Countering WMD

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U.S. Army Nuclear and Countering WMD Agency

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Mission Statement

The Countering WMD Journal is published semi-annually by the U.S. Army Nuclear and Countering WMD Agency. It furthers the education and professional development of military leaders and members of government and academia concerned with the nuclear and countering WMD matters.

Article Submission

We welcome articles from all U.S. Government agencies and academia involved with Countering WMD matters. Articles are reviewed and must be approved by the Countering WMD Journal Editorial Board prior to publication. Submit articles in Microsoft Word without automatic features; include photographs, graphs, tables, etc. as separate files. Please email us for complete details. The editor retains the right to edit and select which submissions to print. For more information, see the inside back-cover section (Submit an Article to Countering WMD Journal) or visit our website at www.usanca.army.mil/.

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About the cover

Soldiers perform chemical, biological, radiological and nuclear operations in full chemical gear at Camp Arifjan, Kuwait, May 18, 2016. The soldiers are assigned to 369th Chemical Company, an Army Reserves unit. Army photo by Sgt. 1st Class Marisol Walker.

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Notes from the Director

COL Pat Nikkila

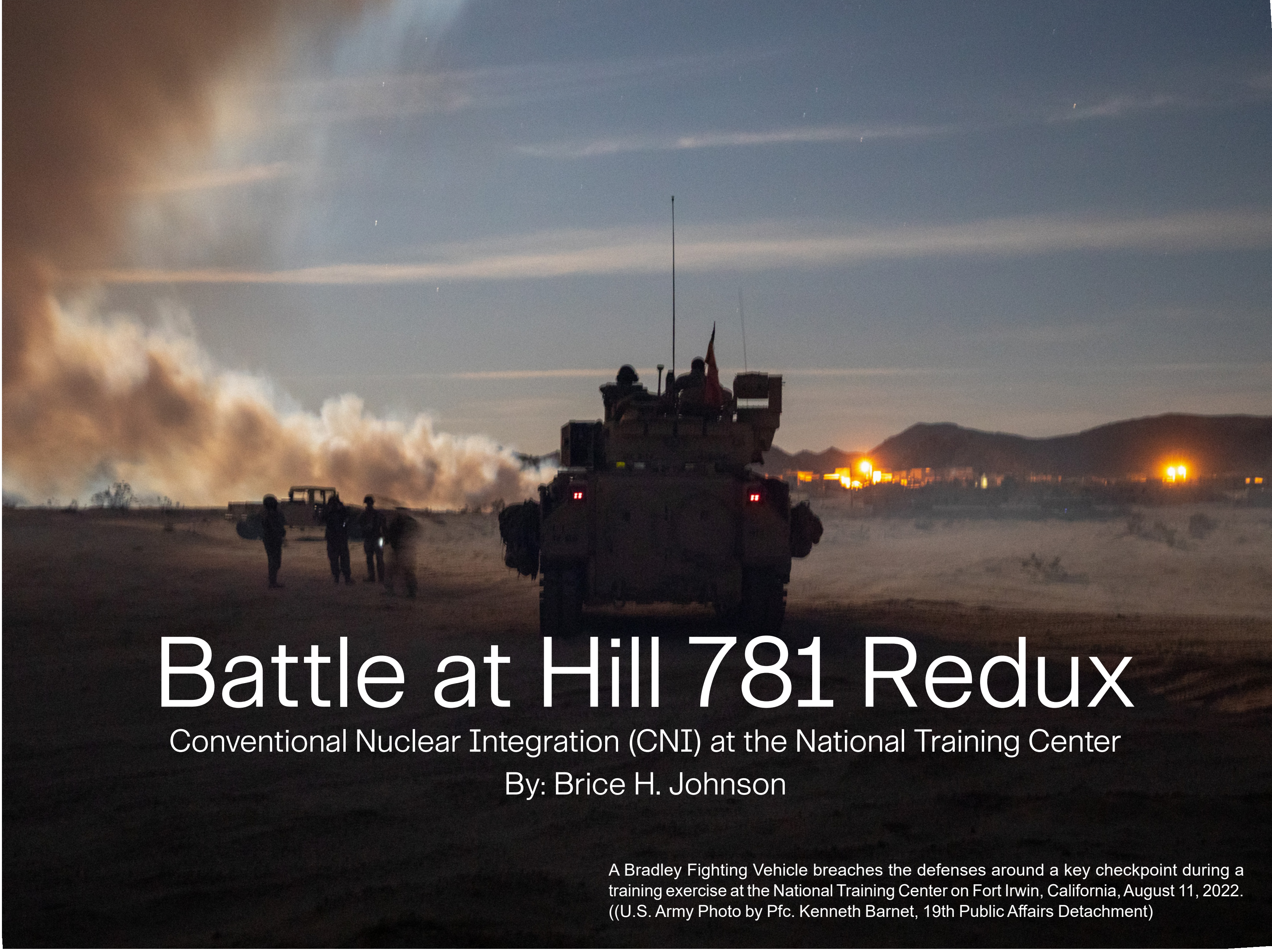
Welcome to another great issue of the Countering Weapons of Mass Destruction (WMD) Journal. As USANCA Director for the past year, I have had a chance to travel and visit many of you and your organizations. I have seen, first-hand, your teams' efforts in advancing and increasing the Army's and Joint Warfighter's Countering Weapons of Mass Destruction (CWMD) communities', impacts on modernization, deterrence, and relevance. I continue to be incredibly impressed by the contributions and accomplishments of our community and all Nuclear and CWMD stakeholders as we continue to provide our Nation with strategic deterrence options, CWMD advice, and planning expertise. While we continue to make improvements to our CWMD plans, policies, and capabilities, we must recognize that our adversaries are improving their abilities to acquire, develop, and potentially employ a broad range of chemical, biological, nuclear, radiological, and explosive devices. As the speed of change increases in our strategic environment, we as an Army, must have the capabilities and capacities to deter the use of WMD anywhere in world, shape the environment to create conditions unfavorable to WMD proliferation, and if required, fight and win in contaminated environments to achieve national objectives. Our nation is counting on us.

USANCA and the entire Nuclear and CWMD community continue to represent the Army's equities in nuclear and CWMD matters throughout the Department of Defense. The collaboration of FA52s with other CWMD stakeholders has enhanced the CWMD readiness posture of the Army, and USANCA is making strides toward a more lethal and survivable force. We continue to lead Army Campaign Objective 10B to Enhance CBRN Readiness. While simultaneously preparing to execute programs to address biodefense gaps within the Army.

In addition to these resourcing efforts, USANCA continues to pursue changes in doctrine, training, and education required for multi-domain operations. We are focusing on several initiatives to enhance Army readiness and increase deterrence by demonstrating to our adversaries that our Army can compete and win in contaminated battlespaces. USANCA's Nuclear Employment Augmentation Teams (NEATs) continue to support the integration of US nuclear weapon effects into joint operations in coordination with the geographic Combatant Commands and USSTRATCOM. The teams provide preclusion analysis products to enable planning while also informing and educating leaders and staffs on the impacts of nuclear employment on conventional operations. To improve CBRN-Defense readiness, we are developing relevant metrics to assess formations readiness to conduct core and assigned tasks in CBRN environments. As the office of primary responsibility (OPR) for Biodefense, USANCA continues to implement the Army Biological Defense Strategy (ABDS) to address natural, accidental, and/or deliberate biological incidents. Additionally, USANCA is supporting a broad range of study programs focused on creating strategic options and informing Army senior leadership decisions in the nuclear and CWMD battlespace. USANCA continues to support the Army Science Board in its Secretary of the Army-directed study of the Army's ability to fight and win on a nuclear battlefield.

