Command and Control on the Nuclear Battlefield in Multi-Domain Operations

A Monograph

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By analyzing the effects of a low-yield battlefield nuclear weapon, this monograph provides an assessment of an Army corps' command and control (C2) resiliency in the event of a nuclear strike. In particular, it examines the ability to conduct multi-domain operations (MDO) after nuclear effects degrade components of the C2 system; people, command posts, networks, and processes. The analysis shows that a single low-yield battlefield nuclear weapon cannot destroy the entirety of an Army corps' C2 system due to the redundancy and dispersion of command nodes. The severity of C2 degradation is a function of the number of nuclear weapons employed, C2 nodes destroyed, and if an adversary is willing to strike nodes in the continental United States or in space. Although a low-yield battlefield nuclear weapon targeting land forces may not be optimal to deny network connectivity, their use has implications for C2 system design as maneuver units will likely increase dispersion for survivability.

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Abstract

Command and Control on the Nuclear Battlefield in Multi-Domain Operations, by MAJ Jeff Fanelli, 38 pages.

By analyzing the effects of a low-yield battlefield nuclear weapon, this monograph provides an assessment of an Army corps' command and control (C2) resiliency in the event of a nuclear strike. In particular, it examines the ability to conduct multi-domain operations (MDO) after nuclear effects degrade components of the C2 system; people, command posts, networks, and processes. The analysis shows that a single low-yield battlefield nuclear weapon cannot destroy the entirety of an Army corps' C2 system due to the redundancy and dispersion of command nodes. The severity of C2 degradation is a function of the number of nuclear weapons employed, C2 nodes destroyed, and if an adversary is willing to strike nodes in the continental United States or in space. Although a low-yield battlefield nuclear weapon targeting land forces may not be optimal to deny network connectivity, their use has implications for C2 system design as maneuver units will likely increase dispersion for survivability.

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Abbreviations

A2/AD	Anti-Area/Area Denial
ABMS	Advanced Battle Management System
ADP	Army Doctrine Publication
ATO	Air Tasking Order
C2	Command and Control
DARPA	Defense Advanced Research Projects Agency
EMP	Electromagnetic Pulse
EMS	Electromagnetic Spectrum
FEMA	Federal Emergency Management Agency
FM	Frequency Modulation
MDO	Multi-Domain Operations
HEMP	High Altitude Electromagnetic Pulse
ITO	Integrated Tasking Order
JADC2	Joint All-Domain Command and Control
JADO	Joint All-Domain Operations
KT	Kiloton
LYBNW	Low-yield Battlefield Nuclear Weapon
NC3	Nuclear Command, Control, and Communications
PACE	Primary, Alternate, Contingency, Emergency
SACP	Support Area Command Post
SREMP	Source Region Electromagnetic Pulse
TREE	Transient Radiation Effects on Electronics
TRILOS	Terrestrial Transmission Line of Sight

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Introduction

As the tacit threat of nuclear war subsided with the end of the Cold War, the possibility that the Army would have to operate on a nuclear battlefield seemed increasingly unlikely. Nuclear knowledge and technical experience in the US Army atrophied as conventional forces engaged in counter-insurgencies against non-nuclear powers. Meanwhile, Russia and China modernized their nuclear forces and the Democratic People's Republic of Korea explicitly threatened their use. Although an all-out nuclear exchange remains unlikely, security analysts are beginning to acknowledge the possibility of limited nuclear war.[1]

The Army's newly published multi-domain operations (MDO) concept explicitly assumes that nuclear weapons will not be employed. The document states that nuclear weapons would "so significantly alter the strategic context that different operational approaches would be required."[2] This assumption is not without precedent in contemporary operational thinking, in which the concept of limited nuclear war "had been nearly banished from the strategic lexicon, especially in the West."[3] Considering that US Army will be expected to operate on the battlefield even if nuclear weapons are used, how would the use of low-yield battlefield nuclear weapons impact the Army's ability to command and control (C2) ground forces in MDO?

This monograph begins by reviewing the MDO concept, joint all-domain command and control, and the four components of the Army C2 system; people, command posts, networks, and processes. The monograph will then describe nuclear hazards and assess their impact on the C2 system following a modified version of a disaster risk assessment methodology used by the

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[1] Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, *The Nuclear Weapons Effects National Enterprise* (Washington, DC: June 2010), 12.

[2] US Department of the Army, Training and Doctrine Command (TRADOC) Pamphlet 525-3-1, *The Army in Multidomain Operations 2028* (Washington, DC: Government Printing Office, 2108), A-1.

[3] Joseph D. Becker, "Strategy in the New Era of Tactical Nuclear Weapons," *Strategic Studies Quarterly* (Spring 2020): 118.

Federal Emergency Management Agency (FEMA).[4] It concludes with implications for an Army corps' ability to C2 MDO on the nuclear battlefield.

As it stands, a single low-yield battlefield nuclear weapon cannot destroy the entirety of an Army corps' C2 system due to the redundancy and dispersion of a corps' command nodes. The severity of the corps' C2 degradation is a function of the number of nuclear weapons employed, amount of command nodes destroyed, and if an adversary is willing to strike network nodes in the continental United States or in space. Striking targets in space and in the United States carry significant strategic consequences beyond targeting land forces on the battlefield. Although nuclear weapons may not be optimal to deny network connectivity, their use prompts increased dispersion by maneuver units for survivability which has implications for C2 system design. Future C2 systems must be able to support the proliferation of sub-units on a nuclear battlefield as maneuver will likely fragment into multiple, smaller penetrations or infiltration-like raids.

Command and Control in Multi-Domain Operations

Multi-Domain Operations Concept

The Army released its MDO concept in 2018 in response to new adversary military capabilities that counter US military strengths. Stand-off provided by anti-access/area denial (A2/AD) systems allow adversaries to separate US land forces from air support and reserves causing the AirLand battle doctrine to no longer be feasible.[5]

At the onset of conflict, the MDO concept calls for Army forces to penetrate into an adversary's A2/AD bubble to identify and destroy enemy systems. Land and air forces can subsequently exploit any gaps created in the adversary's defense. If A2/AD systems are not dis-

[4] The FEMA threat hazard identification and risk assessment (THIRA) is a prioritization of threats to the homeland infrastructure, examining plausible threat scenarios, and recommending mitigations. This modification takes a narrower view by investigating nuclear effects and hazards to military C2 in an MDO scenario.

[5] US Army, TRADOC Pamphlet 525-3-1 (2018), vii.

integrated, land forces become increasingly isolated from friendly support as they penetrate deeper. The Army must work as part of a larger multi-domain effort to dis-integrate enemy defenses and restore combined-arms maneuver to the battlefield.

Three tenets enable effective MDO. First, calibrated force posture and preparing forward deployed assets. The initial salvos of long-range fires require careful positioning of assets, including intelligence platforms, to begin neutralizing adversary long-range systems at the onset of conflict. Second, multi-domain formations require the capacity and endurance to operate in all domains against adversaries. This is particularly true for forward deployed forces that will be in immediate contact as friendly strategic reinforcements maneuver forward. Third, MDO strives to attack an enemy with multiple forms of attack in all domains, known as convergence. Convergence is "the continuous integration of capabilities from multiple domains, the electromagnetic spectrum, and the information environment, to create multiple dilemmas for the enemy."[6] By coordinating forces across multiple domains, MDO can optimize effects to generate a marked advantage over an enemy than if the forces were employed individually.[7]

Additionally, the US Air Force released their joint all-domain operations (JADO) concept in 2020. JADO envisions an integrated and synchronized joint force operating in all domains at a speed and scale to gain an advantage over adversaries. The Air Force is particularly interested in defeating adversary A2/AD systems that restrict air power's freedom of maneuver. JADO's solution is twofold. First, present the enemy with multiple dilemmas by converging effects from multiple domains. Second, operate at a tempo faster than the adversary. Through superior information management, JADO can take advantage of opportunities as they arise. JADO should

[6] US Department of the Army, Army Doctrine Publication (ADP) 6-0*, Mission Command* (Washington, DC: Government Printing Office, 2019), 1-18.

[7] US Army, TRADOC Pamphlet 525-3-1 (2018), 33.

enable the "engagement of thousands of targets in hundreds of hours" at a tempo that overwhelms an opponent's ability to adapt.[8]

MDO and JADO concepts require new technologies, some still undeveloped, to reach their fullest potentials. It requires multi-domain collaborative C2 architecture to enable converging effects from all domains. To solve this, the military is pursuing joint all-domain command and control (JADC2).

