FERC Testimony
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The Office of Electricity within the U.S. Department of Energy and the U.S. Department of Homeland Security jointly initiated a research project in mid-2016 at Los Alamos National Laboratory (LANL) intended to look broadly at the impacts of electromagnetic pulses (EMPs) generated by the detonation of stockpile nuclear devices on the transmission and generation aspects of the U.S. bulk electrical system (BES). The ultimate intent of this research was to build the knowledge and understanding of such nuclear electromagnetic pulses (NEMPs) and their interaction with the BES that would be necessary to develop a scientific workflow whereby the resilience of the U.S. BES could be evaluated.

Importantly, at the outset, constraints were established for the scientific workflow; LANL would only consider an NEMP insult as an event of concern if it (1) caused long-term damage to the BES requiring in excess of three days to repair, and (2) impacted a significant portion of the BES resulting in excess of $4 billion dollars a day in lost economic activity to the United States. Previous studies on the impact of NEMP generally attempt to consider a very fine grain detail in terms of impact to the BES (e.g., whether an NEMP would cause large-scale blackout). By constraining the study at the outset, the problem becomes far more focused and vastly simplified while remaining relevant; we are only interested in damage to the electrical system that would result in a long-term inability to supply power to consumers over a large area. Given these constraints to the study, issues like cascading failure and sub-cycle dynamic processes are not considered, and the impact can be evaluated by looking at the steady pre- and post-insult states.

In the first two phases of this work, which LANL has only recently completed, NEMP insults were parameterized, a list of benchmark events covering this parameterization were generated, and LANL determined which of those benchmark insults were most likely to rise to the threshold of the study constraints.

In the LANL-developed parameterization, NEMP insults could be broken into two distinct categories, each with their own parameterization. The first insult category considered was endo-atmospheric insults, which are nuclear bursts that occur for altitudes less than $20 \rightarrow 40km$. Endo-atmospheric insults can be further broken into air bursts that occur above $1 \rightarrow 2km$ and surface bursts. Although air bursts are perfectly capable of creating an EMP, the pulse magnitude is sufficiently small so it would not rise to the threshold constraints of the study. Thus, for endo-atmospheric insults, only surface bursts were considered.

LANL parameterized endo-atmospheric insults by the device yield and ground range from the surface burst. The EMP hazard field generated by the surface burst occurs entirely within the so-called “source region”. Source-region EMP is caused by the release of gamma rays very early in the nuclear device’s detonation (prompt gammas) and the interaction of those gamma rays with the surrounding atmosphere through Compton scattering. Source-region EMP is experienced by an observer on the ground before any thermal or pressure effects are experienced. Due to the density of the atmosphere, the source region is constrained to a kilometer or so away from ground zero. Within this source region, a very intense electromagnetic field occurs. The field can couple into lines and systems and destroy them. Moreover, the conductivity of the air itself is altered within the source region, which would have deleterious impacts on any devices that utilize air resistance for insulation. For relatively weak nuclear devices, e.g., $10\ kTon$ bursts, it is possible that the source region will extend beyond the damage region created by the burst. As the device strength increases, however, the source region is subsumed by the region of physical damage.

Electromagnetic effects can extend farther than the source region; should the electromagnetic fields in the source region couple to a conductive line, it would launch a current pulse down the line that could travel well beyond the source region/physical damage area. Natural resistance within transmission lines, however, would attenuate these conducted pulses within $10\ km$ or so. Thus, for any surface burst, the maximum range of the source region, physical damage region, and conducted pulse region is relatively short, $10km$ or so; it is not expected to result in total consequences from loss of electrical power delivery capability that exceed the thresholds of concern for this study. In other words: The primary concern for civilian infrastructure for endo-atmospheric surface bursts is the resultant crater in the ground, not the brief pulse of electromagnetic energy that occurs just before the crater's creation.

