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Source Region Electromagnetic Pulse Planning Considerations

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ABSTRACT

The study focuses on source region electromagnetic pulse (EMP), and provides considerations regarding the impact from an EMP due to a low-altitude nuclear denotation.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
E1, & E2	EMP waveform rise times (fast, intermediate)
EMP	Electromagnetic Pulse
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
SREMP	Source Region EMP

1. INTRODUCTION

No matter where they occur, nuclear detonations are accompanied by an electromagnetic pulse (EMP). While the EMP is certain, the intensity and duration of the pulse can differ, impacted by the burst location (latitude, longitude, and height-of-burst) and the specifics of the device (design and yield).

The mechanism of EMP formation changes when explosions occur at different altitudes. In high-altitude detonations (above 30km), the EMP is generated over a distributed area of atmosphere. In low-altitude detonations (no more than a few km), the EMP is generated very near to the detonation and is referred to as Source Region EMP (SREMP). SREMP is the focus this analysis.

SREMP is the largest electric field produced in a near-surface burst, with a strength of 10s of kV/m, but the field reduces quickly with increasing distance from the source. SREMP can affect equipment either through the direct illumination of equipment by the electric field or by conduction of an electric signal through exposed conductors (e.g., transmission lines).

A nuclear detonation at or near the ground produces its EMP through a variety of physical mechanisms. The SREMP and ground asymmetry EMP mechanisms considered in this work produce an early-time component (E1) that rapidly rises (associated with prompt gamma radiation displacing electrons) to a very high amplitude (field strengths in the many 10s of kV/m) and lasts a fraction of a µs. Followed by a longer-time component (E2) from the scattered gammas and neutrons that has only a moderately high amplitude (field strengths up to about 10 kV/m) but lasts many µs. Both components have the potential to damage electrical and electronic equipment. The E1 component couples well to smaller devices, structures, and lines. The E2 component couples well to long lines, such as electric power transmission and distribution lines.

1.1. Background

This work was originally done in support of the 2021 update of the 2010 Planning Guidance for Response to a Nuclear Detonation. The Chemical, Biological, Radiological and Nuclear Office at the Federal Emergency Management Agency was tasked with developing a revised document that will provide key information for federal, state, and local response planners. This update will address the diverse nuclear detonation threats currently faced by the U.S., and detail steps that can be taken to reduce casualties and other national impacts should a nuclear detonation occur. To support this activity, EMP environments and coupling calculations were performed for the following heights of burst and yields:

- Ground detonations using 0.1 kt, 1 kt, 10 kt, 100 kt yields
- 1,000 ft. air detonation using 100 kt yield
- 5,000 ft. air detonation using 100 kt yield
- 10,000 ft. air detonation using 1,000 kt (1 Mt) yield

The details and key assumptions of these calculations are discussed in the following refence (Pennington, et al., Nov 2020). Key findings are provided in this document.

2. PLANNING CONSIDERATIONS

The analysis done here only considers SREMP impacts. It is noted the mechanism of EMP formation is qualitatively different in explosions at or near the surface than at high altitudes. There are two major disruptive effects from the SREMP for the scenarios considered.

(1) **Radiative effects in which the electromagnetic fields produced by the detonation travel through the air and can impact electronic equipment through induced voltage on its internal wires and conductors.** This is also referred to as EM illumination and field strengths are typically measured in terms of kV/m. The damage threshold associated with impact on commercial equipment was chosen at 20 kV/m, and the threshold for temporary upsets at 4 kV/m.

(2) **Coupled line charges that create large voltage/current surges in long running power lines and other conductors that pass near the detonation point.** The concern with coupled line SREMP is that it can propagate the EMP significant distances from the detonation point, with the possibility of causing damage to the electrical system and potentially regional impacts. Impacts considered in this study include damage at the wall socket with a 1 Joule threshold, and damage to transformer and relay components at the substation.

A summary of range to these effects, along with the indication of blast damage at 5 psi, is shown Table 2-1 and Figure 2-1.