In this issue of the Countering WMD Journal you will first notice our new format. To reach a wider audience while continuing to serve our dedicated contributors and readers, we have modified the construction and appearance of the Journal. Please let us know what you think as we appreciate and value your feedback. This issue features 11 articles organized around our FY23 Themes of deterrence, relevance, and modernization. Additionally, there are several articles that address technical aspects of our work. Between the covers, you will find an account of revisiting Hill 781 at the National Training Center with conventional nuclear integration (CNI) at the forefront; an update on USANCA partnering efforts to evaluate the radiation protection provided by U.S. Army vehicles; a review of potential improvements to Armed Forces Pandemic Response Policy; an illustrative look at the capabilities and limitations of theater nuclear operations planning tools; an examination of using system engineering trade analysis applied to aeromedical evacuation; a case study in nuclear events software usability testing as well as articles on great power competition, reducing exposure to airborne pathogens, backscatter imaging in explosives detection, and an argument for greater emphasis on science, technology, engineering, and mathematics competencies within the officer corps.

There is no shortage of work for the USANCA team and the CWMD community at large. Our adversaries' capabilities and ambitions are expanding. We will continue to stay focused on developing solutions that enable the Army, in conjunction with our Allies and Partner, to fight and win in contaminated environments. The work you do is essential, important, and necessary. We at USANCA strive to support you, the wider nuclear and CWMD community, with regards to plans and operations, testing, policy, doctrine, effects analysis, and advocacy for our nation's security requirements. Please do not hesitate to let us know how we can help. Also, please send us your comments and ideas on how we can provide better support or improve the Countering WMD Journal. ■



Battle at Hill 781 Redux

Conventional Nuclear Integration (CNI) at the National Training Center

By: Brice H. Johnson

A Bradley Fighting Vehicle breaches the defenses around a key checkpoint during a training exercise at the National Training Center on Fort Irwin, California, August 11, 2022. ((U.S. Army Photo by Pfc. Kenneth Barnet, 19th Public Affairs Detachment)

Then: Catalyst for Change

As the brigade commander prepared for the brigade's rotation to the National Training Center (NTC), the commander focused on proficiency in the mission essential tasks necessary to ensure the brigade was fully proficient and combat ready in the event of a real-world deployment. The commander planned to demonstrate proficiency in the following tasks: movement to contact, conduct a deliberate attack, conduct an area defense, and conduct sustainment operations.

At one of several pre-deployment update briefings, the Division's Commanding General asked, 'Is the brigade proficient in breaching an obstacle and is that something the brigade needs to exercise and evaluate as part of the rotation?' The commander carefully considered the question and then responded, "Breaching an obstacle is a very important task but we have an engineer detachment that can address that contingency. Due to time and resource constraints, we need to use our NTC rotation training opportunity as effectively as possible. Movement to contact, fires, and maneuver on the objective are higher priority tasks."

The brigade subsequently deploys to the NTC, develops a masterful movement to contact plan and a brilliant scheme of maneuver to seize its objectives. However, shortly after crossing the line of departure, the main effort encounters a substantial obstacle blocking the entire movement corridor. The opposing force commander, realizing the OPFOR lacked sufficient force structure and firepower to defeat the attacking brigade directly, employed superior knowledge of the 'home field' terrain to block and channelize the attacking formations. The engineer detachment was not properly equipped and organized for a breach. Additionally, the 'contingency' breaching operation was not integrated into the brigade's plan. Consequently, the brigade attack stalls, the opposing force exercises its well-planned mobile defense anchored on the obstacle and destroys the brigade's main effort. The brigade, now mired with casualty evacuation, equipment recovery, and mission command challenges, never has the opportunity to conduct its maneuver plan and falls well behind its planned rotational schedule. The brigade cannot demonstrate proficiency in most of the mission essential tasks identified for the rotation.

This vignette is representative of many offensive operations conducted at the NTC. A review of Center for Army Lessons Learned material related to obstacle breaching is illustrative and presents an interesting analogy when consid ering the current environment. In the case of obstacles, the Service recognized and addressed the challenges and shortcomings associated with combined arms breaching operations. In 1999, Training and Doctrine Command (TRADOC) developed a trends-reversal program to address several mission essential tasks and combined arms breaching was high on the list for review and assessment.[1] TRADOC further designated NTC Rotation 00-10 as a combined arms breach-focused rotation.[2]

Trends related to obstacle breaching requiring reversal included inadequate reconnaissance and surveillance planning, poor terrain analysis, poor breach planning, poor preparation, and unsynchronized execution.[3] Collectively, the maneuver community continued to struggle with breaching operations, initially addressed under a mobility, survivability, NBC battlefield operating system (BOS) construct, CBRN and WFF in contemporary parlance. The Engineer community worked to develop techniques for organizing, properly equipping, planning, breaching, marking, traffic control, Intelligence Preparation of the Battlefield (IPB) and overall integration into brigade-level planning while brigade plans failed to identify and address brigade breaching operations responsibilities.[4] Brigade staffs continued to focus on maneuver schemes, actions on contact, movement to the objective and actions on the objective. Based on NTC trends, this tendency continued through the early part of 21st century rotations with incremental improvements in engineer equipping and organization and very gradual improvements in platoon and company-level unit proficiency in organizing for and improving techniques for breaching obstacles.[5] However, brigades struggled to develop schemes of maneuver using the breaching fundamentals, breaching organization, mass, and synchronization.[6]

The maneuver force mindset continued to prioritize fire and maneuver, actions on contact, and actions on the objective ahead of breaching, an activity proceeding and critical to meeting brigade-level training objectives. Trends from 2003 continued to read ‘Brigades struggle to develop schemes of maneuver using breaching fundamentals, breaching organization, mass, and synchronization.’[7] Some progress is evident as breaching trends from 2004 were more focused on Brigade and Task Force planning and execution. This change in emphasis demonstrates that engineer and maneuver forces were better equipped and organized to conduct combined arms breaching operations, but that brigade and task force plans lacked the required level of detail necessary to successfully execute combined arms breaching operations. Perhaps the greatest lesson learned was a collective recognition that breaching operations were a commander’s responsibility requiring detailed staff planning, coordination and synchronization.

Recognizing the real world need for proficiency in combined arms breaching operations against the context of threat capabilities, senior leaders directed its inclusion as a critical task in NTC rotations. Consequently, the NTC continued to present obstacles, requiring planning, organization, and synchronization, to maneuver units. The units began to recognize the need to organize equip, plan and train to successfully breach obstacles while maintaining momentum in the attack and to reach, fire and maneuver on, and seize attack objectives. While never perfect, maneuver brigade commanders and, consequently, staffs recognized the importance of planning for and synchronizing combined arms breaching operations.