Joint All-Domain Command and Control

JADC2 leverages capabilities "across all domains and with mission partners to achieve operational advantage in both competition and conflict" thereby turning decision-making into action.[9] JADC2 is not a single piece of hardware or software, but a network of linked systems. JADC2 intends to link every sensor with every shooter while synthesizing information from all domains.

JADC2 will end the model of self-contained kill chain platforms in which one system acquires and engages targets independently from other systems. Instead, a highly connected sensor-shooter network will create a "kill web" so that one system can pass rapidly pass data to other systems for engagement.[10] The Army successfully tested the concept in September 2020 during a Project Convergence exercise. Air Force sensors sent target information to a command center in Fort Lewis, Washington. The information was then processed and passed to an artillery

[8] US Department of the Air Force, Doctrine Note 1-20, *USAF Role in Joint All-Domain Operations* (5 March 2020), 3, accessed on 26MAY21, https://www.doctrine.af.mil/Portals/61/documents/Notes/Joint%20All-Domain%20Operations%20Doctrine--CSAF%20signed.pdf.

[9] US Department of the Air Force, Annex 3-99, *Department of the Air Force Role in Joint All-Domain Operations (JADO): Command and Control (C2)* (8 October 2020), 6, accessed on 26MAY21, https://www.doctrine.af.mil/Portals/61/documents/AFDP_3-99/AFDP%203-99%20DAF%20role%20in%20JADO.pdf.

[10] Timothy Grayson at The Mitchell Institute, "Aerospace Nation: Actualizing Joint All Domain Command and Control--The Way Ahead," accessed on 02APR21, https://www.youtube.com/watch?v=AdzXInAUV24&feature=emb_title.

unit in Yuma, Arizona which successfully engaged the target. The entire process, which normally takes minutes, took only 20 seconds.[11] Lieutenant General Samuel Clinton Hinote, the Deputy Chief of Staff for Strategy, Integration, and Requirements of the US Air Force, said all-domain awareness and connectivity allows commanders to be “agnostic about where sensing and effects come from.” The unimagined C2 options unlocked by JADC2, he continued, “could be revolutionary.”[12]

The Air Force is the lead for JADC2 development for the joint force. The Air Force is using its Advanced Battle Management System (ABMS) concept as the backbone for JADC2.[13] Battle management systems collect and integrate data to assist commanders with command and control by achieving total data fusion. Other military services are developing their own battle management systems. The Navy’s Project Overmatch and the Army’s Project Convergence must now however, be developed to function within the context of JADC2.[14] It is important to note that a battle management system is not necessarily a comprehensive C2 suite. Until JADC2 evolves and integrates a broad range of systems to coordinate other military warfighting functions, it remains narrowly focused on identifying and engaging targets.

The goal for JADC2 is to find a delicate balance in software standards that allow interoperability without degrading system functionality. The pitfall of establishing universal data and coding standards according to Timothy Grayson, the head of strategic technologies at

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[11] US Library of Congress, CRS, *The Army’s Project Convergence,* CRS Report IF11654 (Washington, DC: Office of Congressional Information and Publishing, October 8, 2020).

[12] LTG S. Clinton Hinote at The Mitchell Institute, “Aerospace Nation: Actualizing Joint All Domain Command and Control--The Way Ahead,” accessed on 02APR21, https://www.youtube.com/watch?v=AdzXInAUV24&feature=emb_title.

[13] Mark Pomerleau, “Air Force Looking at How to Defend JADC2 Systems,” *C4ISRNET*, September 16, 2020, accessed on 26MAY21, https://www.c4isrnet.com/digital-show-dailies/air-force-association/2020/09/16/air-force-looking-at-how-to-defend-jadc2-systems/.

[14] US Library of Congress, CRS, *Joint All-Domain Command and Control (JADC2),* CRS Report IF11493 (Washington, DC: Office of Congressional Information and Publishing, updated March 18, 2021), accessed on 26MAY21, https://crsreports.congress.gov/product/pdf/IF/IF11493.

Defense Advanced Research Projects Agency (DARPA), is that it produces an over-engineered product designed to accomplish everything, but fails to do anything well. Instead, he argues that standards should be flexible enough to allow systems to operate within their unique specifications while still sharing relevant information across domains.[15] Indeed, JADC2 will depend on filtering large amounts of data from a wide array of collection platforms and turning it into actionable intelligence. Recent DARPA software tests have successfully translated data between non-interoperable systems.[16] The tests prove that JADC2 is possible in a heterogenous network, provided that the success is scalable.

Military leaders realize that waiting for the right C2 solution to emerge from the defense acquisition process will not keep pace with technological innovation. Instead, they are fielding unproven equipment for testing as an evolutionary process toward JADC2. Fielding nascent technology during exercises allows immediate bottom-up feedback and troubleshooting to improve system integration on the spot. General Terrence O'Shaughnessy, the former US Northern Command commander involved with the testing, applauds the "helpful attitude of the Air Force to fail fast."[17] The usually long, iterative process between feedback and development in military acquisitions is now happening at accelerated pace.

The C2 System in MDO

Army doctrine defines command and control as "the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of mission."[18] According to Army Doctrinal Publication (ADP) 6-0, the command and control

[15] Timothy Grayson at The Mitchell Institute, "Aerospace Nation: Actualizing Joint All Domain Command and Control--The Way Ahead."

[16] Ibid.

[17] General Terrence O'Shaughnessy at The Mitchell Institute, "Aerospace Nation: Gen O'Shaughnessy, Commander of NORTHCOM and NORAD," accessed on 02APR21, https://www.youtube.com/watch?v=l4g_HGnKzfo.

[18] US Army, ADP 6-0 (2019), 1-16.

system consists of people, processes, networks, and command posts. The components are complementary and enable exercising effective command and control of forces (figure 1). Failure in one component degrades overall effectiveness of the system.

Figure 1. Combat power model. US Department of the Army, Army Doctrine Publication (ADP) 6-0, *Mission Command* (Washington, DC: Government Printing Office, 2019), 1-20.

ADP 6-0 states that people are the most important part of the C2 system.[19] In fact, the Army says that future warfare in MDO will remain "fundamentally a human endeavor."[20] Soldiers with technical expertise are necessary to manage and maintain the complexities of cross-domain operations and networks. The MDO concept envisions man-machine interfaces using artificial intelligence to improve human decision making "in both speed and accuracy."[21] Even if artificial intelligence becomes prominent in new JADC2 systems, the military is committed to keeping humans in the decision-making loop, especially for kinetic strikes. New JADC2 systems will assist people execute multi-domain operations, not replace them.

[19] US Army, ADP 6-0 (2019), 1-16.

[20] US Army, TRADOC Pamphlet 525-3-1 (2018), C-10.

[21] Ibid., 20.

ADP 6-0 defines processes as a series of actions toward an end state that drives the operations process.[22] In MDO, C2 processes must support an enhanced targeting cycle of "see-strike" or "stimulate-see-strike."[23] For example, drones can provoke an enemy to activate air defense radars so that they can be engaged by long range fires. Since adversary A2/AD bubbles have hundreds of integrated systems, MDO targeting processes need to continuously synchronize strikes to first penetrate a way through enemy systems, and then keep the avenue open. The Air Force integrated tasking order (ITO) is the conceptual model for MDO targeting. Like the current air tasking order (ATO) that runs on 72-hour rhythm, the ITO would be an AI enhanced process that continuously synchronizes capabilities from all domains in real time.

Networks enable commanders to communicate information, to control forces, and are key enablers of successful operations.[24] Two components of networks are important to consider. First, networks require physical equipment such as computers and servers. Military servers store data that any user can access through regional or tactical network nodes with the appropriate permissions. In the future, JADC2 and MDO will rely on an information "data lake" stored on servers that any sensor or shooter on the battlefield can access.

Second, a network requires links between systems to provide connectivity and transfer of data. Army doctrine refers to this as network transport. A corps headquarters has three ways of linking C2 nodes; physical connections such as fiber optic or wire, satellites, and line of sight radio communications.[25] JADC2 requires nearly instantaneous sharing and pulling data from the "data lake" to enable speeds demanded in MDO. Digital data sent via line of sight systems has limited range compared to satellite global coverage. This makes a global JADC2 network highly dependent on uninterrupted satellite communications to avoid physically tying maneuver units to

[22] US Army, ADP 6-0 (2019), 4-7.

[23] US Army, TRADOC Pamphlet 525-3-1 (2018), 39.

[24] US Army, ADP 6-0 (2019), 4-8.

[25] Ibid.

a fiber optic or wire connection. The new terrestrial transmission line of sight (TRILOS) system, however, has good bandwidth and lower latency, which can help build resilient C2 networks in localized geographic areas.