LANL considered a second category of NEMP insult—exo-atmospheric bursts that occur at altitudes in excess of $20 \rightarrow 40km$. EMPs created by exo-atmospheric bursts are frequently referred to as high-altitude electromagnetic pulses, or HEMP. The EMP produced on the ground from an exo-atmospheric burst is generally experienced by observers within line of sight of the nuclear burst (thus, a burst at $400km$ altitude above the central United States would cover much of the continental United States (CONUS) with an EMP) and can contain up to three distinct pulses, each created by different physical process. These are referred to as "E1", "E2" and "E3". "E1" refers to a high-amplitude pulse of less than a microsecond duration that results from the interaction of prompt gamma rays created by the nuclear burst with the Earth's upper atmosphere. "E2" is a lower amplitude pulse of around a millisecond duration, also caused by gamma ray interaction, although these gamma rays are either by-products of the initial prompt gamma scattering or created from neutron decay. Due to the time scales of E2 being comparable to lightning strikes, to which the BES is already resilient, the E2 pulse is generally ignored.[1] The "E3" pulse is broken into two distinct pulses: "E3 blast" and "E3 heave". Both denote magneto-hydrodynamic effects caused by the nuclear burst that distort the Earth's magnetic field, resulting in electric fields on the ground similar to those created by solar storms. The "E3 blast" is short, less than 10 seconds, while the "E3 heave" can be a few minutes long.

LANL parameterized exo-atmospheric bursts by device yield and burst altitude (or height of burst). This parameterization follows from an understanding of the physical processes that

[1] We note that this simplification needs to be further researched.

generate each hazard field. Briefly, the E1 hazard is ever-present for any nuclear device detonated above $20 \leftrightarrow 40km$. All nuclear devices, whether a fission or thermonuclear device, release gamma radiation immediately after the burst. There is no hard and fast rule that dictates how much of the energy yield of the burst goes into prompt gamma radiation, although 0.3% is an oft-quoted figure from Glasstone.[2] Thus, one limitation of our parameterization is that we used device yield as a linear proxy for prompt gamma yield, an assumption that is well known to be inaccurate. There is no way around this simplification, however, without delving into classified, weapons-specific details.

Both E3 hazards (E3 blast and E3 heave) occur only for detonations energetic enough to significantly distort the earth's magnetic field. The E3 blast dominates at high altitude. It arises from the interaction of Earth's magnetic field with the expanding plasma ball created by the nuclear burst. At higher altitudes there is less air friction to slow the plasma ball expansion. The E3 heave arises from a rising body of air ionized by the gamma radiation from the burst. E3 heave dominates at lower altitude where the burst can ionize and heat the layers of air below the burst more efficiently.

The LANL parameterization of exo-atmospheric NEMP insults for single-stage stockpile devices is summarized as follows: All such devices create an E1 pulse. The magnitude of the E1 pulse weakly depends on device yield, but falls off rapidly with increasing altitude. Low yield nuclear devices create E1 pulse, but do not have enough energy to create significant E3. As the yield of the device increases to around $100\ kTon$, significant E3 pulse begins to occur. For higher yield devices at lower altitude, E1 and E3 heave are the primary pulses that occur, while for higher yield device at higher altitude E1 and E3 blast are the primary pulses that occur.

Using this parameterization, LANL identified five benchmark exo-atmospheric bursts (high-altitude nuclear events). These benchmark events do not correspond to any particular nuclear weapon or weapon delivery capability. Rather, they have been chosen to clearly delineate regions of interest where certain effects (e.g., E3 heave and E3 burst) are dominant. Based on height of burst and yield, these events cover the space of nuclear EMP hazards by emphasizing the individual components of E1, E3 blast and E3 heave; and by creating strong combinations of the E1 plus E3 blast and E1 plus E3 heave.