Additionally, lessons learned from the NTC, other Combat Training Centers (CTC), and the Battle Command Training Program were captured in after action reviews (AARs) and collated in tactics techniques and procedures. The lessons were further codified in doctrine and integrated across Professional Military Education. In this way, the Army built the necessary subject matter expertise and formations that were properly trained, equipped and cognitive of effective combined arms breaching operations. Units started to plan, train, and organize to meet the requirements for successful execution. However, as the maneuver community began to gain proficiency in combined arms breaching operations, world events changed the focus of both NTC rotations and brigade-level mission essential tasks.

A review of Center for Army Lessons Learned material related to obstacle breaching presents interesting similarities when considering the current environment and the concept of Conventional Nuclear Integration (CNI). In the case of obstacles, the Service recognized the challenges and shortcomings associated with combined arms breaching operations and addressed the challenge. In the case of CNI, the Army also recognizes potential shortcomings and is taking positive steps to address the challenge.

Fast Forward: Time for a new Catalyst

As the brigade commander prepared for the brigade’s rotation to the NTC, the commander focused on proficiency in the mission essential tasks necessary to ensure the brigade was fully proficient and combat ready in the event of a real-world deployment. The commander planned to demonstrate proficiency in the following tasks: conduct movement to contact, conduct attack, conduct a defense, and conduct area security.

At one of several pre-deployment update briefings, the Division Commanding General asked, ‘Can the brigade operate in a post nuclear strike environment and is that something the brigade needs to exercise and evaluate as part of the rotation?’ The commander carefully considered the question and then responded, “Continuing operations in a post nuclear strike environment is a very important task but we have just sent our S3 and S3 Air to the Theater Nuclear Operations Course and Nuclear Weapons Orientation Course, where they earned a 5H skill identifier. In addition to that expertise, we have CBRN enablers attached for the rotation. They have the equipment and expertise to address that contingency and *ensure the brigade's ability to successfully accomplish the assigned mission. A nuclear attack will just stop our training and it seems imprudent to have the brigade sit idle while we wait for enablers to solely deal with a high risk but very low probability event! Due to time and resource constraints, the brigade needs to use its NTC rotation training opportunity as effectively as possible. Movement to contact, fires, and maneuver on the objective are higher priority tasks."*

The brigade subsequently deploys to the NTC, develops a masterful movement to contact plan and a brilliant scheme of maneuver to seize its objective. However, shortly after crossing the line of departure, lead reconnaissance forces strike a low-yield nuclear landmine. The main effort halted its advance, unsure of the effects of the post nuclear attack environment on its ability to maneuver. The opposing force commander, realizing the OPFOR lacked sufficient force structure and firepower to defeat the attaching brigade directly, employed a tactical nuclear device augmented by superior knowledge of the 'home field' terrain to block, delay, and confound the attacking formations. The brigade was not properly equipped and organized to fight, survive, and win in a nuclear environment. The attached CBRN enablers were not properly positioned or integrated across the formation and lacked the capacity to address the environment across the entire brigade front. Additionally, the brigade failed to properly integrate the resident staff expertise available from the two 5H Officers into the brigade's planning process, so their expertise was of no value added to the team. Finally, the maneuver force itself was not properly trained or equipped to fight, survive, and win in a nuclear environment. Consequently, the brigade attack stalls, the opposing force exercises gains in time and space to preserve and reposition combat power while simultaneously exercising its well-planned fires and close air support to destroy the brigade's main effort element. The brigade, now mired with contaminated casualty evacuation, contaminated equipment recovery, and mission command challenges, never has the opportunity conduct its maneuver plan and is consequently unable to demonstrate proficiency in several of its mission essential tasks identified for the rotation.

In the 22 years since 9/11, the international environment has changed. Great power competition, shaped by nuclear order, was largely bilateral between the United States and Russia. Additionally, the threat of nuclear weapons proliferation and employment was thought to be reduced and governed by negotiated arms control measures and limitations.[8] That relationship has deteriorated as Russia continues modernization of its nuclear arsenal, and China has risen to consideration as one of the most powerful states in the international system.[9] Additionally, following protracted counterinsurgency operations, the Army is transitioning following two wars that lasted almost two decades. In 2018, Army focus, and emphasis returned to large scale combat operations (LSCO).[10]

Soldiers with Delta Company, 103rd Brigade Engineering Battalion, 56th Stryker Brigade Combat Team, 28th Infantry Division, Pennsylvania Army National Guard, endure a CS gas attack at the National Training Center, Fort Irwin, California Aug. 17, putting their Chemical, Biological, Radiological, and Nuclear defense training to use during the early morning surprise attack. (U.S. Army National Guard photo by Cpl. Hannah Baker)

Addressing the gap through education, training, and doctrine

Recognizing atrophy occurred in the Army's individual and collective skills related to operating in a CBRN environment, the Army has placed new emphasis on CNI. This emphasis is consistent with guidance the 2022 National Defense Strategy which calls for bolstering nuclear deterrence through better synchronization of conventional and nuclear aspects of planning which includes improving conventional forces' ability to operate in nuclear, chemical, and biological attacks. This improvement is intended to deny benefits to the adversaries from possessing and employing these weapons.[11] Additionally the 2022 Nuclear Posture Review advocates for integrated non-nuclear and nuclear planning, exercises, and operations to deter and undermine adversaries' confidence in strategies that involve using the threat of nuclear escalation. The NPR also states that conventional forces must be able to survive and continue to operate in the face of limited nuclear attack sending a message that nuclear escalation will not render U.S. and allied forces incapable of achieving warfighting missions.[12]

This effort is well underway within TRADOC at the Center for Initial Military Training, Warrant Officer Education, Army University, the NCO Leadership Center of Excellence, the Sergeants Major Academy, and the Army War College. The PME portion of this effort will be fully implemented by 2nd Quarter of FY24. With level appropriate general knowledge in CNI across all echelons of formations, the Army will be better prepared to understand, train for, prepare for, and react to potential nuclear environments. The Army is simultaneously working to train and develop CNI tactics, techniques, and procedures to inform training and doctrine.

Given time, recognition, and command emphasis, the combination of education and training will drive the development of TTPs, and doctrine needed for success in the nuclear environment. The deliberate integration of nuclear-related education, doctrine and training will enable the Army to fulfill its critical role in nuclear deterrence by demonstrating the ability to fight, survive, and win in chemical, biological, radiological, and nuclear environment.

The Future State

As the brigade commander prepared for the brigade's rotation to the NTC, the commander focused on proficiency in the mission essential tasks necessary to ensure the brigade was fully proficient and combat ready in the event of a real-world deployment. The commander planned to demonstrate proficiency in the following tasks: conduct mission command, conduct movement to contact, conduct attack, conduct a defense, and conduct area security. Additionally, based on progressive and sequential professional military education the commander wanted to demonstrate that the unit could fight, survive, and win in chemical, biological, radiological, and nuclear environments. Consequently, the commander added "prepare for a nuclear attack" and "react to a nuclear attack" as critical tasks for the rotation.

Leaders at all levels within the brigade formation were schooled, trained and proficient in nuclear-related tasks and battle drills. Soldiers, platoons, companies, detachments, and augmentation units possessed the required equipment, knew how to operate, and maintain radiation detectors and monitors, and were also knowledgeable in where to position the equipment within formations. The entire unit knew how to assess the CBRN threat, implement coordinated CBRN plans, determine and implement the mission-oriented protective posture (MOPP) level, deploy, and activate detectors, execute environmental sampling operations, designate and prepare shelters, watch for attack indicators, cover, conceal, and disperse unprotected mission-essential equipment, conduct meteorological monitoring, integrate available alarms and properly use the Chemical, Biological, Radiological, and Nuclear Warning and Reporting Systems (CBRNWRS).