ADP 6-0 states that commanders organize the C2 system into command posts to facilitate synchronization and information sharing among the staff.[26] A command post can be a building, tent, vehicle, or any other physical space where the staff organizes. Commanders arrange the other three components of the C2 systems in command posts.[27] As C2 interfaces and processes change, so will the command posts designed to house them. The current technique used by military headquarters is to put staff officers in close proximity to one another so that they can pull data from an Air Force system, for example, and walk it over to staff officers operating on an Army system. Sarcastically referred to as the “sneaker net,” this process is too slow to achieve rapid convergence in MDO.[28] In the future, algorithms and data translation software will synthesize information between a mix of systems to reach the speed necessary for MDO. Already the US Air Force expects this to allow smaller, more distributed operations centers to improve survivability and redundancy against enemy long range precision attack. Likewise, future US Army command posts could reduce personnel manning requirements and become a set of mobile command vehicles instead of a massive conglomerate of tents.

Martin van Creveld warns in his seminal work *Command in War* that no C2 system is optimized for all situations. A system designed for logistics or the offense may be less effective for targeting or the defense respectively.[29] Andrew Bacevich points out that the 1950’s Pentomic Division, designed specifically for the nuclear battlefield, had a cumbersome C2 and

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[26] US Army, ADP 6-0 (2019), 4-9.

[27] Ibid., 1-21.

[28] LTG Hinote at The Mitchell Institute, “Aerospace Nation: Actualizing Joint All Domain Command and Control--The Way Ahead.”

[29] Martin Van Creveld, *Command and War* (Cambridge: Harvard University Press, 1985), 261.

organizational structure that was impracticable for anything but nuclear war.[30] Conversely, a C2 system designed to support MDO may not be adequate for a nuclear battlefield.

Early nuclear strategists imagined that nuclear weapons would rip apart defenses and troop concentrations. The logic of the Pentomic Division was using battalion-sized battlegroups that were robust enough to operate independently, but small enough that their loss in a nuclear strike would not be detrimental to the survival of the division.[31] The Pentomic Division eliminated intermediate brigade headquarters, putting five battlegroups directly under divisional control as a way to add redundancy and flexibility on the nuclear battlefield. The new divisions would operate dispersed along a 27km front. In comparison, the planning factor for a WWII division was a 7km front.[32]

The result was a span of control too big for a division headquarters. Divisions were responsible for up to 16 subordinate units when considering all the support organizations.[33] Battlegroups lacked sufficient logistic capabilities and depended on assistance from the division headquarters which further overloaded the division staff. Additionally, there was no existing radio technology that had the range to realistically exercise command control over the distances envisioned in the pentomic doctrine.[34] The Army needed to modernize and field new C2 technologies. Instead, the Army remained undermanned, ill-equipped, and abandoned the doctrine after only a few years.[35]

The short-lived Pentomic Division experiment illustrates the challenges associated with marrying C2 technology to emerging concepts. Ground forces remain just as vulnerable to

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[30] A. J. Bacevich, *The Pentomic Era: The US Army Between Korea and Vietnam* (Washington, DC: National University Press, 1986), 134.

[31] Bacevich, *The Pentomic Era: The US Army Between Korea and Vietnam,* 115-117.

[32] Jack F. Smith, "Pentomic Doctrine: A Model for Future War" (Monograph, School of Advanced Military Studies, Fort Leavenworth KS, AY 93-94), 23.

[33] Bacevich, *The Pentomic Era: The US Army Between Korea and Vietnam,* 134.

[34] Smith, "Pentomic Doctrine: A Model for Future War," 23.

[35] Ibid, 25.

nuclear weapons today as they were in the 1950s. If commanders keep forces consolidated to facilitate C2, they are at risk of being destroyed on the nuclear battlefield. As formations disperse to increase survival, the C2 structure bears an increased burden. Like the Pentomic Divisions in the past, MDO is counting on undeveloped C2 technology. How effective will JADC2 be in MDO if it is being developed without the nuclear battlefield in mind?

Nuclear Effects on the C2 System

By gaining an understanding of the effects of nuclear weapons, one can assess the impacts that a low-yield battlefield nuclear weapon (LYBNW) would have on the components of the C2 system. A LYBNW is a nuclear weapon with a yield of less than 15 kilotons and used to create tactical or operational effects against military targets, primarily ground forces, within a specified theater. Explosive yield equates to pounds of TNT. A 1-kiloton yield would be equal to 1,000 tons of TNT. A 1-megaton yield would equal a million tons of TNT, one-thousand times stronger than a kiloton. The use of such weapons also has strategic implications.

A LYBNW may be delivered through the use of cruise missiles, artillery shells, ballistic missiles, gravity bombs, or any other appropriate method. Past examples in the US nuclear arsenal include the Little Boy gravity bomb, Davy Crocket artillery shell, and Genie rocket. Currently, the US nuclear arsenal includes variable yield weapons such as the B-61 gravity bomb and the air launched cruise missile. The W 76-2 submarine launched intercontinental ballistic missile is the newest low-yield option in the US nuclear arsenal. The Russian, Chinese, Indian, Pakistani, Israeli, and North Korean nuclear arsenals also include low-yield battlefield nuclear weapons.

This assessment assumes that an adversary employs a single 10-kiloton LYBNW in a ground burst or low-altitude air burst against an army corps in the field. An air burst is when the nuclear fireball does not touch the surface of the earth. Air bursts are better against populations centers and unprotected troops in the open. Ground bursts can destroy bunkers, runways, and reinforced military structures.[36] High-altitude bursts can have indirect effects on land forces, but are much less deadly.

Examining the effects of a single detonation helps dispel any exaggerated preconceptions of nuclear effects. Additionally, nuclear strategist Herman Kahn argued that the first use of nuclear weapons is more likely to send a political message rather than destroy military forces.[37] The more nuclear weapons employed, the greater the escalation control implications which is beyond the scope of this discussion.

As seen in figure 2, the immense amount of energy released by a nuclear weapon is partitioned among three primary effects: the blast wave, heat, and ionizing radiation. The electromagnetic pulse (EMP) and atmosphere ionization are secondary effects that are harmless to humans but can degrade C2.

Nuclear Effects	**Energy Partition**
Blast	50%
Heat	35%
Ionizing Radiation	15%
Secondary Effects	
EMP	
Atmosphere Ionization	

Figure 2. Nuclear Effects. Adapted from Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, *Nuclear Matters Handbook* (Washington, DC: 2020), 225.

Heat: Nuclear Fireball and Thermal Radiation

Nuclear weapons release significantly more thermal energy than conventional explosives. X-rays created by the nuclear explosion heat up the surrounding air creating an incandescent fireball. A 10-kiloton air burst produces a fireball 136 meters wide. The fireball reaches tens of

[36] Ralph Pasini, “The Threats to Survival in a Nuclear Environment,” Thesis, Air War College (Air University, Maxwell Air Force Base, AL, 1987), 12-13.

[37] Lawrence Freedman, "The First Two Generations of Nuclear Strategists," in *Makers of Modern Strategy*, ed. Peter Paret (Princeton, NJ: Princeton University Press, 1986), 763.

millions of degrees and will vaporize anything within its radius, even scorching a crater out of dry soil.[38]

Beyond the fireball, thermal radiation travels outward at the speed of light. Thermal radiation is ultraviolet, visible, and infrared light felt as heat. Since nuclear explosions produce such extreme temperatures, even brief exposure can cause severe flash burns at long distances. An estimated 20-30% of casualties in Hiroshima and Nagasaki were caused by flash burns.[39]

The strength and range of thermal radiation is a factor of yield, distance, and atmospheric conditions. Higher yielding nuclear weapons release more energy and consequently more thermal radiation. They are generally better incendiary weapons since their thermal effects extend beyond their blast damage radius. For example, blast waves in low-yield weapon tests destroyed wooden houses that were ignited only moments earlier. The effects were reversed in tests with weapons using megaton yields.[40]

A low air burst maximizes the coverage area of thermal effects. Effects weaken as the height of burst increases since the atmosphere absorbs most of the thermal radiation before it reaches the ground. Thermal radiation, like all forms of radiation, loses intensity as an inverse square to distance. In other words, the radiation will be at twenty five percent strength at twice the distance.[41] A foggy day or debris kicked up into the atmosphere by the detonation would further attenuate thermal effects. The relationship between yield and height of burst allows planners to calculate the optimal height of burst for thermal effects. Detonating lower yield

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[38] Freedman, "The First Two Generations of Nuclear Strategists," in *Makers of Modern Strategy*, 227.

