EFFECTS OF ELECTROMAGNETIC PULSES ON COMMUNICATION INFRASTRUCTURE

AN IST PRIMER

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Effects of Electromagnetic Pulses on Communication Infrastructure:
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About the Institute for Security and Technology

As new technologies present humanity with unprecedented capabilities, they can also pose unimagined risks to global security. The Institute for Security and Technology's (IST) mission is to bridge gaps between technology and policy leaders to help solve these emerging security problems together. Uniquely situated on the West Coast with deep ties to Washington, DC, we have the access and relationships to unite the best experts, at the right time, using the most powerful mechanisms.

Our portfolio is organized across three analytical pillars: **Innovation and Catastrophic Risk**, providing deep technical and analytical expertise on technology-derived existential threats to society; **Geopolitics of Technology**, anticipating the positive and negative security effects of emerging, disruptive technologies on the international balance of power, within states, and between governments and industries; and **Future of Digital Security**, confronting the systemic risks of societal dependence on digital technologies.

IST aims to forge crucial connections across industry, civil society, and government to solve emerging security risks before they make deleterious real-world impact. By leveraging our expertise and engaging our networks, we offer a unique problem-solving approach with a proven track record.

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Introduction

It is important to acknowledge that the blast effects of a nuclear detonation are horrific and, in such a scenario, it is right that emergency response (including communications) go first to support those people who are affected. IST's Innovation and Catastrophic Risk team is focused on one aspect of crisis prevention and, in the worst case, response: the international prevention and de-escalation of catastrophic nuclear risk through additive communications solutions.

CATALINK is IST's Innovation and Catastrophic Risk initiative that proposes just such an additive communications solution. This concept presents a framework through which nuclear-armed states can discuss how to mature the current options for intra-state nuclear crisis communications. In order to help advance such discussion, it is important to examine in detail the extensive technical needs of such a communications solution.[1]

As a first step, this primer details the effects of a nuclear detonation on communication devices, infrastructure, and networks to highlight the capabilities needed in an additive technical solution for international crisis communications. As a result, this primer focuses on the electromagnetic interference, specifically electromagnetic pulses (EMPs)[2] and associated radiation, generated by a nuclear detonation.[3]

Overview of EMP Effects

Although every nuclear weapon detonation produces an EMP, the characteristics of each EMP (for instance, intensity and duration) will vary depending on the specifics of the weapon, including its design, altitude reached, and the energy released.[4]

High-altitude detonations produce a High-Altitude Electromagnetic Pulse (HEMP),[5, 6] generated over the atmosphere. Meanwhile,

1 This paper is intended to serve as a simplified thought-exercise in that it provides an overview of the impact of EMPs on communications infrastructure. As such, it does not discuss any of the myriad of factors that would affect a state's ability to communicate internationally, such as the portion of its communication infrastructure not affected (including specifics related to its geography, level of infrastructure development, size, and location of conflict), or follow-on actions in such a hypothetical conflict.

2 Notably, other weapons can also produce EMPs, such as e-bombs. Washington State Department of Health, *Electromagnetic Pulse (EMP) Fact Sheet* 320-090, September 2003, https://doh.wa.gov/sites/default/files/legacy/Documents/Pubs/320-090_elecpuls_fs.pdf.

3 There are also naturally occurring phenomena that can create similar effects, such as geomagnetic disturbances and solar flares. See Aaron Larson, "How an EMP or GMD Could Destroy the Power Grid and Create Chaos," *PowerMag*, April 13, 2023, https://www.powermag.com/how-an-emp-or-gmd-could-destroy-the-power-grid-and-create-chaos/ or Joshua E. Owen, "An EMP or Solar Incident Could Result in Blackout Warfare" *Proceedings*, February 2023, https://www.usni.org/magazines/proceedings/2023/february/emp-or-solar-incident-could-result-blackout-warfare.

4 Also known as "yield."

5 Above 30 km. Heather M. Pennington et al, *Source Region Electromagnetic Pulse Planning Considerations*, U.S. Department of Energy, June 1, 2021, https://www.osti.gov/servlets/purl/1813668.