The brigade commander and staff understood their responsibilities for planning and synchronizing CBRN activities across all Warfighting functions. Trained, proficient, and prepared CBRN staff principles understood the Joint Warfighting and Reporting Network 2 (JWARN-2) system and were prepared to plot and track contamination throughout the brigade's area of operations. Soldiers across the entire brigade knew their ability to fight, survive, and win in a nuclear environment would likely be tested. However, they did not know at what point in the training rotation such an event might occur. They also understood that their collective expertise and preparedness might cause the enemy to shy away from employment of nuclear weapons.

The brigade subsequently deploys to the NTC, develops a masterful movement to contact plan and a brilliant scheme of maneuver to seize its objectives. However, shortly after crossing the line of departure, the brigade received a ballistic missile warning, and immediately adopted an increased protective posture. The missile detonated above the lead elements of the main effort in a low yield nuclear detonation. The opposing force commander, realizing the OPFOR lacked sufficient force structure and firepower to defeat the attaching brigade directly, employed a low yield nuclear weapon augmented by superior knowledge of the 'home field' terrain to block, delay and confound the attacking formations.

However, the brigade was properly trained, equipped, and organized to fight, survive, and win in a nuclear environment. Because main effort formations adopted tactical dispersion to mitigate the effects of indirect fires, the nuclear detonation failed to achieve widespread catastrophic effects. Following the nuclear attack, evacuation proceeded quickly to minimize residual radiation impacts, clean and dirty routes to tactical decontamination sites were employed to limit contamination of the battlefield, and CBRNWRS was used to quickly disseminate CBRN Reports to all downtrace units for contamination avoidance. The brigade staff, over half of whom had earned the 5H ASI, played an integral role into the brigade's operations process. Once communications were re-established shortly after the attack, the staff updated the CBRNE COP, confirmed combat power status and adjusted the scheme of maneuver to minimize maneuver through expected contaminated areas. Finally, and most importantly,

Soldiers from 92nd Chemical Company conduct decontamination operations at NTC rotation 23-05 at Fort Irwin, CA. (Photo by MAJ Courtney Zimmerman)

the maneuver force itself, was properly trained and equipped to fight, survive, and win in a nuclear environment. The brigade's formations continued the attack, switched to alternate communications as required and augmented anticipated combat power loss with indirect fires. The brigade's main effort shifted to the reserve conducting a follow and assume role. This element quickly identified, reacted to, and negotiated local obstacles in the battlefield and destroyed the opposing force. During consolidation and reorganization, the brigade took up a hasty defense and its reserve forces employed their organic CBRN Reconnaissance teams to augment the capacity of the CBRN enablers to fully develop the commander's understanding of nuclear fallout contamination and adjust the scheme of sustainment to best protect the brigade and follow-on forces. The brigade flawlessly executed decontamination operations, contaminated casualty evacuation, contaminated equipment recovery, and minimized the impacts of nuclear detonation induced challenges to mission command systems and processes. As a result of its thorough training and preparation, the brigade successfully demonstrated proficiency in several of its critical tasks. ■

Notes

1. Thomas H. Magness, "Seven Breaching Habits of Highly Effective Units," *Engineer Magazine*, October-December (2003), 44.
2. Magness, "Seven Breaching Habits," 44.
3. Magness, "Seven Breaching Habits," 44.
4. Center for Army Lessons Learned, *NTC Trends Compendium,* No. 01-11, 3QFY98 through 4QFY99, (May 2001), 119.
5. Center for Army Lessons Learned, *CTC Trends, National Training Center*, No. 01-12, 3QFY99 and 4QFY99, (May 2001) 36-37.
6. Center for Army Lessons Learned, *CTC Trends, National Training Center*, No. 03-30, 1QFY03 and 2QFY03 (Nov. 2003), 52-53.
7. Center for Army Lessons Learned, *NTC Trends and TTP*, 3rd and 4th Quarters, FY03, (Oct 2003), 18-19.
8. Steven E. Miller, "A Nuclear World Transformed: The Rise of Multilateral Disorder," *Daedalus*, Vol. 149, No. 2, (Spring 2020), 18, jstor.org/stable/48591310.
9. Miller, "A Nuclear World Transformed," 17-18.
10. James King, "Large-Scale Combat Operations: How the Army Can Get Its Groove Back," *Modern War Institute*, (Jun. 2018), https://mwi.usma.edu/large-scale-combat-operations-army-can-get-groove-back/.
11. Office of the Secretary of Defense, 2022 National Defense Strategy: 9-10.
12. Office of the Secretary of Defense, 2022 Nuclear Posture Review: 10.

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USANCA Enhancing Extended Deterrence

May 2023 Engagement at USSTRATCOM

By: Dr. Donna Wilt, LTC Jason C. Wood, and Mr. John White

Introduction

US Army Nuclear and Countering Weapons of Mass Destruction Agency (USANCA) and United States Strategic Command (USSTRATCOM) have a long history in supporting the integration and deconfliction of nuclear operations with ground-based conventional operations. In May 2023, USSTRATCOM invited USANCA to provide a seminar addressing integration and deconfliction principles, the Theater Nuclear Operations Executive Seminar (TNOES), to distinguished General Officers of the Republic of Korea (ROK), United States Forces Korea and USSTRATCOM as part of a mil-to-mil information exchange.

Background

On 17 May, Maj Gen Park Hu Soung, the director of the Republic of Korea Joint Chiefs of Staff's Countering Weapons of Mass Destruction directorate, and Maj. Gen. Robert B. Sofge, Combined Forces Command (CFC) Assistant Chief of Staff for Strategic Planning and Policy, met with U.S. Air Force Gen. Anthony Cotton, the commander of USSTRATCOM. The visit focused on continued extended deterrence efforts and ongoing discussions on mutual defense, which has been the bedrock of the U.S.- ROK Alliance for 70 years. Gen. Cotton emphasized the U.S.'s ironclad commitment to the Alliance and USSTRATCOM's strong and credible capabilities for U.S. extended deterrence.[1]

Above: Maj Gen Park Hu and U.S. Air Force Gen. Anthony Cotton, the commander USSTRATCOM, 17 May, Photo by Zachary Hada

Recognizing the importance of being prepared to defend against a potential North Korean nuclear or other WMD attacks, Maj Gen Park stressed the importance of the Alliance's work to further strengthen information sharing, consultative mechanisms, joint planning, and execution.[2]