[39] Samuel Glasstone and P. J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed. (Washington, DC: 1977), 566.

[40] Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, *The Nuclear Weapons Effects National Enterprise* (2010), 63.

[41] Glasstone and Dolan, *The Effects of Nuclear Weapons,* 635.

weapons closer to the ground will achieve similar thermal effects as a larger megaton weapons at higher altitudes.

Thermal radiation will severely burn and incapacitate soldiers exposed in the open. As shown in figure 3, fifty percent of soldiers within one mile slant distance of a 10-kiloton air burst are prone to 3rd degree burns on a clear day if not protected by some type of cover. Slant distance is the straight-line distance from the point of burst in the air to the target on ground. The actual ground distance would be shorter than the slant distance.

Thermal Effects	**Radiant Exposure**	**Slant Distance**
50% 1st degree burn	2 cal/cm2	2800m
50% 2nd degree burn	4 cal/cm2	2300m
50% 3rd degree burn	8 cal/cm2	1700m
Retinal burn minimum safe distance	-	18 miles
Tinder ignites (leaves, dry rot, etc.)	4-6 cal/cm2	2000m
Newspaper ignites	6 cal/cm2	2100m
Olive-green t-shirt ignites	14 cal/cm2	1450m
Wood charring	15 cal/cm2	1300m

Figure 3. Thermal effects of a 10kt air burst. Calculated by author from Samuel Glasstone and P. J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed. (Washington, DC: 1977), 291.

Thermal radiation will also ignite flammable material around command posts. Cardboard boxes and printer paper easily catch fire. Fuel containers ruptured by the blast wave can catch fire from any smoldering debris.[42] Rubber O-rings and seals melt under high temperatures, which affects equipment serviceability.[43] Nuclear tests even ignited upholstery in automobiles.[44] If a command post is located in a forest or a city, thermal effects can spark mass fires that are catastrophic to equipment and personnel.

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[42] Daniel F. Uyesugi, *Nuclear Notes Number 9: Nuclear Weapons Effects Mitigation Techniques* (Fort Belvoir, VA: US Army Nuclear Agency, 1982), 35.

[43] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters*, Nuclear Matters Handbook* (2020), 228.

[44] Glasstone and Dolan, *The Effects of Nuclear Weapons,* 283.

Thermal radiation travels along line of sight and has virtually no penetrating power. Terrain, walls, vehicles, and even clothing will block thermal radiation. This created the unique burn patterns observed on victims in Hiroshima and Nagasaki who suffered burns only on the exposed skin facing the explosion. More horrific were human silhouettes etched on walls and sidewalks from bodies blocking thermal radiation. Regardless, because minimal amount of cover easily protects against thermal effects, it is not expected to be responsible for the most casualties unless soldiers are caught exposed in the open or very close to the nuclear explosion.

Blast Wave

Most damage from a nuclear explosion comes from the blast wave.[45] Extreme temperatures compress gases near the fireball that quickly expand outward. The resulting overpressure wave creates a crushing effect. A vacuum follows immediately behind it, creating a nearly instant drop in pressure. Air rushes in to fill the vacuum while the hot fireball sucks air back toward the explosion's epicenter.[46] This creates additional dynamic pressure and hurricane-strong winds that rip buildings apart and tumble objects along at high velocities. An air burst maximizes blast wave effects due to a phenomenon called the Mach Stem, in which blast waves reflect off the ground and amplify overpressure.[47]

The velocity and power of the blast wave increases with explosive yield. A 20-kilototon weapon's blast wave moves one mile in three seconds whereas one from a megaton weapon covers one mile in 1.4 seconds.[48] The blast wave then slows to about the speed of sound and

[45] Glasstone and Dolan, *The Effects of Nuclear Weapons,* 80.

[46] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters*, Nuclear Matters Handbook* (2020), 229.

[47] Glasstone and Dolan, *The Effects of Nuclear Weapons,* 89.

[48] Ibid.*,* 83.

takes approximately five seconds to cover the next mile.[49] As the blast wave continues outward, the wall of air widens and overpressure decreases rapidly.

Small amounts of differential pressure can have devastating effects.[50] At 7-9 pounds per square inch (psi) overpressure, concrete buildings are severely damaged or destroyed. Just a five psi pressure differential will cause 160 mph winds and a twenty psi differential causes 472 mph winds.[51] High winds tear apart buildings, rip off antennas, and sweep away satellite dishes and other unsecured equipment. Flying debris would crash into generators, computers, and ancillary equipment. Department of Homeland Security scenarios estimate that a 10-kiloton nuclear blast wave will cause severe damage in an urban area within a half-mile radius and lesser damage out to three miles.[52]

A soldier would see light and feel heat from the nuclear explosion before being hit by the blast wave moments later. Within 300 meters (60psi) of a 10-kiloton blast, there is little chance for survival for troops in the open. More dangerous to humans, however, are the injuries sustained from flying debris, collapsed buildings, and flipped vehicles. In nuclear tests, 5-6 psi overpressure hurled human-sized test dummies over ten feet which increases the likelihood of blunt force trauma death.[53] When considering the secondary effects of the blast wave, the planning factor for a 10-kiloton burst is 50% casualties within a 550-meter radius in open terrain and within a 630-meter radius if in a built-up area.[54]

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[49] National Security Staff and Office of Science and Technology Policy. *Planning Guidance for Response to a Nuclear Detonation,* 2nd ed. (Washington, DC: Office of Science and Technology Policy, 2010), 15.

[50] Overpressure is the excess pressure over normal atmospheric pressure (14.7 psi).

[51] Esther Inglis-Arkell, "How Big of an Explosion Could you Realistically Survive?" *Gizmodo*, April 20, 2011, accessed on 02APR21, https://www.gizmodo.com.au/2011/04/how-big-an-explosion-could-you-realistically-survive/.

[52] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters*, Nuclear Matters Handbook* (2020), 226.

[53] Glasstone and Dolan, *The Effects of Nuclear Weapons,* 554.

[54] Ibid., 558.

Blast Wave Effects	Psi	Distance
Windows shatter	1	4600m
Parked aircraft and helicopters damaged	3	2000m
Wood buildings collapse	4	1800m
Concrete buildings collapse	7-9	1100m
Effects on Humans		
Threshold for eardrum rupture	5	1600m
Threshold for serious lung damage	15	800m
99% fatality rate	60	300m
50% casualties open terrain	-	550m
50% casualties built up terrain	-	630m

Figure 4. Blast wave effects of a 10kt air burst, with Mach Stem. Calculated by author from Samuel Glasstone and P. J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed. (Washington, DC: 1977), 113, 115.

Ionizing Radiation

One of the more pernicious effects of nuclear weapons is the ionizing effects from neutrons and gamma rays. Ionizing radiation is radiation that has enough energy to strip away electrons from atoms, thus ionizing an atom. Gamma rays and neutrons are particularly harmful to living tissue. As they pass through living tissue, they break down cell chromosomes and weaken the cell membrane. Moreover, radiation exposure stunts the cell division process that rebuilds living tissue.

Nuclear radiation is classified either as prompt radiation or residual radiation. Prompt radiation, also referred to as initial radiation, is associated with neutrons and gamma rays released in the first minute of the nuclear explosion. Residual radiation is a byproduct radioactive decay occurring after the first minute of blast. It is predominately a result of nuclear fallout and ground induced radiation.

Neutrons are particles emitted by the nuclear reaction that travel slightly slower than the speed of light. When neutrons collide with other atoms, the excess energy is released as gamma rays, a type of electromagnetic radiation that travels at the speed of light. If not under appropriate cover, soldiers can receive a lethal dose of prompt radiation nearly instantaneously.

Neutrons and gamma rays have incredible penetrating power. Only dense materials or depth of protection will block radiation. For instance, 3.3 inches of steel or 16 inches of earthworks would stop 90% of gamma rays.[55] Because radiation scatters as it hits particles in the atmosphere, protection is needed from all directions to be effective.

The range of gamma rays and neutrons extends well beyond the dangerous distance of blast and thermal effects. At a 1,100 meters slant range from of a 10-kiloton fission weapon, a soldier would receive enough radiation to cause death within one to two weeks. Within 750 meters slant range of the blast, a soldier would die within two days. Soldiers exposed to doses above 300 roentgens would likely become incapacitated from illness and be unable to perform their jobs.[56]

Gamma radiation from a 10kt air burst		
Roentgen Dosage (rads)	**Effects**	**Slant Distance**
50 rads	No effect	1800m
100 rads	vomiting, slight illness	1600m
300 rads	Serious illness – recovery in a few months	1370m
1000 rads	Likely lethal within 1-2 weeks	1100m
5000 rads	Death within 48 hours	750m

Figure 5. Gamma radiation effects from a 10kt fission weapon air burst. Calculated by author from charts in Samuel Glasstone and P. J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed. (Washington, DC: 1977), 333.

