigate unique EMP impacts through collaborations like the Spare Transformer Equipment Program.[57]

Particularly those in the defense community with direct EMP experience emphasize the expanding threat of an EMP attack from rogue nations, and America's ever-increasing dependence on electricity to conduct basic functions of everyday life.

Others, particularly those in the defense community with direct EMP experience, emphasize the expanding threat of an EMP attack from rogue nations, and America's ever-increasing dependence on electricity to conduct basic functions of everyday life. A reasonable response, they argue, is to harden the most critical components of the grid first in order to minimize the possibility of cascading failures. A "triple threat" approach could also be taken in which prevention measures against geomagnetic disturbances and cyber attacks are also included.[58] Combining threats accomplishes the necessary protection in a way that reduces costs.

Lack of leadership has resulted in little or no direct action on EMPs. For example, President Barack Obama issued an executive order in 2016 for the development of principles, goals, and action items for a federal response to space weather, but it is unclear what came of this order.[59] Many, particularly those in the electricity industry, seem satisfied with mitigating measures managed through NERC and FERC. Neither entity, however, has set standards directly related to EMPs, although NERC has established standards for geomagnetic disturbances that would address some reliability issues related to an EMP attack. For example, NERC developed physical reliability standards in response to the attack of transformers outside San Jose in 2013.[60] NERC also developed standards for industry to develop mitigation plans in response to solar storms and to assess transmission vulnerabilities every five years.[61] In late 2017, EPRI also published the technical results of mitigation options against the E3 wave of an EMP event, which included "automated switching and load shedding schemes,"[62] and a second report on options for company-specific mobile control centers.[63]

Lack of Clarity About Responsibilities

At the core of the discussion and perhaps the most important point of disagreement is determining who is responsible for aspects of the effort to prevent, mitigate, respond to, and recover from an EMP event. There is no lack of ideas to address EMP, nor a shortage of resources to better understand the problem and develop solutions. What is lacking is leadership and coordination.

There are a variety of interested and responsible parties engaged on EMPs. It is regulated by NERC, a nonprofit body charged with setting industry standards to ensure grid reliability. It is also regulated through FERC, which as an independent agency under the DOE and can require NERC to develop standards. The DOD and DHS are each charged with aspects of providing for common defense. The DOE has inserted itself as a coordinating body between the public and private sectors, and has conducted valuable research on grid vulnerabilities and resilience. Congress has played a role in passing legislation, such as the Critical Infrastructure Protection Act contained within the 2017 NDAA, and through the establishment of the EMP Commission. Section 1913 of the 2017 NDAA contained a number of EMP-related tasks for the DHS to perform.[64] It is unclear whether any have been accomplished to date.

> There is no lack of ideas to address EMPs, nor a shortage of resources to better understand the problem and develop solutions. What is lacking is leadership and coordination.

An EMP attack would be an act of war. The EMP threat therefore is first and foremost a question of missile defense which, if completely successful, makes any other civil infrastructure investments redundant. Consequently, some, particularly in industry, see managing the EMP risk as a federal issue under the purview of national security organizations, while deeming reliability issues caused by geomagnetic disturbances the appropriate responsibility of the electric industry.[65]

On the other hand, the electric industry has the inherent mission to prioritize risk and protect the assets which form the core of their business. Reliability is one of the electricity sector's most competitive characteristics as "from an investment perspective, high grid reliability is a key factor in the treatment by investor of utilities (both public and private) as low-risk investments with predictable returns."[66] This would argue for EMP preparedness to be accomplished by industry through channels like NERC and FERC as a function of their mission to assure grid reliability.

In the midst of confused responsibilities, some states and utilities are working to better understand their own risks and develop solutions. For example, Duke Energy has embarked on a pilot project with Clemson University to "island" Duke's coal, nuclear, and hydropower generation plants at Lake Wylie along the North Carolina and South Carolina border, and to understand how best to bring power back online after an event. Duke has also worked with the National Guard and local government to develop contingency plans.[67] Similarly in 2013 the state of Maine passed legislation directing its public utility commission to conduct a study to determine grid vulnerabilities, recommend options, and define costs.

In summary, there is little agreement or direction on how, when, and to what extent the U.S. grid should be protected against an EMP event. Various parties have done reports, conducted research and surveys, and taken initial steps of action to address related non-EMP threats. However, each party seems convinced that the EMP threat is ultimately someone else's problem, leaving little incentive or impetus for action. Because important information and lines of communication have yet to come together, U.S. preparedness is sorely lacking.

Recommendations

The United States must ensure better preparedness of its critical infrastructures as well as its citizens to the threats of a large solar storm or an adversarial EMP attack, be it a large-scale HEMP attack or coordinated conventional attacks against one or more parts of the electric grid. An integral part of that preparedness is better understanding the risks and costs associated with an EMP attack. Congress and the federal government should therefore:

- **Advance U.S. missile defense capabilities, particularly boost-phase missile defense systems.** Since one of the most effective ways to inflict massive damage on an advance nation is to deliver a nuclear warhead on a ballistic missile and detonate it at a high altitude, shooting down that missile before it fulfills its objective is the best way to prevent the devastating consequences. Robust defense capabilities are the best defense against a successful EMP attack. The United States must invest more resources into boost-phase and space-based ballistic missile defense technology research and development.