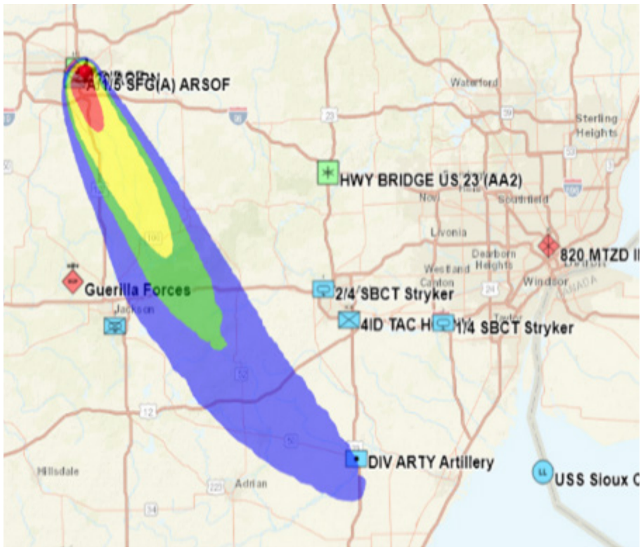
Above: USSTRATCOM, Offutt AFB, Nebraska

The U.S. and ROK generals agreed to expand and deepen the cooperation between the major commands of ROK JCS, USSTRATCOM, future ROK Strategic Command, and U.S.-ROK CFC. This included working in lockstep on the Alliance's combined defense posture and planning activities such as a new tabletop exercise to be conducted with USSTRATCOM.[3]

USANCA Expertise

Dr. Donna Wilt and LTC Jason Wood of USANCA's Nuclear and CWMD Operations Division (NCOD) led the TNOES which covered topics including Nuclear Effects, Conventional Nuclear Integration (CNI), Preclusion Analysis, and Nuclear Employment Augmentation Teams (NEAT).

This engagement aligns with objectives called out in the *Army's Strategy to Integrate Nuclear Implications into Conventional Operations*, aka the Army's CNI Strategy. Strategy objectives are to gain the ability to dominate operations in and through a nuclear environment; exploit the resiliency advantage; provide conventional operational support to nuclear operations; and prepare for post-strike recovery with allies and partners and as part of the Joint Force.[4] Ground forces with capability to continue conventional operations in a nuclear environment demonstrates capability and resolve to support objectives regardless of the options the adversary has to employ. The seminar highlighted key planning considerations for conventional operations in a nuclear environment which augments planning discussions related to the U.S. extended deterrent. As a conventional force, the ROKs appreciated the information sharing as informative to their planning.



Above: 18 May, USSTRATCOM student's modeling of fallout to support Preclusion Analysis during TNOC

As a NEAT Chief, LTC Wood was ideally suited to provide the seminar. NEATs assist in the integration of nuclear effects with theater objectives and maneuver operations using Preclusion Analysis. Preclusion Analysis is a process that models nuclear weapon effects on U.S., Allied, partnered, and third-party weapon systems, structures, and forces. Preclusion Analysis is a tool for identifying and mitigating risks to maneuver so that units maintain the ability to continue operations in a nuclear environment as required by doctrine.[5] NEATs represent the Army subject matter expertise legacy of when the Army was a nuclear force and integrated both conventional and nuclear ground operations.

NEATs have deployed numerous times over the last several years to support joint and allied exercises and to advise and assist CCMDs with detailed operational planning. Deployed or through home-station reach-back, NEATs provide Preclusion Analysis and hazard prediction capability, the ability to integrate nuclear and conventional targets, reach back support to other elements of the nuclear enterprise in the national capital region, and USSTRATCOM. USANCA has a permanently stationed NEAT Chief, Mr. John White, at USSTRATCOM to increase coordination with USSTRATCOM and to facilitate NEAT participation in events like this.

When not deployed or providing operational analysis, NEATs provide a Theater Nuclear Operations Course (TNOC), both as a Mobile Training Team requested by an organization and through regularly scheduled offerings at the Defense Nuclear Weapon School and USANCA. TNOC is designed for planners, support staff, and targeteers and provides an overview of nuclear weapons capabilities, and effects as well as a U.S. nuclear policy and joint nuclear doctrine for their use in planning, exercises, and training. During the 18 May TNOES, other NEAT members of NCOD were in the building teaching USSTRATCOM staff members Preclusion Analysis during a TNOC.

The Director, USANCA is responsible to the HQDA G-3/5/7 for Nuclear and CWMD planning and execution expertise for the implementation of Army CWMD strategy and policy at the operational and theater levels. With the unique role given to NEATs in the Joint Force, USANCA is enhancing and strengthening our U.S. strategic and extended deterrent. ■

Notes

[1] U.S. Strategic Command press release, 19 May 2023, ROK CWMD Director Discusses U.S.- ROK Extended Deterrence Efforts During Visit to USSTRATCOM; https://www.dvidshub.net/news/445151/rok-cwmd-director-discusses-us-rok-extended-deterrence-efforts-during-visit-usstratcom.

[2] Ibid.

[3] Ibid.

[4] Army Strategy for Integrating Nuclear Implications into Conventional Operations, 2022: pg. 1.

[5] Operations in a Nuclear Environment, ATP 3-72, MCRP 10-10E.9, NTTP 3-72.1, AFTTP 3-2.65, March 2022; https://armypubs.army.mil/epubs/DR_pubs/DR_c/ARN34872-ATP_3-72-000-WEB-1.pdf; 2-5.

Dr. Donna Wilt is the Army's Nuclear Strategist and Chief of the Army's Nuclear and CWMD Operations Division (NCOD) reporting to the Army G3/5's Strategy, Plans, and Policy Directorate and the Director of the US Army Nuclear and CWMD Agency (USANCA). In her strategist role she develops, shapes, coordinates, or messages the strategy defining the Army's role in the offensive or defensive use of nuclear weapons on the battlefield and represents the Army's strategic deterrence messaging and Army position in nuclear fora.

Lieutenant Colonel Jason Wood is an Army Nuclear and Countering Weapons of Mass Destruction (CWMD) Officer and Army Engineer. He is a member of the Army staff, serving as the Deputy of USANCA's NCOD and as a Nuclear Employment Augmentation Team (NEAT) Chief since 2020. NEATs are the Army's only deployable teams that support nuclear targeting integration into Combatant Command operational plans. He is one of the primary instructors of the Theater Nuclear Operations Course and the accompanying Theater Nuclear Operations Executive Seminars.

Mr. John White is a USANCA NCOD NEAT Chief with duties at USSTRATCOM providing integration expertise and on-call analytic products that support command planning, exercises, and training across the competition spectrum.

Measuring Radiation Protection

Partners from across the Nuclear Enterprise Evaluate the Radiation Protection of US Army Vehicles

By: LTC Andrew Decker and Dr. Robert Prins

Introduction

Recent mounting nuclear threats and postures from adversary nation-states, such as Russia, China, North Korea, and Iran, represent a clear danger to the interests and security of the United States of America and its Allies. To meet these threats, the 2022 Nuclear Posture Review requires the Department of Defense (DoD) to design, develop, and manage a combat-credible U.S. military which, among other prioritizations, is survivable. A survivable force can generate combat power despite adversary attacks.[1] As such, the US Army must prepare today to set the conditions for successful conventional warfare on the nuclear battlefields of tomorrow. Our Army cannot afford to project weakness, uncertainty, or vulnerability in the attainment of decisive victory over enemy forces on the ground, even when pursuant to hostile nuclear weapon employment.