Estimating the amount of radiation produced by a nuclear weapon requires nuanced calculations, including variables such as the construction material of the device. As a rule of thumb, higher yielding weapons emit more neutrons and cause more radiation. Thermonuclear nuclear weapons give off more radiation than fission weapons simply due to the unique atomic catalysts of the fusion reaction.[57] Any weapon that uses elements of fusion to boost the nuclear reaction will produce more radiation.

[55] Glasstone and Dolan, *The Effects of Nuclear Weapons*, 337.

[56] National Security Staff and Office of Science and Technology Policy, *Planning Guidance for Response to a Nuclear Detonation,* 2nd ed. (2010), 33-34.

[57] Glasstone and Dolan, *The Effects of Nuclear Weapons*, 345.

Unless a command post is underground with 360-degree protection, it would need to relocate away from ground induced radiation and fallout. Ground induced radiation is the result of atoms in the ground releasing gamma ray radiation as they absorb neutrons from the nuclear explosion. Ground induced radiation is strongest near ground zero and decays to a safe level after approximately five to seven days in normal soil.[58]

Fallout is radioactive material that accumulates as a thin shell around debris particles sucked up into the mushroom cloud. Falling back from the sky, the debris contaminates wide areas. Ground bursts carry more debris and cause significant fallout. On the other hand, a high enough air burst would produce almost no fallout. The extent of the fallout area is a function of the wind spreading the debris carried in the mushroom cloud. A 10-kiloton ground burst would produce a mushroom cloud that reaches 3.78 miles (20,000ft) high in the atmosphere under normal conditions.[59] The 15-megaton ground burst at Bikini Atoll in 1954 caused widest recorded fallout over 7,000 square miles. Fallout fell for ten hours up to 350 miles away from ground zero.[60] Fallout radioactivity decays by the 7–10 rule. Every sevenfold increase in time results in a tenfold decrease in radiation.[61]

Radiation also contaminates equipment and supplies. Contaminated equipment exposes soldiers to additional ionizing radiation much like ground induced radiation. Ingesting contaminated food and water increases the body's absorption rate which often has deadly effects several years later. A command post would need to decontaminate all equipment to mitigate risks to any surviving or replacement personnel.

[58] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters*, Nuclear Matters Handbook* (2020), 236.

[59] Glasstone and Dolan, *The Effects of Nuclear Weapons*, 431.

[60] Ibid., 37.

[61] National Security Staff and Office of Science and Technology Policy, *Planning Guidance for Response to a Nuclear Detonation,* 2nd ed. (2010), 30.

Military equipment that survives the nuclear blast may still have electronic components fail from radiation exposure. Transient radiation effects on electronics (TREE) is damage to electronic components caused by ionizing radiation. Gamma rays disrupt electrons to generate electromagnetic fields in circuitry similar to an EMP. Neutrons collide with atoms in microchips which damages microchip crystal structures and prevents circuitry paths from functioning normally. The result is radiation induced upset or burnout of electronic equipment.

Some analysts discount the damaging effects of TREE since equipment can be designed to resist radiation, called rad-hardening.[62] However, rad-hardening is a matter of cost and priority. As noted in a Defense Science Board review, "many new systems have not been explicitly required to meet nuclear survivability standards from their inception…we simply do not know how the mix of old and new systems will perform together."[63]

Nuclear Electromagnetic Pulse

Ever since the nuclear test ban treaty in 1962 eliminated above ground nuclear tests, scientists have relied on past nuclear test data, simulations, and experiments to verify EMP models.[64] Experts have a good understanding of the EMP but lack consensus on the severity of its effects. The EMP is also prone to over-exaggeration, particularly as fictional cinematic trope that renders all modern technology useless. In reality, the EMP is not certain to be the one-shot wonder weapon as it is often portrayed.

The EMP is a byproduct of the electrical current generated by ionizing radiation knocking electrons from atoms. Detonations above Earth's atmosphere propel gamma rays

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[62] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters*, Nuclear Matters Handbook* (2020), 242.

[63] Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, *The Nuclear Weapons Effects National Enterprise* (2010), 26- 27.

[64] Los Alamos National Laboratories. *EMP/GMD Phase 0 Report: A Review of EMP Hazard Environment and Impacts* (October 24, 2016), 13.

downwards which are captured by Earth's magnetic field. This scatters electrons in the earth's atmosphere which generates an electric current and the high altitude EMP (HEMP). The HEMP spreads down to the ground and covers large areas (figure 4a). A one-megaton device detonated at fifty kilometers above the ground would create a HEMP covering over 600 square miles, roughly the size of the National Training Center at Fort Irwin, California.[65]

The EMP forms differently within the Earth's atmosphere. Ionizing radiation scatters electrons and creates a positively charged blast area and a negatively charged periphery. The radial extent that gamma rays scatter electrons is the "disposition region" or "source region." The scattering electrons generates a powerful electrical field in the source region that is significantly stronger than the HEMP. This electrical field, or source region EMP (SREMP), was considered the primary threat to military electronics within hardened targets such as missile silos during the Cold War.[66]

Theoretically, the source region expands in a perfect sphere and quickly dissipates as counter currents nullify the electrical charge. In reality, the atmosphere or ground deforms the spherical propagation causing an asymmetrical accumulation of electrons in a directional current. The greater the deformation of the sphere, the stronger the current and resulting EMP (figures 6b and 6c).

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[65] Glasstone and Dolan, *The Effects of Nuclear Weapons*, 519.

[66] Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, *The Nuclear Weapons Effects National Enterprise* (2010), 60.

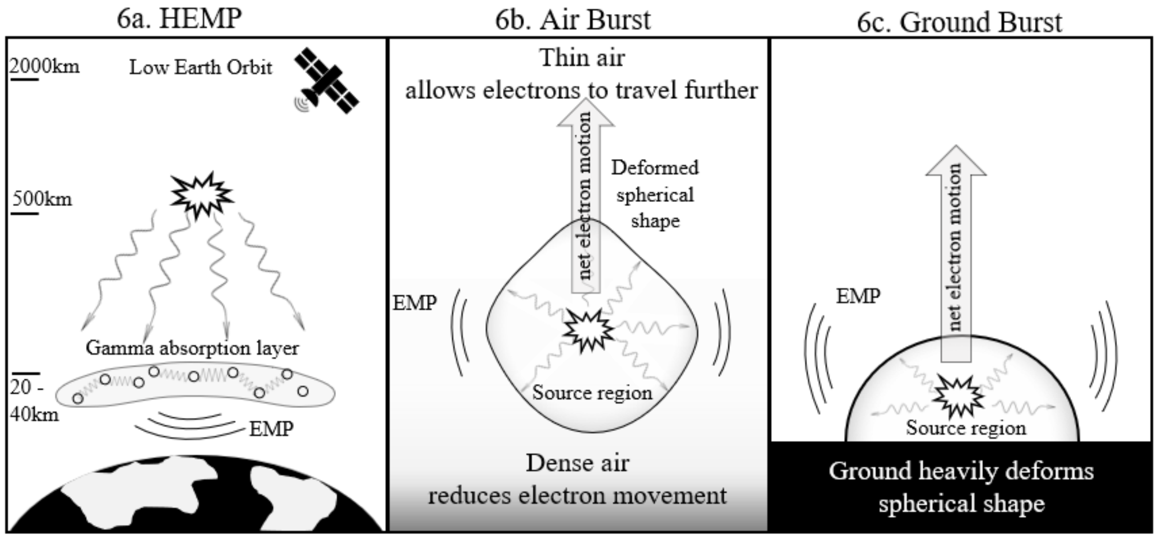

Figure 6. EMP formation. Adapted by author from Samuel Glasstone and P. J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed. (Washington, DC: 1977), 518(6c), and Los Alamos National Laboratories. *EMP/GMD Phase 0 Report: A Review of EMP Hazard Environment and Impacts* (October 24, 2016), 24(6a), 42(6b).

In devices of 10-kilotons or less, the SREMP extends outside the blast wave radius and is a considerable hazard to military electronics that survive the primary nuclear effects.[67] A 10-kiloton ground burst would produce a SREMP reaching between 3.2-8km.[68] The EMP strength drops off significantly outside of the source region and becomes less of a threat.[69]

The EMP is simply a surge of electromagnetic radiation concentrated across a wide range of radio frequencies. Antennas designed to pick up a range of radio frequencies will pick up similar EMP frequencies. The rapid energy spike from the EMP overloads and damages electronics. It is like an opera singer hitting the perfect frequency to shatter glass, but the EMP hits multiple frequencies all at once, increasing its chances of success.