6 U.S. Department of Energy, *U.S. Department of Energy Electromagnetic Pulse Resilience Action Plan*, January 2017, https://www.energy.gov/oe/articles/doe-electromagnetic-pulse-resilience-action-plan#:~:text=Although%20an%20EMP%20is%20also,produced%20by%20high%20altitude%20detonations.

low-altitude detonations generate a “Source Region EMP (SREMP)” close to the detonation point.[7] These differences in detonation altitude in turn impact the type and nature of infrastructure components affected by an EMP. In the event of a SREMP, even though the pulse is localized and the ground acts as a radiation absorber,[8] the ground can also act as an electrical conductor.[9] Electrically, the SREMP can lead to large voltage and current surges in long running power lines and other conductors.[10] In the event of a HEMP, an atmospheric nuclear detonation can create free electron levels in the surrounding atmosphere that can disrupt electromagnetic waves that pass through it.[11] This can also lead to shortening in generators and current-induced physical damage.

Another important factor to consider when distinguishing the effects of EMPs is the multi-phase pulse released from a nuclear weapon, which determines how communication components are affected, including secondary or amplifying effects over time. E1 (early time), E2 (intermediate time), and E3 (late time) each generate different lengths and types of pulses, thus impacting infrastructure in different ways.[12] E1 can induce high voltages in electrical conductors and transformers in the power grid, which causes disruptions or damage and leads to temporary or permanent loss of functionality. E2 can be considered as a similar pulse to lightning strikes, which can lead to exploded capacitors, crushed coils, and punctured insulation in radio infrastructure. E3–generated by the fireball of a nuclear explosion[13]–can last minutes, and is low frequency, thereby able to penetrate the ground.[14] Like in the case of a SREMP, the E3 pulse generates energy that can be multiplied by cables, leading to a build up of current that destabilizes or damages connected equipment like transformers.[15]

7 U.S. Department of Energy, *U.S. Department of Energy Electromagnetic Pulse Resilience Action Plan.*

8 U.S. Department of Energy, *U.S. Department of Energy Electromagnetic Pulse Resilience Action Plan.*

9 Lisa Andivahis et al. “DTRA J9’s Electromagnetic Pulse Modeling and Simulation Project,” *The Dispatch* 5, no. 3, June 2016, https://www.dtra.mil/Portals/61/Documents/DTRIAC/Dispatch%20June%202016.pdf.

10 Pennington, *Source Region Electromagnetic Pulse Planning Considerations*.

11 Brandon Wilson et al, *Effects on Communications Wavelengths from an Atmospheric Nuclear Detonation*, U.S. Department of Energy, September 9, 2022, https://www.osti.gov/servlets/purl/1894207.

12 George Lane, “Effects and Responses to Electromagnetic Pulses (EMP),” PowerPoint presentation, NPS Center for Homeland Defense and Security 10th Anniversary Homeland Defense & Security Education Summit, Monterey, CA, March 23, 2017, https://www.chds.us/ed/resources/uploads/2010/05/2017_HS_Summit_Lane_Electromagnetic_Pulses.pdf.

13 George Friedman and Phillip Orchard, “The EMP Threat: How It Works and What It Means for the Korean Crisis,” *Geopolitical Futures*, February 26, 2018, https://geopoliticalfutures.com/emp-threat-works-means-korean-crisis/.

14 U.S. Department of Energy, *U.S. Department of Energy Electromagnetic Pulse Resilience Action Plan.*

15 Lane, "Effects and Responses to Electromagnetic Pulses (EMP)."

EMP Effects on Communications[16]

One of IST's core initiatives within the Innovation and Catastrophic Risk pillar is the CATALINK concept, a project that proposes an open-source, mesh network-based communication system for leaders to use in order to communicate to either de-escalate a nuclear crisis, or to effectively terminate one in the worst case scenario. The CATALINK project proposes an additive communication solution that can adjust to the availability of frequencies and bandwidth and the need for multilateral communication.

The effects of a nuclear detonation on communication depend not only on the characteristics of the electromagnetic waves generated from the detonation, but also, how those waves impact existing communication infrastructure.

Communication infrastructure includes, but is not limited to, the physical radio towers, cell towers, satellites, ground stations, and networks of above and below-ground fiber optic, copper, and coaxial cables, including undersea cables. At the micro level, all of these components in some way transmit electromagnetic waves, which is why a nuclear detonation—which inherently emits electromagnetic interference—will impact communications. Additionally, many of these components are themselves built on or rely on hardware that is similarly affected by electromagnetic interference. Lastly, at the macro level, communication infrastructure and the electric grid are interconnected: communication infrastructure has physical dependency on power to perform data transmission and the electric grid relies on communication systems to monitor and manage transmission.[17] This means a disruption in one and will likely can cause a disruption in the other.