LANL qualitatively analyzed the five benchmark high-altitude nuclear events for the dominant hazards and the expected impact to the BES. We note that this qualitative analysis accounts for the approximate spatial distributions of E1, E3 blast, and E3 heave. In particular, the maximum hazard from E3 blast is rather remote from the ground point below the detonation; E1 is generally the largest. This spatial separation will presumably lessen the interaction between E1 and E3 blast for those events where significant E3 blast is generated.

<u>Benchmark Event #1</u>: A 25kTon fission weapon detonated at 100 km does not have sufficient energy to create either a significant plasma ball or to heat the upper atmosphere and,

[2] Glasstone, S. (1964). The effects of nuclear weapons.

therefore, does not produce significant E3 blast or E3 heave. The relatively low height of burst focuses the gammas from the burst creating a substantial E1 over a smaller region, e.g., the size of several U.S. states. With E1 as the only substantial hazard, the consequences for the power system are expected to be the loss of some protection equipment (relays) and communications over a state-sized area. The consequences of Event #1 are dominated by other benchmark events.

<u>Benchmark Event #2</u>: A 25kTon fission weapon detonated at 400 km does not have sufficient energy to create either a significant plasma ball or to heat the upper atmosphere and, therefore, does not produce significant E3 blast or E3 heave. The relatively larger height of burst disperses the gammas over the CONUS-scale, creating a relatively low E1 over a much larger region as compared to Event #1. E1 is still the only substantial hazard. The lower amplitude and broader coverage of the E1 hazard will create the same type of damage as in Event #1, but the impacts are expected to be patchy and dispersed over a larger area. The consequences of event #2 are dominated by other benchmark events.

<u>Benchmark Event #3</u>: A 125kTon fusion weapon detonated at 100 km does not have sufficient energy to overcome atmospheric drag to create a large plasma ball, therefore, little E3 blast is generated. There is sufficient energy to heat the upper atmosphere and substantial E3 heave is produced. The relatively low altitude of detonation will again focus the gammas from the fission primary burst, creating a substantial E1 over a smaller region, e.g., the size of several states. The E1 and E3 heave are both relatively high amplitude and generally centered around the point underneath the burst so their areas of high amplitude overlap. Event #3 produces a potentially consequential combination of E1 and E3 heave that dominates Events #1 and #2 in every way.

<u>Benchmark Event #4</u>: A 125kTon fusion weapon detonated at 400 km is at a sufficient height of burst to avoid atmospheric drag and create a large plasma ball and significant E3 blast. The large height of burst lowers the efficiency of atmospheric heating and reduces E3 heave relative to Event #3. The relatively large height of burst disperses the gammas over the CONUS scale, creating a relatively low E1 over this much larger region when compared to Event #3. In Event #4, we expect a similar widespread and patchy impact from E1 as in Event #1. In contrast to Event #3, there will be more E3 blast, however, the spatial offset of E3 blast and E1 lowers the anticipated magnitude of E3 blast relative to the maximum E3 blast field. The E3 blast field in Event #4 is much shorter-lived than the E3 heave expected in Event #3. Taking all of these consideration into account, we expect that the consequences of Event #4 will be dominated by the consequences of Event #3.

<u>Benchmark Event #5</u>: A 1,000kTon fusion weapon detonated at a moderate 200 km height of burst is sufficiently energetic both to overcome atmospheric drag and to create atmospheric heating and simultaneously generate substantial E3 blast and E3 heave. The E3 heave is expected to be the highest of all of the events. The E3 blast within the region of substantial E1 is also expected to be the highest, except for possibly Event #4, which is detonated at a higher altitude. The moderate height of burst for Event #5 disperses the gammas over a region of size

between a few states and all of CONUS—an extent similar to an interconnection of the BES. In terms of spatial extent, the E1 field for Event #5 will fall between Events #1 and #3, but with possibly a lower peak E1 field magnitude. The spatial extent and magnitude of the hazards for Event #5 dominate all of the other events, expect for Event #3, which creates a higher magnitude, although more spatially compact, E1 field.