The critical factor for the EMP to damage electronics is its ability to couple with a conductor. The EMP travels most efficiently through the earth's atmosphere between 100

[67] Los Alamos National Laboratories. *EMP/GMD Phase 0 Report: A Review of EMP Hazard Environment and Impacts*, 43.

[68] National Security Staff and Office of Science and Technology Policy, *Planning Guidance for Response to a Nuclear Detonation,* 2nd ed. (2010), 36.

[69] Glasstone and Dolan, *The Effects of Nuclear Weapons*, 518.

kilohertz and one gigahertz.[70] Radios operating in these frequencies, such as FM radios, are most sensitive to the EMP. Antennas and systems designed for ultra-high frequencies outside of the typical EMP range fare better. An Army report published in the 1970s recommended using ultra-high frequency and super high frequency communications equipment on the nuclear battlefield when possible.[71]

Some say modern LYBNWs can produce EMPs more efficiently than larger weapons.[72] Increasing the yield of a nuclear weapon does not necessarily produce proportional increases in the EMP's strength. Even though larger devices create more gamma rays and scatter more electrons, increased counter electrical currents limit the source region's strength.[73] Additionally, as weapon yield increases, the physical damage radius expands faster than the extent of the source region. Large thermonuclear weapons damage areas beyond the source region, so in this case, the SREMP is only a concern for military equipment that can survive the initial nuclear blast.[74] This means low-yield weapons produce an EMP more efficiently relative to other nuclear effects than larger weapons.

There is a tradeoff between using a LYBNW in a ground burst for localized, strong SREMP and using one in a high altitude burst to create a widespread but weaker HEMP. The HEMP causes most concern for national infrastructure survivability. Vulnerability of the national power grid, cell towers, computer networks, and industrial control systems are often subject to congressional inquiry. Some publications state that the HEMP can have "devastating

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[70] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters*, Nuclear Matters Handbook* (2020), 241.

[71] Uyesugi, *Nuclear Notes Number 9: Nuclear Weapons Effects Mitigation Techniques* (1982), 31.

[72] Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, *The Nuclear Weapons Effects National Enterprise* (2010), 61.

[73] Los Alamos National Laboratories, *EMP/GMD Phase 0 Report: A Review of EMP Hazard Environment and Impacts*, 27.

[74] Ibid., 43.

consequences."[75] But, physicist Jack Steinberg argues that the HEMP threat is exaggerated and should not precipitate significant funding to overprotect domestic infrastructure. His calculations indicate that maximum energy surge from a HEMP is not significant enough to cause widespread damage.[76] To complicate matters, there is no guarantee that the EMP cause damage even if it reaches electronic equipment. The EMP path of travel through an electronic system is dependent on many intricate circuitry details so it is difficult to analyze system failures beforehand.[77]

Ionization of the Atmosphere

Radio communications are carried on electromagnetic waveforms created by an antenna oscillating electrons. A receiving antenna interprets the waveform into the radio message. A nuclear blast ionizes parts of the atmosphere with an abundance of free electrons. If communication transmissions enter an ionized area, the free electrons decay or bend the signal.

A burst near the surface or at lower altitudes creates an ionized area up to tens of kilometers.[78] Fortunately, it dissipates within in a few minutes as the free electrons recombine with neutral particles. As altitude increases, the lower air density allows ionizing radiation to travel further and persist longer. A burst fifty kilometers above the battlefield would cause a large ionized area that could interfere with ground to satellite communication links for a few hours.[79] The worst blackout occurs at the epicenter of an explosion. Radio waves would not be able to

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[75] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters*, Nuclear Matters Handbook* (2020), 241.

[76] Christopher W. Blair, Casey Mahoney, Shira E. Pindyck and Joshua A. Schwartz, "Trump issued an executive order to prepare for an EMP attack. What is it, and should you worry?" *The Washington Post*, March 29, 2019, accessed on 02APR21, https://www.washingtonpost.com/politics/2019/03/29/trump-issued-an-executive-order-prepare-an-emp-attack-what-is-it-should-you-worry.

[77] Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, *The Nuclear Weapons Effects National Enterprise* (2010), 60.

[78] Office of the Deputy Assistant Secretary of Defense for Nuclear Matters*, Nuclear Matters Handbook* (2020), 243.

[79] John A. Berberet, *Nuclear Notes Number 4: Nuclear Blackout of Tactical Communications* (Fort Bliss, TX: US Army Nuclear Agency, 1976), 14.

pass through the heavily ionized fireball region for a few seconds up to several minutes.[80] The chance of radio blackout decreases the farther away the signal is from the ionized area.

Burst type	**Estimated duration of blackout to line of sight communications**	**Estimated duration of blackout to satelliete communications**
Ground	Few seconds to a few minutes	Negligible
Low altitude	Few seconds to 1 minute	Negligible
High altitude	Few seconds to few minutes	Minutes to hours

Figure 7. Ionization radio blackout duration. Adapted from John A. Berberet, *Nuclear Notes Number 4: Nuclear Blackout of Tactical Communications* (Fort Bliss, TX: US Army Nuclear Agency, 1976), 19-22.

Implications for Command and Control in Multi-Domain Operations

#1. An Army corps can still C2 ground forces after a nuclear strike

A single 10-kiloton LYBNW strike would not destroy an Army corps' ability to command and control land forces due to the redundancy and distribution of a corps' C2 system. The corps has up to four command posts that can easily operate at distances beyond the radii of nuclear effects of a LYBNW.[81] The corps controls operations from the main command post. The smaller tactical command post and mobile command group deploy from the main command post and are both capable of maintaining limited C2 during operations.[82] Corps can also establish a support area command post (SACP) which almost always co-locates with the maneuver enhancement brigade separate from the main command post.[83] Each division assigned to the corps has multiple command posts that provides additional redundancy.[84] It would take several accurate LYBNW strikes to physically destroy the majority of the corps' C2 structure unless it was all co-located in a single area.

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[80] Glasstone and Dolan, *The Effects of Nuclear Weapons,* 470.

[81] Reference figures 3, 4, 5, and 7 for nuclear effect distances.

[82] US Department of the Army, Army Techniques Publication (ATP) 6-0.5, *Command Post Organization and Operations*, (Washington, DC: Government Printing Office, 2017), 1-4.

[83] US Department of the Army, Field Manual (FM) 3-0, *Operations,* (Washington, DC: Government Printing Office, 2017), 2-37.

[84] US Army, ATP 6-0.5 (2017), 1-5.

Ionization, which can disrupt or blackout electronic communications, covers a wider area than the primary effects of a 10-kiloton nuclear weapon. The command post has no direct protection against radio blackout, but it is easily mitigated. First, ionization does not affect communications through fiber optic cables which send data by light. Second, satellite links would likely be available since ionization would be localized in a low-altitude burst that targets land forces. Another mitigation technique is to simply relay communications through other stations around the ionized region until it dissipates.[85]

Ionization illustrates the importance of a PACE plan (primary, alternate, contingency, emergency) and redundant communications. A corps headquarters can communicate via satellite, line of sight radio, and fiber optic cable or wire. To blackout the totality of a corps' communications, an adversary would need to disrupt satellite links with well-placed high altitude burst over the battlefield, cut fiber optic line connections with cratering ground bursts, and ionize much of the lower atmosphere with multiple detonations to block line of sight radio transmissions. The C2 network appears relatively resilient to blackout, short of massive nuclear exchanges.

Recommendations for EMP protection depend on sufficient early warning of a nuclear strike. Recommendations for military units deployed in the field include actions such as disconnecting antennas from radios, shortening power cables to reduce surface area exposed to the EMP, or shielding electronics by storing them in fully enclosed metal cases.[86] Since having early warning is not a given fact, the SREMP radius is the limiting factor in assessing maximum potential EMP damage. Again, the corps' command structure has redundancy of command nodes

[85] John A. Berberet, *Nuclear Notes Number 4: Nuclear Blackout of Tactical Communications* (Fort Bliss, TX: US Army Nuclear Agency, 1976), 27.