Large scale combat operations require planning for near peer adversary threats involving chemical, biological, radiological, and nuclear (CBRN) weapons. If nuclear weapons are ever employed against US ground forces by an adversary, our Soldiers will likely face open combat amid a radioactive fallout contaminated environment, while risking subsequent nuclear attacks as they advance (Figure 1).[2] Knowing that weapon of mass destruction (WMD) use does not terminate a conflict but rather creates a different operational scenario enables units to prepare through the advanced knowledge of survivability, both for materiel and personnel. Combat units prepared to operate in, around, and through contaminated environments are fundamental to deterring adversary use of WMD.[3] One critical concern in both the prompt and delayed nuclear environment is radiation, and the ground commander must determine how to weigh the risk of Soldier exposure against mission objectives.

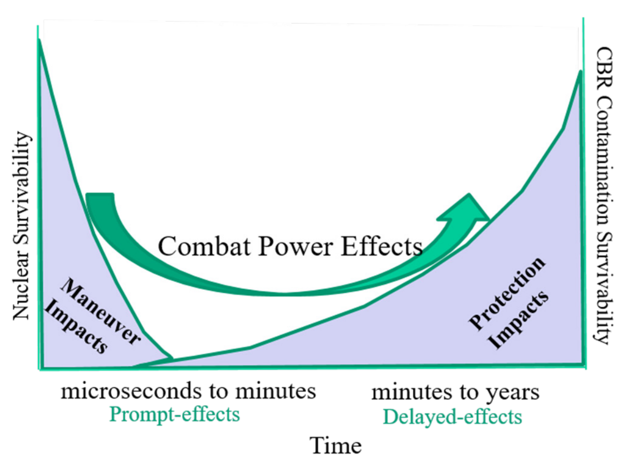


Figure 1. Survivability effects and combat power. [2]

This determination is simplified for dismounted Soldiers wearing only the Mission-Oriented Protective Postures suit and taking shelter in a bunker or foxhole for certain types of radiation; however, when considering mechanized and armored units, the US Army must improve its understanding of the radiation shielding afforded by different vehicle types. As an example, in March 2011 during OPERATION TOMODACHI in Japan, such consideration was required to support operational decisions.[4] The amount of radiation protection provided by US Army vehicles is known only for a handful of legacy variants.[5] This is partially due to the lack of a nuclear threat during the Global War on Terror, and that fight's need to rapidly field dozens of new armored combat vehicles and vehicle variants. Although these new vehicles offered enhanced ballistic shielding, evaluation of the radiological protection afforded to the crews within these vehicles was not emphasized.[4-6] Consequently, such information is missing for many vehicles in the current US Army inventory, combat or otherwise. Reducing this uncertainty is important for future large scale combat operations on nuclear and CBR-contaminated battlefields.

The Radiation Protection Factor – How well do military vehicles protect occupants?

The US Army quantifies the protection afforded to occupants within any crew-served vehicle as the radiation protection factor (RPF) value. Each radiation measurement depends on the thickness and composition of the shielding material, as well as the type and energy of the incident radiation. Therefore, RPF values must be determined either through direct experimentation or complex simulation methods, and they are calculated from the ratio of radiation dose outside (unshielded) compared to the dose present inside the vehicle (shielded) using the equation,

$$RPF = \frac{Unshielded\ Dose\ (neutron\ and\ gamma)}{Shielded\ Dose\ (neutron\ and\ gamma)}. \quad (1)$$

Since neutrons and gamma rays represent the two most biologically significant sources of radiation following a nuclear weapon detonation, a more detailed analysis of vehicle RPF can be obtained by defining both the neutron protection factor (NPF) and the gamma protection factor (GPF) for each vehicle:

$$NPF = \frac{Unshielded\ Neutron\ Dose}{Shielded\ Neutron\ Dose}, \quad (2)$$

$$GPF = \frac{Unshielded\ Gamma\ Dose}{Shielded\ Gamma\ Dose}. \quad (3)$$

Consequently, RPF values represent a summation of the GPF and NPF components, as shown in Equation 1. The clear implication is that the larger the RPF value, the better the degree of radiation protection afforded by the vehicle.[4-6]

Determination of such information is well-established historically. Prior to the collapse of the USSR, the US Army routinely conducted experimental and computational assessments of mission critical platforms to determine the degree of radiological protection afforded to crews.[6-8] This information assisted commanders in assessing the threat to vehicle crews operating in contaminated areas, as well as informed force deployment decisions to maximize vehicle survivability if threatened with likely nuclear attack. Furthermore, knowledge of RPF values assisted the designers of US Army combat systems, so specific radiation shielding materials could be incorporated early, thereby maximizing the degree of radiological protection to crews while enabling a more cost-effective and efficient design.[7,8]

During the Cold War, computer codes, such as the Vehicle Code System (VCS) and Monte Carlo Adjoint Shielding code system (MASH), provided rough RPF estimates to US Army planners. These vehicle RPF predictions were frequently benchmarked against physical experiments, typically utilizing simplified surrogate military vehicles.[7,8] Experiments such as these proved critical in quantifying the degree of uncertainty associated with radiation transport code assessments of RPF.

In 2014 the DoD tasked the Defense Threat Reduction Agency (DTRA) and the US Army Nuclear and Countering Weapons of Mass Destruction Agency (USANCA) with identifying an optimal methodology for assessing US Army vehicle RPF values. DTRA and USANCA then partnered with the Air Force Institute of Technology (AFIT) to focus FA52 graduate-students on this research topic.[6]

Recent RPF Research: Identifying a new evaluation tool and methodology.

In 2018, following a rigorous, multi-year verification and validation (V&V) campaign, DTRA approved a new RPF assessment methodology.[9-15] This new approach leveraged the Monte Carlo N-Particle v6.2 (MCNP6©) simulation code, maintained and updated by Los Alamos National Laboratory (LANL).[16] Despite long acceptance by academia of MCNP6© as the world's preeminent radiation transport code, it was never previously used to determine vehicle RPF estimates due to the associated computational resources required for such a complicated simulation - a limitation overcome only in recent decades by advances in computer processing capability. As such, these V&V efforts culminated in a full-vehicle evaluation in 2018 at the White Sands Missile Range (WSMR) in New Mexico. Specifically, a RPF value was experimentally measured for a Stryker vehicle variant using a fission neutron and high-energy gamma ray source, and a computational estimate of the same was determined using MCNP6©.

Future RPF Research: Establishing repeatable evaluation conditions.

The 2018 Stryker experiment was complicated and costly to plan and execute. To implement at large scale, the US Army's approach to vehicle RPF evaluation benchmarking needs to fundamentally change. Full-scale experiments need to occur more rapidly and at lower cost for Army vehicles and variant RPF values to be evaluated and certified across multiple likely radiation exposure scenarios.

To this end, AFIT, DTRA, WSMR, and USANCA recently reinitiated coordination to provide necessary vehicle RPF evaluation requirements. Specifically, WSMR and USANCA are partnering to provide the WSMR Fast Burst Reactor (FBR) facility for future RPF vehicle assessments. The FBR is ideal for many reasons, not the least of which are its well-characterized neutron and gamma ray emission spectra. As in 2014, AFIT will provide the nuclear engineering graduate students to conduct the necessary physical experiments and computer simulations to meet the technical challenge. Two FA52 officers have already volunteered for this research, with their experiments scheduled to occur in the Fall of 2023. Lastly, DTRA is providing AFIT with necessary funding and equipment to support this research through the Nuclear Science and Engineering Research Center (NSERC) at West Point, NY, which represents just one of many research efforts that DTRA supports at AFIT, including investigations into novel detectors, machine learning, and nuclear weapon effects.