Table 2-1. Summary of Effects

Effect	0.1 kt at Surface	1 kt at Surface	10 kt at Surface	100 kt at Surface	100 kt at 1,000 ft	100 kt at 5,000 ft	1 Mt at 10,000 ft
5 psi: Blast overpressure likely damaging buildings and infrastructure.[1]	0.1 mi 0.2 km	0.3 mi 0.5 km	0.6 mi 1.0 km	1.3 mi 2.2 km	1.4 km 2.3 km	1.9 mi 3.0 km	4.1 mi 6.6 km
20 kV/m: EM illumination and coupling into the grid can cause permanent failure to *some* electronics.	0.2 mi 0.3 km	0.3 mi 0.5 km	0.5 mi 0.9 km	0.8 mi 1.3 km	0.8 mi 1.3 km	Does not reach 20 kV/m on ground	Does not reach 20 kV/m on ground
High voltage transmission line propagation may cause electric grid substation burnout/damage[2].	Damage threshold not met	Damage threshold not met	Damage threshold not met	12.4 mi 20 km	12.4 mi 20 km	6.2 mi 10 km	6.2 mi 10 km

[1] Calculated using Specialized Hazard Assessment Response Capability (SHARC) tool build data 8/10/2020.

[2] This range is very location specific due to the details of the electric grid design. For example, in our test cases of three different cities, the distance to control relay expected damage ranged from about 2 miles to 22 miles depending on the details of the grid design. The values in the table are estimates of typical distances that will include most of the impacts to substation equipment. Power outages are likely to occur outside of this range.

Effect	0.1 kt at Surface	1 kt at Surface	10 kt at Surface	100 kt at Surface	100 kt at 1,000 ft	100 kt at 5,000 ft	1 Mt at 10,000 ft
1 Joule: Line induced surge can potentially permanently damage *unprotected* equipment plugged into the wall-socket due to coupling into the grid [3].	6.2 mi 10 km	9.3 mi 15 km	9.3 mi 15 km	9.3 mi 15 km	6.2 mi 10 km	6.2 mi 10 km	3.1 mi 5 km
4 kV/m: EM illumination can temporarily upset some commercial electronics including computers and networks.	0.6 mi 1.0 km	1.0 mi 1.6 km	1.4 mi 2.2 km	1.9 mi 3.0 km	1.9 mi 3.0 km	1.1 mi 1.8 km	1.0 mi 1.7 km
Tripping of circuit breakers (~4kA) [3].	3.1 mi 5 km	6.2 mi 10 km	6.2 mi 10 km	62.1 mi 100 km	62.1 mi 100 km	62.1 mi 100 km	62.1 mi 100 km