[86] Uyesugi, *Nuclear Notes Number 9: Nuclear Weapons Effects Mitigation Techniques* (1982), 31.

operating at distances beyond the SREMP radius. Also, the EMP is not a lingering effect so any new equipment brought into the area will function normally.[87]

#2. However, a nuclear strike will degrade C2 for minutes to days

Although a single LYBNW would not destroy a corps' C2 system, it would degrade overall system effectiveness. The challenge on a nuclear battlefield is to regain operational tempo by restoring and replacing damaged components of the C2 system.

People are the most vulnerable part of the C2 system. If commanders and staff officers are wounded or killed, command and control is hindered until the corps backfills losses. This process could take a few hours if succession of command plans are well-rehearsed. When needing personnel replacements, the process could take days.

Command posts are highly susceptible to physical nuclear effects. Clearly, a direct hit would be catastrophic. A nearby nuclear strike would disrupt the pace of operations until survivors relocate the command post away from residual radiation, decontaminate equipment, tend to wounded personnel, and replace any damaged equipment. These processes can be an all-day event for a corps headquarters. Reconstituting a totally destroyed command post with new equipment and personnel would take longer.

The EMP and TREE damages internal electronic components in radios and computers that are not readily available at front line units. A command post would have to rely on any surviving communications until logistical depots in the rear repair or replace equipment. Additionally, the corps is exposed to an increased set of vulnerabilities if it is reliant on civil infrastructure to maintain a C2 network. This could be the case for forward deployed headquarters that have a long-standing presence in buildings or garrisons. The EMP effects on civil infrastructure, while unpredictable, requires a more sophisticated response to re-establish the

[87] National Security Staff and Office of Science and Technology Policy, *Planning Guidance for Response to a Nuclear Detonation,* 2nd ed. (2010), 36.

network. Having partnerships with civil authorities or having the ability to quickly standup an alternate field network are some options.

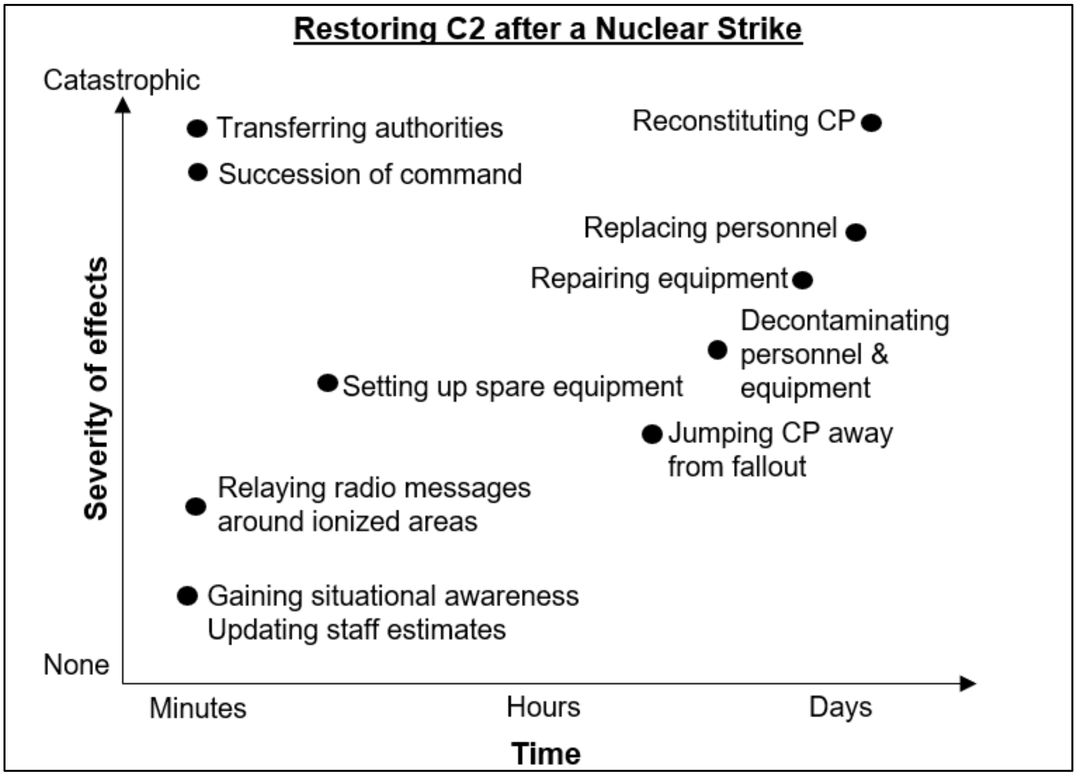

Figure 8. Restoring C2 after a nuclear strike. Created by author.

#3. JADC2 can increase C2 resiliency to nuclear strikes

There are several methods to reduce risk of nuclear effects on the C2 system. The most straight forward way is to harden command posts or place them underground to withstand nuclear strikes. Another method is having multiple command posts to provide redundancy. This also allows "echelon bypass" in which a higher headquarters assumes command when a lower headquarters is destroyed. Military assessments during the Cold War recommended a combination of all of the above protective measures.[88]

[88] Wiles, Richard I., Davis E. Reed Jr., Herbert T. Casey, and William R. Kraft Jr. *A Net Assessment of Tactical Nuclear Doctrine for the Integrated Battlefield* (Washington, DC: Defense Nuclear Agency, 1980), 146-147.

Some of the suggested protective measures may not be suitable for MDO or military budgets in the near future. First, heavy radiation shielding or underground C2 bunkers sacrifices mobility that may be required for a corps in the field. Second, the lack of an overt threat of nuclear war over the past few decades has made it difficult to justify the cost to harden conventional military equipment against TREE. As one report notes, hardening of equipment to allow "fighting through" nuclear effects have been long neglected.[89] Furthermore, military C2 networks are often enabled by commercial off-the-shelf (COTS) electronics that are not built to military nuclear survivability specifications. Even if critical components of JADC2 are rad-hardened, COTS equipment, air conditioning systems, or power generators could still be vulnerable.

Attempting to harden every new C2 system is also counter to the JADC2 philosophy of staying abreast with leading innovation. Avoiding cumbersome military acquisition requirements helps JADC2 evolve at the pace of innovation. Rad-hardening will most likely be an afterthought if speed of innovation is prioritized. It is safe to assume that in the future the US Army will field interdependent systems with a mixed level of protection.

An alternative to protecting everything is to leverage JADC2 to multiply the number of C2 nodes. AI enabled software could create smaller, more efficient command posts that can proliferate across the battlefield. It also can help accelerate echelon bypass so that a command post seamlessly assumes the duties of another. System resiliency increases with more nodes which also presents a more complex problem to the enemy.[90]

JADC2 also allows for increased standoff. A command center at Fort Lewis, Washington can process target data just effectively as a forward deployed command post in Yuma, Arizona as

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[89] Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, *The Nuclear Weapons Effects National Enterprise* (2010), 16.

[90] Heather Penney at The Mitchell Institute, "Aerospace Nation: Actualizing Joint All Domain Command and Control--The Way Ahead," accessed on 02APR21, https://www.youtube.com/watch?v=AdzXInAUV24&feature=emb_title.

demonstrated by the recent Project Convergence exercise. The dispersion of the nodes across the globe provides redundancy and standoff from localized nuclear effects.

The argument that JADC2 adds resiliency to the overall system rests on the assumption that each command node is equal. In reality, losing a main command post, a data center, or a key commander are larger setbacks than other nodes. JADC2 improves resiliency of transferring data at machine speeds throughout the network across multiple nodes, but it ignores the human aspect of commanding and managing operations. Transitions create friction and it takes time for a new commander to appraise unfamiliar situations. Martin Van Creveld argues that a single communications or data processing technology, such as JADC2, will not guarantee adequate C2 in war.[91] Although JADC2 may create a resilient kill web, it may not be as effective addressing other functions of command.

#4. Burdens on the C2 system increase with dispersed maneuver in MDO

Early nuclear strategists pondered how maneuver would change with the introduction of nuclear weapons on the battlefield. In the offense, they imagined nuclear weapons would destroy enemy positions and an advancing army would clear any survivors. A defender would strive to destroy massed troops concentrations at terrain choke points while covering any gaps between pockets of resistance with organic nuclear artillery. A mobile or airborne counter-attack would quickly follow to regain the initiative.[92]

When facing a firepower induced stalemate, a penetration accompanied by massive firepower tends to become the preferred form of maneuver. World War I tacticians focused on achieving a breakthrough with massed artillery on a narrow section of the front that cavalry could exploit and restore maneuver to the battlefield. Similarly, nuclear tacticians imagined nuclear

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[91] Creveld, *Command in War,* 261.