Below, we outline the effects of a nuclear detonation on the electric grid, electronics, satellites, radio and cellular, and wired communications. Because the **vectors of disruption** to communication vary across hardware, network, and infrastructure components, the below listed communication components are not equivalent, are interdependent, and sometimes overlap.

Electric Grid

In the event of a nuclear bomb detonation, electrostatic discharge feeds into electric grid wiring, leading to potential disruptions such as shortening in generators and transmission

16 In "The Command and Control of Nuclear War," Ashton B. Carter's 1985 article for *American Scientific*, he writes: "strategic communications systems must be designed to resist all kinds of interference, including physical destruction, jamming, interception or mimicking by enemy intelligence, disturbance by the ionosphere and disruption by the EMP effect." See also *Managing Nuclear Operations* (1987), edited by Ashton B. Carter, John D. Steinbrunner, and Charles A. Zraket, a pioneering work in which 22 experts describe in detail the U.S. nuclear operations and command, control, communications, and intelligence (C3I) and their peace-time safety, control, and survival under nuclear attack and impact on command posts, warning sensors, and communications technologies.

17 Xin Liu et al, "Electric power grid resilience with interdependencies between power and communication networks – a review," IET Smart Grid, February 26, 2020, https://ietresearch.onlinelibrary.wiley.com/doi/full/10.1049/iet-stg.2019.0202#.

lines.[18] The impact–including the time it takes to resume operations–depends partly on the existing redundancy built into the grid, such as the ability of microgrids to "island."[19]

Electronics

The electromagnetic waves released by a detonation can couple to equipment circuits and short-circuit a wide range of electronic equipment. These devices could include computers, traffic lights, ethernet cables, and routers–essentially, any device that contains semiconductors.[20] This device-level interference will disrupt and impede an individual's ability to connect to Local Area Networks and Wide Area Networks.[21] "Hardening"–efforts to reduce such vulnerabilities–can prevent some of these effects.[22] However, although certain elements of communication networks may be hardened, populations writ large do not generally employ mitigation strategies, such as EMP-protected equipment enclosures.[23]

Satellites

Satellite systems require ground terminals to uplink, downlink, and deploy control functions. Although SREMPs can disable ground terminals, only HEMPs and space-originated geomagnetic disturbances directly create interference that affects satellites.[24] In the event of a HEMP or space-originated geomagnetic disturbance associated with a nuclear blast, the energy of the blast can create immediate disruptions, such as immediate current-induced damage (i.e. burnout) or disruptions over time, such as through the buildup of an electric field within a satellite's surface materials or through the eventual generation of discharge as a result of poorly shielded internal materials.[25] Additionally, HEMPs can create artificial radiation belts, leading to a persistent hazardous environment that can interfere with satellite performance or cause physical damage over time.[26]

Radio and Cellular

When the EMP releases its pulse of radiofrequency fields, structures such as

18 There are also naturally occurring phenomena that can create similar effects, such as geomagnetic disturbances and solar flares. Larson, "How an EMP or GMD Could Destroy the Power Grid."

19 Daniel Shea, "States Turn to Microgrids to Bolster Energy Resilience," National Conference of State Legislatures, June 22, 2022, https://www.ncsl.org/state-legislatures-news/details/states-turn-to-microgrids-to-bolster-energy-resilience.

20 Washington State Department of Health, *Electromagnetic Pulse (EMP) Fact Sheet*.

21 Washington State Department of Health, *Electromagnetic Pulse (EMP) Fact Sheet*.

22 Washington State Department of Health, *Electromagnetic Pulse (EMP) Fact Sheet*.

23 U.S. Department of Homeland Security, *Electromagnetic Pulse Shielding Mitigations: Best Practices for Protection of Mission Critical Equipment*, August 2022, https://www.dhs.gov/sites/default/files/2022-09/22_0902_st_emp_mitigation_best_practices.pdf.