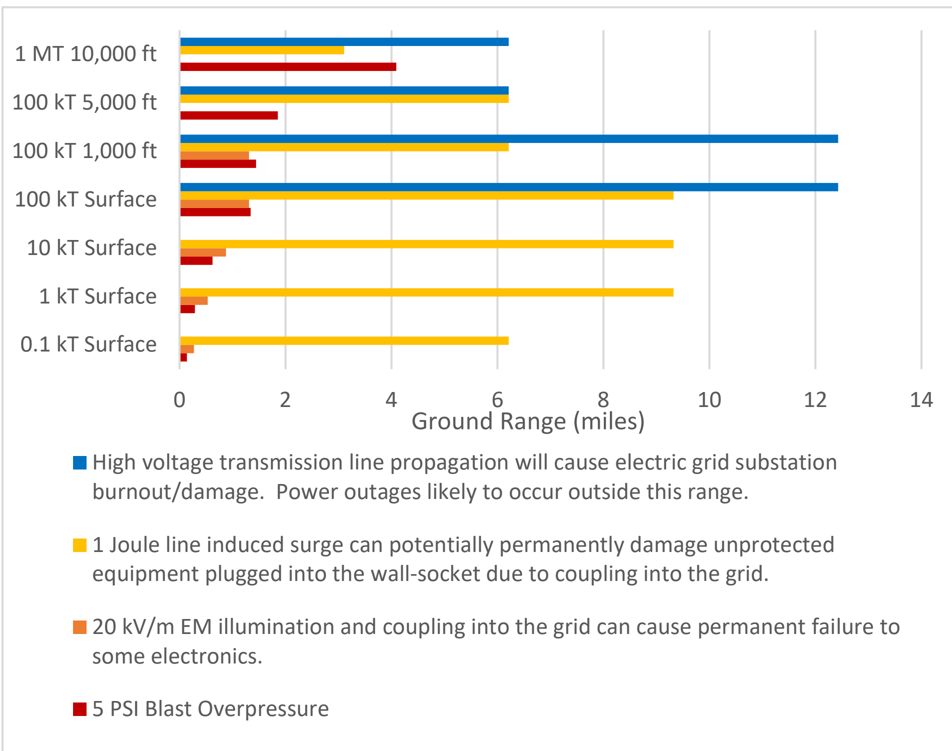

Figure 2-1. Range to Damaging Effect Miles

[3] This range is also very location specific due to the details of the electric grid design. The values in the table are estimates of typical distances. Power outages are likely to occur outside of this range.

2.1. Expected Power Outages

The conducted EMP damage is dependent on the power grid configuration and the distance from the detonation. For example, a power system with few branching connections can conduct an electrical pulse for several tens of miles, while a power system with more branching can only carry a pulse a few miles. Short-term (hours to days) power outages are dependent on topology of the power grid and may be beyond city limits.

Actual impacts will depend on the specific layout of the electric grid, an in the notional example shown in Figure 2-2. In an analysis of three different U.S. cities, expected transformer damage (leading to long outages) ranged from 0.5 miles to 3 miles, shorter-term damage caused by relay burnout (replaceable substation parts) ranged from about 2 miles to 22 miles. Similarly, expected substation circuit breaker trips ranged from about 3 miles to 60 miles.

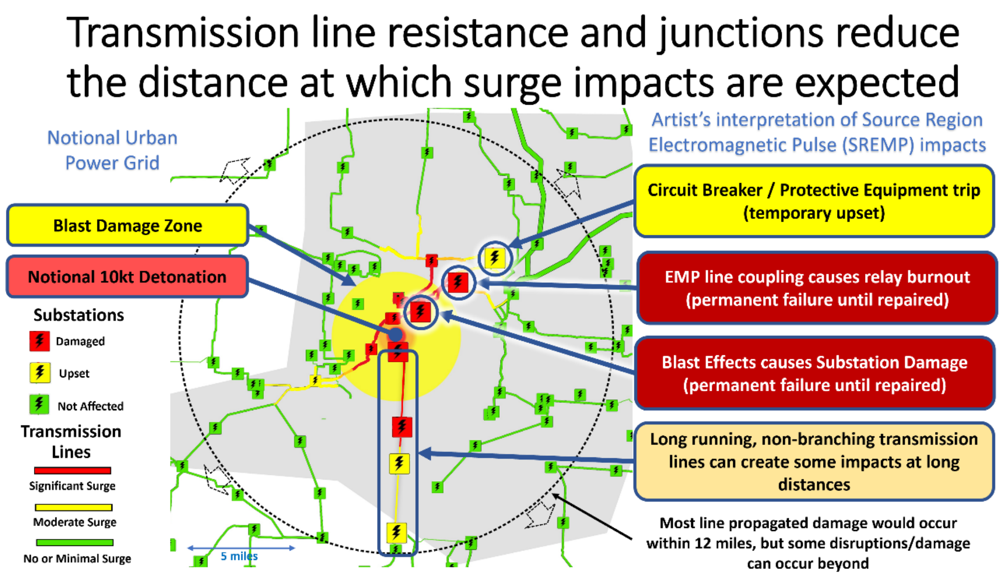

Figure 2-2. Notional SREMP Impacts on an Electrical Grid

Power outages should be expected in the event of a low-altitude nuclear detonation. The time evolution of the outages will be influenced by several factors, including the extent of damage done by the detonation, the characteristics of the power system design, and the characteristics of the power system control system. In general, the outage should evolve as follows: 1) the detonation will cause certain damage from the blast and SREMP effects; 2) the system will see an imbalance with too much load, too much generation, or a complex combination of both; 3) the control systems will begin to compensate for this situation but are unlikely to balance the system immediately; 4) this will likely result in the system shedding more load to protect the overall system and in a cascading outage that will extend well beyond the area where actual damage was done; 5) after some time, the power system will stabilize, and power will begin to be restored to areas where the system has not been physically damaged. The utilities will restore electric power to the undamaged areas in a reasonably short time – typically hours to a few days; and 6) repair and restoration to areas where physical damage occurred will take longer and all recovery aspects will be dependent on the ability to work in the areas due to fallout considerations. Note, back-up power[4] and surge protection can help mitigate this impact on important equipment.

