STATEMENT of

MR. SCOTT A. McBRIDE
INFRASTRUCTURE SECURITY MANAGER
NATIONAL & HOMELAND SECURITY
IDAHO NATIONAL LABORATORY

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Mr. Scott A. McBride, Infrastructure Security Manager, National & Homeland Security, Idaho National Laboratory

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Chairman Johnson, Ranking Member McCaskill, and distinguished members of the committee, thank you for holding this hearing and inviting Idaho National Laboratory's testimony on the potential threat of Geomagnetic Disturbance (GMD) and Electromagnetic Pulse (EMP) to the U.S. power grid. I greatly appreciate the opportunity to address this committee and thank the members for your interest in discussions of the risks these threats represent, and your dedication to develop legislative decisions that will assure that our national energy supply is reliable, resilient and protected.

I request that my written testimony be made part of the record.

I am the Infrastructure Security Manager for National and Homeland Security at Idaho National Laboratory, also known as INL. INL is one of 17 the U.S. Department of Energy (DOE) national laboratories and is the nation's lead nuclear energy laboratory. INL's mission is to conduct research, development and demonstration of solutions that will assure the advancement of nuclear energy, clean energy, and critical infrastructure protection technologies – all with the objectives of assuring the energy, economic, and national security of the U.S. In my role at INL, I have the pleasure and responsibility to lead, influence, and execute research, development, testing, demonstration, and deployment of technology as it applies to securing our nation's critical infrastructure, with an emphasis on the energy sector. My background includes a balance of experiences with development and operations of grid infrastructure for public electric utilities, and power engineering research and testing of security technologies on a unique, full-scale test grid at the INL site. I am one of the principle investigators and test designers for the nation's seminal research of the scientific principles and impacts of geomagnetic disturbance ground induced currents on electrical substations and downstream electrical equipment.

The U.S. electric power grid incorporates new digital technology with legacy infrastructure that can be decades old. This combination results in a grid that is vulnerable to GMD and EMP events, whether the EMP source is from nuclear or non-nuclear sources. The vulnerability of the grid to EMP is due to potential damage to the individual components and the larger, massively interconnected electric generation, transmission & distribution systems, and the breadth of uncertainties of the effects caused by the three waveforms identified by their different magnitude, durations, and interdependencies during an EMP event. E1 and E2 waveforms can couple with long power lines, transmitting thousands of amperes of current to connected systems tens of miles away. This can disable electrical and electronic systems through permanent thermal damage to components or upset to digital electronics. The E3 waveform's associated harmonics and impedance mismatches can damage equipment, including large substation transformers, uninterruptible power supplies, long-haul communications, and possibly generators. GMD causes similar effects to E3. Currently, there is a fairly robust understanding of the scientific principles of E1 and E2 that enable us to predict effects and design protections. Initial experiments have been completed and models are beginning to emerge that assist us in better understanding and characterizing effects and impacts from E3. Research and testing of the interdependent effects of the combined three waveforms on our grid's individual components and interconnected infrastructure is an uncharacterized field of study that needs further exploration and discovery.

At present, the North American Electric Reliability Corporation's (NERC's) Emergency Preparedness and Operations (EOP-10-1) and Transmission Planning (TPL-007) are standards issued that deal exclusively with protection of the electric power grid from a GMD event - not the full range of threats posed by an EMP event and its concurrent waveforms.. My current understanding of the science, and the results of my experiments and tests of developmental protective technologies lead me to a position that – relying on the current industry electric grid protections, based on standards for lightning and GMD protections, leave the grid inadequately protected against the effects of EMP. While existing grid standards may partially alleviate E2 and E3 effects, the grid remains unprotected against the high amplitude, fast rise time characteristics of an E1 pulse.

The Nation's High Voltage (HV) and Extra High Voltage (EHV) power grid contains a few thousand large power transformers which are potentially vulnerable to the threat of GMD events. These transformers are very expensive to build and typically have long lead times of 18 to 24 months. EHV transformers are not currently manufactured in the U.S., and industry maintains very few critical spares. GMD events drive HV and EHV transformers into heavy half-cycle saturation that then induces voltage harmonics in power systems which can cause damage to power system components and loads. The induction of quasi-Direct Current (DC) in power systems can also be caused by the "Blast" and "Heave" portions of the EMP E3 from a nuclear device detonated above 80 kilometers altitude.

A mature, tested and validated technology has been developed and represents one potential solution to protect HV and EHV power transformers from the threat of both GMD's and EMP's. The EMP hardened transformer Neutral Blocking Device (NBD) is designed to provide automatic protection for HV and EHV transformers against GMD and EMP events - when GMD or EMP induced currents in a transformer are detected. The device provides a metallic path to solidly ground the transformer during normal operation and an Alternating Current (AC) effective grounding path for the transformer for only short periods (i.e. a few minutes to hours) when a solar disturbance (GMD) or an EMP event is impacting the earth. Power grid modeling and studies have shown that neutral blocking in a power grid provides significant reductions in reactive power (VAR) consumption and Ground Induced Current (GIC) harmonics as well as protection against protective relay mis-operations. Additionally, NBD's enhance the protection of Generator Step-Up (GSU) transformers at hydro-generation facilities which can provide important black-start resources for a power grid.

Even with the NBD's, the "Blast" and "Heave" portions of the EMP E3 pose a direct threat to the large power transformers that our country depends on and is not yet equipped to replace.