RPF Experimentation this year will focus largely on characterizing the FBR emission spectra and calculating radiation dose at previously unevaluated locations relative to the reactor core. These experiments will include both shielded and unshielded measurements using a simplified vehicle surrogate, as well as an anthropomorphic phantom to provide accurate dose measurements. Computationally, equivalent simulations of each RPF experiment will also leverage MCNP6©, which will benefit from high-fidelity models of the FBR facility provided by a national laboratory.

As such, these experimental and computational efforts support both the future measurement and simulation of vehicle RPF values for the US Army. Specifically, the characterization of dose and emission spectra enables an efficient and cost-effective means of measuring vehicle RPF values at the FBR, while simulated estimates of RPF for a surrogate vehicle provide an additional benchmark of MCNP6©. Therefore, this research is significant because it establishes a repeatable and sustainable process by which future MCNP6©-computed RPF vehicle estimates may be benchmarked, thereby supporting reliable full-scale RPF evaluations for all US Army combat and non-combat vehicles.

Conclusion

Further RPF research is critical to maximizing the safety, survivability, and combat effectiveness of US Army Soldiers on the nuclear battlefields of tomorrow. Furthermore, our understanding of how best to employ Army combat systems to mitigate the effects of adversary nuclear weapons, a key advantage provided by RPF analysis, is critical to the deterrence of nuclear warfare.

US Army leaders at USANCA recognize the need to understand the degree of radiation protection afforded by US military combat systems and asked DTRA to help answer the information gap. To meet this requirement, DTRA and USANCA requested experimental and computational research support from AFIT faculty and students, and FA52 officers have once again stepped forward to lead that research and provide critical answers to the US Army. ■

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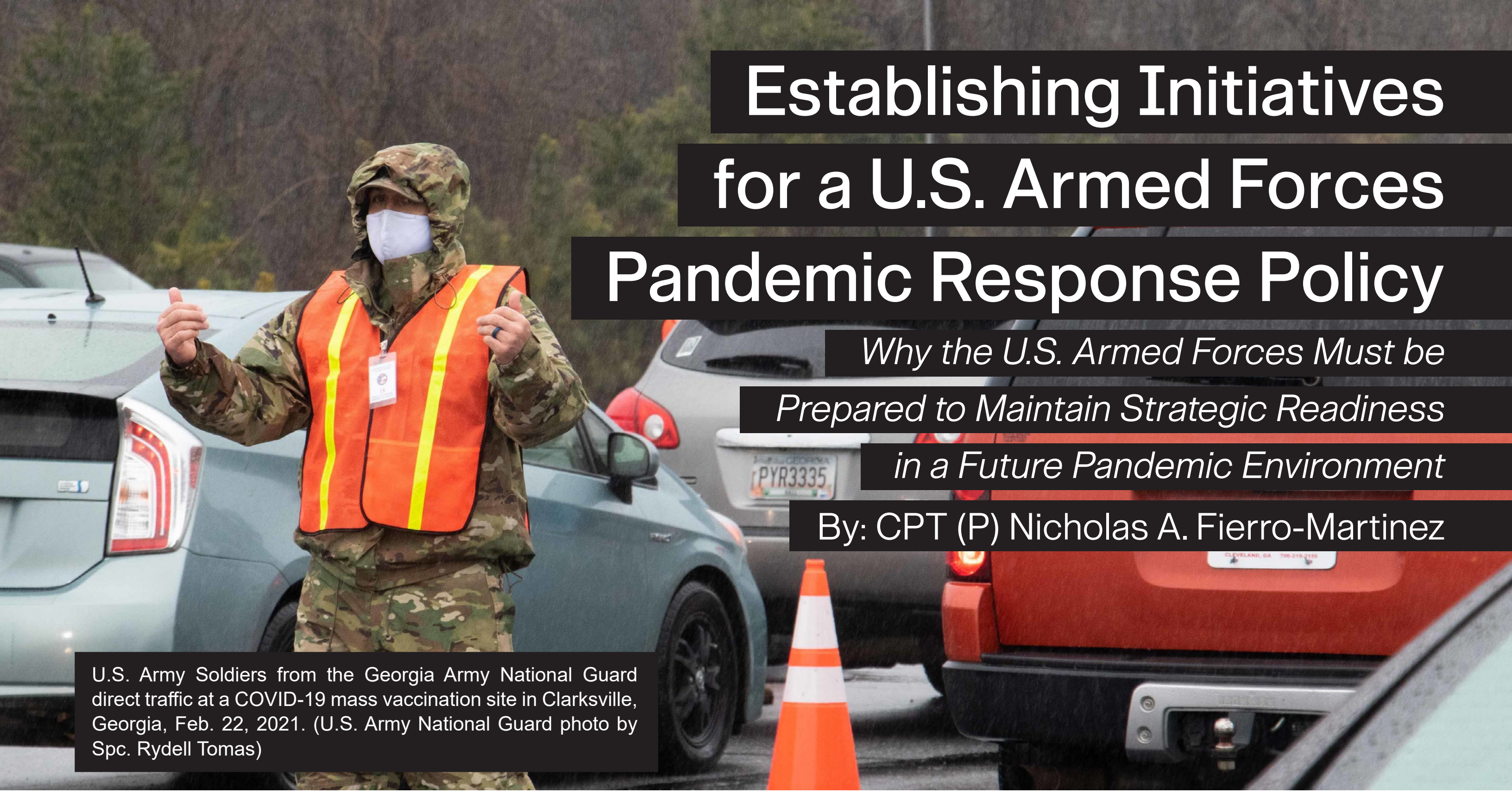
Establishing Initiatives for a U.S. Armed Forces Pandemic Response Policy

Why the U.S. Armed Forces Must be Prepared to Maintain Strategic Readiness in a Future Pandemic Environment

By: CPT (P) Nicholas A. Fierro-Martinez



U.S. Army Soldiers from the Georgia Army National Guard direct traffic at a COVID-19 mass vaccination site in Clarksville, Georgia, Feb. 22, 2021. (U.S. Army National Guard photo by Spc. Rydell Tomas)

Abstract

This entry provides five key initiatives that will assist in building the framework for a future comprehensive U.S. Armed Forces Pandemic Response Policy that will enable executive decision making and improve operational and strategic readiness. These initiatives include Germ Gaming, Supply Chain Management, Maintaining Strategic Tempo, Vaccine Administering Teams, and Federal Agency Interoperability. Success of the proposed initiatives for the future policy will be measured by its ability to bridge strategic gaps seen in the initial U.S. Armed Forces' COVID-19 response, sustainability between administration changes, and its efficiency as a baseline response to various pathogens. These benchmarks and characteristics will be the fundamental building blocks for the future U.S. Armed Forces Pandemic Response Policy.