[4] During equipment testing generators have proven to be very robust against the EMP threat.

3. SUMMARY

EMP from a low-altitude detonation is fundamentally different from high-altitude EMP. This study focuses on SREMP and provides considerations regarding the impact from EMP due to a low altitude nuclear denotation.

There are two major disruptive effects of a SREMP, depicted in Figure 3-1:

(1) **EM illumination:** SREMP impact electronic equipment through induced voltage on internal wires and conductors. These induced voltages may disable or damage equipment, depending on field strength.

(2) **Line coupling:** Large voltage/current surges in long power lines and other conductors that pass near the detonation. This can propagate the EMP significant distances, resulting in disruption and potential damage a few miles outside the blast damage area.

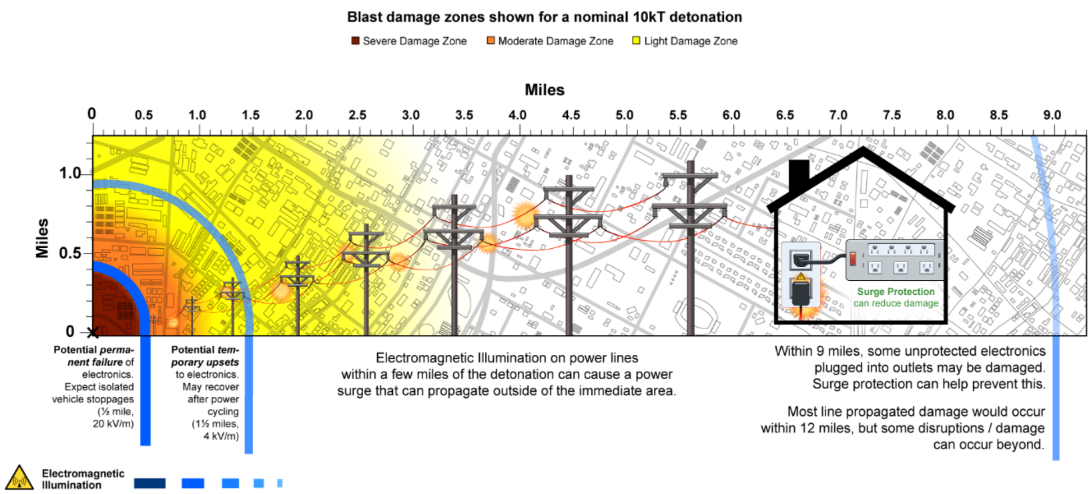

Figure 3-1. SREMP Illumination Range and Power Grid Coupling Disruptions

The following general key points apply to all the exemplar scenarios discussed in section 1.1:

- SREMP effects are only weakly dependent on yield or heights of burst below 3 miles (5 km).
- Power system transformer damage (difficult to repair quickly) from EMP effects is generally limited to a few miles from ground zero.
- Line induced surge can potentially permanently damage unprotected equipment plugged into a wall-socket (to about 9 miles) due to coupling into the grid.
- Emergency response equipment radios, smart phones, and computers can be affected by both illumination and coupling depending on if they are connected to building power. Latching upsets could span several miles. Regaining operation from equipment upsets may require cycling of power or rebooting.
- Easily repairable disruption to power system substation components (tripped breakers, damaged relays, etc.) can occur several miles from the detonation along long running non-branching power lines.
- Temporary (hours to days) power outages may extend many tens of miles beyond the blast damage area, depending on power grid configuration and detonation location.

REFERENCES

Pennington, H., Rogers, J., Schiek, R., McLemore, D., Dinallo, M., & Nelson, E. (Nov 2020). *EMP Methodology and Analysis for Nuclear Detonation Planning Guidance.* Albuquerque, N.M. USA: Sandia National Laboratories SAND2020-13357.