Hence, it can be implied that there must be a priority to protect the most critical large power transformers in place – my preliminary estimates are that this would cost less than $4 billion if we made it a priority to install NBD's at our most critical EHV substations. This is a small fraction of the value of replacement units, but more importantly is negligible compared to the loss of civilian life and long term recovery costs to the economy should they fail during a GMD or EMP event.

A basis for considering this approach is that in February 2015 the American Transmission Company (ATC) installed a NBD manufactured by ABB marketed as SolidGround™ in one of their substations in Wisconsin to improve power grid stability and protect against GMD's. This unit has operated and blocked GIC's as designed without issues during six (6) low-level solar storms (GMD's). SolidGround™ operates automatically and provides several monitoring signals to the Supervisory Control and Data Acquisition (SCADA) system through the substation control house. The experience to date has shown no signs of unintended consequences introduced into protective relays or other power system components. The device blocks GIC, prevents harmonic generation, reduces reactive (VAR) power demand and helps prevent voltage collapse during GMD events. Since this unit was placed in operation it operated over 30 times.

Beyond utilizing NBD's, I also advocate that we improve our capability to fully understand the extent of the vulnerability and reduce or eliminate consequences of GMD and EMP events. The Department of Energy recently tasked the national laboratories to develop a report that updates the extent of our current scientific understanding of the effects of EMP on the electric power grid. Pending this report's publication, significant progress for GMD and EMP grid protection can be made by pursuing three concurrent paths:

1) Define the E1-E2-E3 composite threat environment waveform, including coupled currents and voltages for transmission and distribution lines, in support of developing an informed 'all hazards' protective strategy;
2) Conduct a series of scaled experiments and tests on a variety of representative grid components and restoration assets to close the knowledge gap that affects our ability to understand, predict, and measure the impacts of GMD and EMP events on unprotected systems, as well as the effectiveness of all protective measure options.
3) Identify the priority infrastructure that can lead to a most effective and impactful set of actions that will harden the grid and enable reliable blackstart processes.

This set of targeted actions, with appropriate and coordinated government and private partnerships, can lead to a set of effective hardness and protective measures for GMD and EMP events that add quantifiable, cost-effective resiliency to the grid.

Defining the E1-E2-E3 composite threat environment waveform is needed to de-conflict integrated protection methods and to enable the development of future standards and design requirements for interoperable, all-hazard protection of the grid's digital components and interconnected systems. Research that can advance our understanding of the composite waveform will include determining whether our current understanding of the principles for modeling E1, E2, and E3 are also applicable for HEMP, GMD, and Radio Frequency Weapons

(RFW) environments. Additional research will be needed to further characterize differences well enough that models can be developed for simulating effects across all likely combinations of electromagnetic radiation environments. The results of this research will have most benefit if they are concurrently shared in the development of validation experiments, standards, and regulatory guidance.

Experimentation of effects from waveforms and recovery processes on utility-owned grid assets are impractical, especially if experimentation is needed to validate component and system performance during damaging or full-destructive test events. Hence, INL, along with some of our peer national laboratories, utilized DOE and other government investments in the design and construction of power grid test beds that can perform and recover from the needed experiments. Current gaps in knowledge suggest that the experiments of highest priority need to explore, and are not limited to: a) the propagating electromagnetic radiation effects to assets directly connected to long power lines, antennas, and communication/data lines; b) effectiveness of shielding, including non-conductive critical communication fiber, well-grounded equipment racks, and shielded buildings; c) effectiveness of developmental technologies for transient voltage surge suppression; and d) exercising high-voltage system operations and processes for critical system spares replacement, restoration procedures, and recovery processes. The results of this testing will have the most benefit if they are concurrently shared in the development of priorities for more research that can be utilized to enhance predictive models, and serve as the technical basis for standards, and regulatory guidance.

In balancing the rollout of digital technologies for assuring the cost-effective availability and reliability of the grid, with the sense of urgency to protect the electric grid from the effects of electromagnetic radiation, there is an opportunity to gain a significant level of protection by first focusing on deploying protective measures on the most critical assets for normal grid operation and recovery. Establishing a public-private partnerships allows for information sharing and threat analyses to assist asset owners in identification of the highest priority grid components and systems for protection to maintain electricity delivery and optimize recovery and restoration of services. With this information, a set of government validated credible threats can be evaluated with the research models to predict the effectiveness of protective technologies, design standards, and recovery processes. The integration of this information, including the holistic view of asset owners' vast knowledge and experience with their systems' designs, processes, operational data, and experience, can guide a prioritized series of investments in the installation and implementation of protections.

Even though the electric power grid is vulnerable, protection of the grid against the effects of GMD and EMP, though challenging, is possible. While it may not be plausible to protect all assets, careful prioritization of the implementation of protections can enable critical portions of the grid to survive, or at least be rapidly restored. Cooperation between government and industry will benefit the development of an optimal strategy for completion of the highest priority research and testing, legislative direction, regulatory guidance, engineering standards, and infrastructure modifications. Government and industry can accelerate full implementation of a protection strategy through a common technical understanding of the threat characteristics and system effects.

I thank the Committee's members for the opportunity to share my knowledge and leadership thoughts on the vulnerabilities and solutions for protection of the national power grid. I deeply appreciate the contributions of my fellow panel members' and your strong support for today's discussions. Today's hearing is a highly positive step towards enhancing our mutual understanding of the technical challenges of GMD and EMP threats to the grid, assuring that there is credible science and engineering basis supporting future legislative actions. You have my commitment to continue to obtain and share scientific knowledge as it gained and utilize that knowledge to advocate and pursue the development and testing of technical innovations that will resolve the threats of GMD and EMP.