24 Commission To Assess The Threat To The United States From Electromagnetic Pulse Attack, *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Critical National Infrastructures*, April 2008, http://www.empcommission.org/docs/A2473-EMP_Commission-7MB.pdf.

25 Commission To Assess The Threat To The United States From Electromagnetic Pulse Attack, *Report of the Commission*.

26 Keith Siebert and Jay Kerwin, "Artificial Radiation Belts," *The Dispatch* 3, no. 4, January 2014, https://www.dtra.mil/Portals/61/Documents/dispatch-v3-i4-web-2.pdf.

large antennas or long cables can pick them up. The effect on these components resembles that of a direct lightning strike, including exploded capacitors, crushed coils, and punctured insulation.[27] Although radio and cell towers are designed to withstand lightning strikes, potential points of failures include antennas, power lines, and links, such as those connecting the radio studio to transmitter, cell towers' fiber backhaul link, or a tower's microwave link to another tower. Because radio and cellular communication networks rely heavily on physical infrastructure, it is important not to overlook the potential physical damage to the stations. If the station is heavily damaged by blast effects (such as in the case of a SREMP), any hardening put in place to guard against EMP damage is inconsequential.[28]

Wired Communications

Wired communications can encompass a variety of structures and components. During the E1 phase of an EMP, wired communications such as coaxial cables and ethernet patch cords can short-circuit. Another form of wired communications is undersea telecommunication cables and long-distance telephone lines. During the E3 phase, the long-lasting, low-frequency pulses can penetrate into ocean waters, therefore potentially impacting undersea telecommunication cables. Generally, fiber-optic cables, which make up most long-distance telephone lines in the United States, are more resistant to EMPs than metallic line networks.[29] However, these wired infrastructures depend on repeaters in order to amplify the optical signal; in the case of undersea cables, this means that repeaters are placed every 60 to 70 km on the ocean floor.[30] Meanwhile, on both sides of the ocean, a landing station provides power to the repeaters. Studies have suggested that these systems are redundant and able to withstand disruptions such as solar storms.[31] However, this reliance on power is a potential vector of disruption, as seen by the above description of the vulnerabilities of the electric grid.

Conclusion

Nuclear detonations have the potential to disrupt or even destroy communication devices, infrastructure, and networks. As the global conversation around nuclear risk reduction moves toward the need for a technical system that facilitates nations' bilateral and multilateral communication, this primer highlights the need for systems that

27 D.B. Nelson, "Effects of Nuclear EMP on AM Radio Broadcast Stations in the Emergency Broadcast System," Interaction Notes, Note 159, The University of New Mexico, July 1971, http://ece-research.unm.edu/summa/notes/In/0159.pdf.

28 D.B. Nelson, "Effects of Nuclear EMP on AM Radio."

29 D.I. Crecraft and S. Gergely, *Analog Electronics: Circuits, Systems and Signal Processing* (Oxford: Butterworth-Heinemann, 2002), chap. 12, https://www.sciencedirect.com/science/article/abs/pii/B978075065095350012X.

30 Winston Qiu, "Next Generation Submarine Network – Innovative Repeater Technology," *Submarine Cable Networks* (blog), September 18, 2020, https://www.submarinenetworks.com/en/insights/next-generation-submarine-network-innovative-repeater-technology.

31 Jorge C. Castellanos and Urs Hölzle, "Does the internet need sunscreen? No, submarine cables are protected from solar storms," *Google Cloud Blog* (blog), Google, November 17, 2022, https://cloud.google.com/blog/products/infrastructure/are-internet-subsea-cables-susceptible-to-solar-storms#.

take into account the realities of EMPs' impact on communication networks.

This delineation of how EMPs impact specific types of communication infrastructure also outlines the capabilities and characteristics necessary for any type of communication solution intended to be used in the event of such a crisis. First, the system must be able to adjust to the availability of frequencies and bandwidth. Second, the system must build in redundancies in the event that communication drops or fails altogether, including the initiation of multilateral lines of communication, rather than bilateral. Practically, such a solution should also consider the best hardening practices for devices themselves, such as storage in a shielded, grounded box when not in active use.

IST's CATALINK initiative attempts to address many of these requirements and bring the conversation about de-escalation and de-risking back to the level of state-to-state communication. Through multilateral dialogue it is important to continue to advance the discussion and norms surrounding crisis avoidance and resolution.