[92] Michael Carver, "Conventional War in the Nuclear Age" in *Makers of Modern Strategy*, ed. Peter Paret (Princeton, NJ: Princeton University Press, 1986), 782-783.

weapons would blast open enemy defenses so that exploitation forces could pass through.[93] Today, MDO aims to penetrate into A2/AD bubble by dis-integrating it with an overwhelming convergence of fires and effects and then exploit the resulting breakthrough.

The problem is that firepower is equally effective in breaking up offensive penetrations. Dropping a LYBNW at the point of penetration effectively closes the breach by destroying the attacking force or, at the very least, isolating it from follow on forces with residual radiation. The effects of massed rocket fires with modern conventional munitions are equally dangerous. In 2014, a Russian rocket attack destroyed two Ukrainian tank battalions in an assembly area.[94] A penetration along a single line of operation in MDO is highly vulnerable to a LYBNW as well as massed conventional firepower.

Thus, MDO will likely require smaller penetrations or even infiltration-like raids to remain survivable against modern firepower and LYBNWs. The echelon for MDO operations could be battalion-sized or smaller to survive the destructiveness of firepower. During the pentomic era, the problem was building self-contained, self-supporting units to maneuver outside the mutually supporting distances provided by artillery of the day. Today, the challenge is maintaining connectivity to have access to on-call global support. Modern communications give small pockets of forces the ability to call in massive amounts of long-range fires and cross-domain effects originating anywhere in the world.

Two factors need to be considered for JADC2 when dispersing on the battlefield. First, linking more units, sensors, and shooters to a command post's network affects the span of control. It creates a similar predicament that the Pentomic Division experienced when assigned too many maneuver battlegroups. The important aspect for JADC2 is machine-human interfaces enhancing

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[93] Bacevich, *The Pentomic Era: The U S Army Between Korea and Vietnam,* 109-110.

[94] Amos Fox, "The Russian–Ukrainian War: Understanding the Dust Clouds on the Battlefield," *Modern War Institute,* January 17, 2017, accessed on 26MAY21, https://mwi.usma.edu/russian-ukrainian-war-understanding-dust-clouds-battlefield/.

effective C2 beyond the normal span of control so that the staff and commander are not overwhelmed.

Second, the carrying capacity of the electromagnetic spectrum (EMS) and satellite bandwidth limits the number of sub-units on a network. The EMS becomes more congested as more units try to push communications on a given frequency. More congestion on the spectrum increases the chance of radio interference. Using more digital data requires higher bandwidth. Considering that military satellites have a fraction of the bandwidth as civilian satellites, MDO will require better data throughput in the next generation of military satellites or the ability to use excess civilian bandwidth. Until then, bandwidth is a limiting factor that will likely require commanders to allocate and prioritize C2 capacity during an operation.

#5. JADC2 infrastructure needs survivability similar to NC3.

Connecting front-line forces to assets anywhere in the world with JADC2 can potentially change the way an adversary calculates targeting American forces. If a command post in the continental United States can command and control operations across the globe, an adversary will never be able to kinetically destroy the central of C2 node without extending their targeting beyond the theater of operations. A rational actor may show restraint by only striking forces in the theater of war to avoid escalation. Others may consider striking satellites, data centers, and fiber optic exchange points that are critical enablers for a corps on the battlefield.

Satellite communications allow militaries to maintain global C2 connectivity. Without satellites, military communications rely on line-of-sight radio systems or laying fiber optic cables to connect the front with data servers in the rear. The first anti-satellite weapons were nuclear warheads detonated near satellites. Precision weapons allow more selective targeting, but the nuclear option remains. A rogue regime who is less dependent on space-based assets and lacks precision weapons may be less circumspect on their attack methods.

Destroying satellites and cluttering space with debris may not be as desirable as hitting a few data choke points on the earth. Everything relayed to and from space goes through ground entry point. Adversaries can also target physical warehouses that house the JADC2 servers. To ensure JADC2 functionality in the future, data choke points must be protected or have the redundancy to achieve survivability similar to nuclear command, control and communications (NC3).

#6. Layering effects with nuclear weapons can isolate parts of the battlefield

US Army doctrine has historically recognized no change to operating concepts in the event nuclear weapons were employed. First, it assumed that there would be sufficient warning of a nuclear strike to transition from a conventional to a nuclear posture.[95] This conveniently allowed doctrine writes to ignore nuclear effects on conventional operations, with the exception of the pentomic doctrine that was designed specifically for nuclear warfare. In the 1950s, one colonel lamented that the Army never seriously considered how it would "fight under the conditions that a nuclear war would create in a forward area."[96] Operations manuals from the 1980s assumed the Army would continue to fight conventionally in a nuclear environment, albeit degraded and at a slower pace due to decontamination and increased protection requirements.[97] Today, the MDO concept assumes nuclear weapon use would necessitate an entirely different operational approach.[98]

Yet, emerging technologies coupled with LYBNWs open new possibilities on the battlefield that threaten the integrity of C2. Nuclear weapons could physically isolate or destroy forward forces while electronic jamming could break the C2 connections between forward units and their enablers, reserves, and higher headquarters. Moreover, a nuclear strike close to a

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[95] Wiles, *A Net Assessment of Tactical Nuclear Doctrine for the Integrated Battlefield* (1980), 11.

[96] Bacevich, *The Pentomic Era: The U S Army Between Korea and Vietnam,* 133.

[97] Wiles, *A Net Assessment of Tactical Nuclear Doctrine for the Integrated Battlefield* (1980), 12.

[98] US Army, TRADOC Pamphlet 525-3-1 (2018), A-1.

military formation creates a massive physical disruption. The tempo of military operations slows significantly as land forces must respond to casualties, displace from radiation, and decontaminate. That is a significant task on its own, even for well-trained formations. A nuclear strike layered with EMS jamming or a cyber-attack could be the tipping point that plunges even the most professional units into paralysis. Unless JADC2 is resilient in an EMS-denied, intermittent, and low-bandwidth environment, layering effects could be decisive in achieving momentary, localized advantage over US forces.

Conclusion

Nuclear weapons present a complex set of hazards to a military force on the battlefield. The effects from a LYBNW are not as widespread as megaton-class weapons, but a 10-kiloton device will still cause severe damage within a half mile radius. Thermal radiation can burn exposed personnel beyond a mile. Radiation is extremely deadly at far distances to personnel and non-hardened electronics. Limiting exposure to radiation is also partly a matter of moving away from, and then avoiding, contaminated fallout areas. The SREMP of a LYBNW extends beyond all other nuclear effects and is a serious, but unpredictable threat to military electronics.

The nuclear effects from a 10-kiloton LYBNW do not cover the entirety of a corps battlespace. A corps can deploy multiple command posts with enough separation distance to avoid losing all C2 nodes in a single LYBNW low-altitude air burst. A robust PACE plan using a mix of radios, fiber optic cables when available, and satellite communications protects against a nuclear strike eliminating connectivity between the corps and subordinate units. However, a LYBNW that detonates near a C2 node will disrupt the operational tempo of an army corps as it must repair, replace, and decontaminate equipment and personnel.

The pentomic doctrine in the 1950s relied on dispersion and flexibility to survive the nuclear battlefield. Unfortunately, army divisions were ill equipped and lacked C2 technologies to make it practical and the doctrine was quickly discarded. Likewise, the US military today is pursuing JADC2 to realize the potential of the MDO concept. MDO envisions a dispersed battlefield with land forces penetrating adversary defenses to dis-aggregate A2/AD systems. JADC2, consequently, must have sufficient carrying capacity on the EMS and satellite bandwidth to connect the proliferation of sensors and units across the battlefield. All this must be bounded within the effective span of control possible for a corps headquarters, potentially augmented with machine-human interfaces.

As JADC2 evolves to create global, continuous connectivity between military forces, JADC2 infrastructure in the continental United States become tempting targets for adversaries. Striking satellites or server warehouses outside the theater of war is risky business and has strategic consequences. But, ensuring redundancy and hardening the physical infrastructure supporting JADC2 should not be overlooked.

Another approach that may be more palatable for adversaries would be layering nuclear weapons with other non-kinetic effects to isolate areas of the battlefield, something that current US operational doctrine for conventional forces has not yet considered in detail. As the multi-domain operations concept evolves in tandem with emerging command and control systems, the military should stay cognizant of underpinning nuclear assumptions. Assuming that the force will have time to transition from a conventional to a nuclear posture may catch the US off guard in the critical opening moments of a conflict. Additionally, limited nuclear employment can disrupt operational tempo and provide adversaries a momentary, localized advantage over US forces. But with careful examination, deliberation, and innovation, the MDO concept and JADC2 can evolve to address the unique challenges posed by the nuclear battlefield.

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