- **Fund nuclear-warhead and design development efforts to increase U.S. understanding of other nations' nuclear weapon programs.** The U.S. needs to understand the technological options available to other countries that have no self-imposed restraints regarding the development of new nuclear weapons, including nuclear weapons specifically designed to enhance their EMP effects.

- **Define national security and industry roles.** Ultimately, the lack of cohesive leadership must be addressed, either by Congress or the President. Roles must be defined so that responsibilities are understood by the many parties involved. These responsibilities include the tasks for missile defense; protection of critical national infrastructure; consideration of standards, protection, and mitigation; and response to an EMP event.

  It is appropriately the role of the federal government to prevent an EMP strike through missile defense. The federal government must also effectively plan for and manage national disaster response. Critical national defense assets that rely on the grid should be hardened appropriately by the federal government at the expense of taxpayers.

  The electricity sector is best suited to understand and mitigate vulnerabilities to its infrastructure and to harden assets, just as other industries essential to the well-being of Americans—such as finance, agriculture, water infrastructure, and the Interstate system—must manage their own critical infrastructure. Further, the industry typically best understands what and where critical infrastructure is and where the vulnerabilities are.[68] Industry also has the incentive to innovate, determine technology solutions, and prioritize the most critical infrastructure for surviving and recovering from an EMP event. Key to unleashing the power of industry to tackle this issue is a shared understanding of the protection levels necessary. Further, utilities should not be prohibited from recovering costs for EMP investments.

  The problem at hand is not simply about securing the grid for just today, but also having a governance structure in place to ensure energy transmission is reliable and sustainable into the future, accommodating changes in technology, consumer needs, threats, and national security concerns. For that, the first and most critical task is to align authority and responsibility in the public and private sector for responding to the dangers of an EMP.

- **Increase information sharing among industry and the government.** Industry cannot act effectively if it lacks access to critical data and experience in the government. The federal government must not frustrate industry efforts to address grid-reliability threats. Absolutely critical to industry preparedness on EMPs is access to complete and reliable information. The federal government (principally the DOD and DOE) must find ways to increase the electricity sector's access to models, data, and relevant national lab assets. This should be done by strategically granting security clearances to selective entities in the electricity sector (such as NERC) or by scrubbing models of sensitive information for use by the industry. While models are themselves fallible and should not be the sole basis for policy decisions, they are an important data point in making decisions.

  Advanced modeling and simulation capabilities would improve industry's understanding of EMP-like environments and its impact on new materials. It would also help industry develop innovative solutions to harden its critical infrastructure. Since the United States is no longer conducting nuclear-weapon yield-producing experiments during which it could expose materials and systems to these environments, modeling and simulations are increasingly important for this type of work. For example, a national lab could endeavor to conduct threat-level tests on a transformer. While the DOE productively identified areas where more research is needed, this must not become an interminable national lab project.

- **Develop clear lines of communication.** The federal government through DHS must develop clear lines of communication with the electricity sector. There are no common standard operating procedures through which all the main stakeholders would be notified and able to communicate with each other, making it even more difficult to come up with the best possible actions to minimize effects of EMP-like events. A chain of command and clear understanding of from whom and from where information and directions will come is essential to crisis management and restoration of the grid.

- **Direct FERC to consider developing proposed standards.** FERC and NERC should consider a broad framework for standards for EMP mitigation in the electricity sector. NERC set physical-reliability standards and requirements approved by FERC to develop mitigation plans in response to solar storms that would address some reliability issues related to an EMP attack. EPRI's December 2017 analysis, while not focusing on mitigation strategies, recommended that "hardening of critical electronic systems within transmission control centers, black-start units, and substations included in cranking paths should be considered." FERC or NERC, or both, should provide advisory guidance on system survivability for utilities and distribution companies to consider and inform their own EMP response. This will require filling significant gaps in modeling capabilities, such as the ones EPRI noted in its most recent study on the effects of EMP.[69]

  In a desire to address the challenge of hardening the grid against an EMP attack or solar weather, Congress and federal agencies should resist the temptation to mandate the use of specific technologies, and instead describe the technical challenge to be mitigated. There is yet disagreement among experts over which technologies would adequately protect the grid. There is danger in prescribing certain solutions, only to find they are insufficient or quickly obsolete. Overly prescriptive regulations will quickly become out of date and fail to address threats. In a world of ever-evolving technology and risk, industry needs to be flexible and innovative in order to respond.

- **Conduct the next Grid Security Exercise (GridEx) on EMPs.** Since 2011, NERC's GridEx brings together utilities, government, financial firms, and telecommunications and infrastructure companies (such as for gas and water) to simulate a crisis response to a grid attack every other year. The last exercise was in November 2017 and involved more than 6,500 participants from industry and government organizations in the U.S., Canada, and Mexico.[70] The next exercise in 2019 should simulate an EMP event in order to test communication channels between the related parties and reveal vulnerabilities.

- **Support the work of the EMP Commission to assess the threat to the U.S. from an electromagnetic pulse attack.** Congress should continue to fund and engage in the EMP discussion through the commission. The commission is required to review, assess, and advise Congress on the likelihood of an EMP attack and geomagnetic disturbances as well as the military's and private sector's ability to respond.[71] The next report is due on April 1, 2019. Committee hearings should be scheduled in the interim and after the release of the report.

Taking these steps will put the United States on a path to mitigating the risks of one of the most devastating catastrophes it could experience. The United States does not have the luxury of continuing to wait.

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