Executive Summary

In the last two years, the United States (U.S.) Armed Forces have developed, trained, and refined its ability to conduct routine operations and combat operations in a COVID-19 environment. Today, the U.S. Armed Forces are more prepared than ever to maintain its readiness through the future uncertainties of a pandemic, as long as critical lessons learned are captured, codified, distributed, and practiced. Maintaining readiness will continue to be an enduring U.S. Armed Forces priority due to the unpredictable implications of crisis, conflict, and combat throughout the world. The current strategic nexus of readiness is nested with the perceptual lens of Russia continuing to be an acute threat and China as an emerging strategic competitor. Furthermore, as the U.S. Armed Forces lead through the transition from a pandemic driven environment, it must capitalize on its short comings observed and build a comprehensive and strategically layered plan in order to hedge against future adversaries who will seek to exploit vulnerabilities during a pandemic.

Examining the Problem

Recruiting and Basic Training. Operating in a pandemic environment challenged readiness for the U.S. Armed Forces at every echelon. Despite the sudden pivot from routine business to operating in a pandemic, the U.S. Armed Forces remained resilient and able to maintain readiness through temporary changes, though not always at the highest levels due to impacts on training. A 2022 RAND study that analyzed U.S. Military figures in accession, retention, and end strength suggests that even though recruiting efforts fell short, retention rates increased. This was a pleasant surprise, considering that in-person recruiting efforts were halted for almost two months to allow the U.S. Armed Forces to assist in curbing the pandemic.

Although recruitment was not a critical issue during COVID-19, the next pandemic's pathogen is unpredictable. Analysis must be done now in how to execute prolonged virtual recruitment in the event a future pandemic lasts longer or brings a different array of obstacles that inhibit traditional recruiting methods. Additionally, the utilization of constructive credit prior to U.S. Armed Forces Basic Training should also be socialized as a mechanism to reduce strain on an already constrained program of instruction (POI). Essentially, while future trainees are quarantined at home prior to shipping out, they would complete certain training gateways and thus reduce the amount of time it takes to get basic trainees out to the operational force in order to maintain overall readiness.

Conventional Readiness. Although access to premier U.S. Armed Forces training locations such as the National Training Center (NTC) and the Joint Readiness Training Center (JRTC) was temporarily suspended due to the pandemic, the military still found innovative ways to maintain lethality during that brief space of uncertainty. Overall, this negatively affected training value, especially when large scale exercises or validation exercises were executed at home stations. However, it did not degrade overall combat effectiveness and readiness to the point of complete vulnerability. Additionally, there were times when units were impacted by both service members and civilians being quarantined and isolated due to either a COVID-19 infection or exposure. Again, this had temporary effects at the tactical level but did not affect overall strategic capabilities. Social distancing within formations and when applicable, during training, was institutionalized as another effort towards mitigating the spread.

Although each military installation will use its own playbook and deal with local trends regarding pathogen spread, the Department of Defense (DoD) still owes its "premier" training facilities "premier" guidelines in how to continue to receive units that need validation. The temporary closing of any Combat Training Center (CTC) must be "wake-up" criteria for the implementers of U.S. Armed Forces policy in order to collaborate for a swift re-opening. Our adversaries in the future will likely seek to exploit any sign or hint of military readiness degradation.

Supply Chain/Acquisitions for Protecting the Force. President Biden's 2022 "Securing Defense-Critical Supply Chains" provides the public with a robust policy that augments U.S. Armed Forces readiness through streamlining its methodology for supply chain resilience in order to deliver "decisive advantages to Warfighters in a dynamic threat landscape." However, one key area that this policy overlooks is protecting the force in the event of another pandemic, specifically, how the U.S. Armed Forces will ensure ample amounts of protective equipment for service members and their families.

Just as civilian and privatized supply chains were affected by the global pandemic with shortages, the military also faced similar issues in production and supply transportation transactions. These issues also resonated with the maintenance of vehicles, infrastructure, and equipment. Unfortunately, given the uncertainty of pathogens, a future pandemic may cause a similar "brake" reaction. However, the key will be to develop and execute a "triage" plan as former Undersecretary for Defense for Acquisition and Sustainment, Ellen Lord, stated in a press briefing approximately a year into the pandemic. Essentially, it is imperative to prepare a plan that aggressively revamps production to compensate for any gaps.

Medical Personnel Shortages. A 2017 initiative led by President Donald Trump looked to drastically reduce the amount of health care providers within the U.S. Armed Forces due to "underperforming and disjointedness" within the U.S. Armed Forces medical system. With the pandemic already straining the U.S. Armed Forces medical systems and capabilities, any further reduction in personnel would have likely had devastating consequences on readiness. A 2015 Technology, Entertainment, and Design (TED) Talk from Bill Gates alluded to the idea of building a medical reserve entity that could be augmented with military medicine. This novel concept is ideal in preparation for the pandemic environment that DoD could leverage within a reasonable budget.

Augmenting Past U.S. Armed Forces Pandemic Literature and Strategies

H1N1 vs. COVID-19. Although the 2009 H1N1 Virus (Swine Flu) pandemic did not affect the U.S. Armed Forces on the same scale as COVID-19, there are still valuable lessons to be learned in order to build a better "playbook" for a future pandemic. Unfortunately, the only DoD-level policy that addresses a pandemic within the last 20 years is the 2006 Department of Defense Implementation Plan for Pandemic Influenza and the 2021 Army Biological Defense Strategy. The U.S. Armed Forces certainly missed a prime opportunity to augment or create a more refined pandemic response plan. Additionally, the DoD's 2006 influenza pandemic plan lacks depth in areas that could have been expanded for future policy.

Gaps. A critical gap within the policy was the lack of defined "guidance on roles, responsivities, and lines of authority" for not only the organizations within DoD's pandemic response plan, but also the insertion of key players within the Department of Homeland Security (DHS) and other key role players that could assist through interoperability. Interoperability and organizational priorities will be key in future pandemic policies.

Key Stakeholders

Department of Defense. Because the purpose of this research paper is to recommend and implement a comprehensive policy that sustains U.S. Armed Forces readiness, it is only appropriate that the DoD be the leading entity in this plan. DoD must hold its counterparts within the recommended policy accountable and ensure all benchmarks and future milestones are met when operating in a strategically challenging pandemic environment. Additionally, strategic challenges such as the great power competition and climate change will continue to compete as DoD priorities. If the "2006 Department of Defense Implementation Plan for Pandemic Influenza" has taught policy makers anything, it is that pathogens will act on their own accord and the assurance of DoD preparedness and action must be maintained.

Department of Homeland Security (DHS). The DoD will lead the efforts in the newly proposed Pandemic Response Policy, but it certainly cannot do it alone and will need to leverage the DHS and its critical operational and support components such as the: United States Customs and Border Protection (BCP), Federal Emergency Management Agency (FEMA), and Transportation Security Administration (TSA).

Additionally, the DHS will assist in vaccine distribution efforts.

Center of Disease Control (CDC). A crucial piece to any U.S. policy concerning pathogen and vaccine observations and statistics is the involvement of the CDC and leveraging its epidemiological outreach, global biosurveillance, knowledge and guidance of the future pandemic will be critical.

Food and Drug Administration (FDA). Key to any vaccine approval or novel treatment for a pathogen causing a pandemic is the FDA. DoD will need to work closely with the FDA in order to actively seek approval for pending vaccine results and ensure that its Service Members are prioritized in receiving initial doses.

Proposed Initiatives

As mentioned, the proposed initiatives that should be included in a future and comprehensive policy for U.S. Armed Forces Pandemic Response are only the building blocks for what could be used. It is imperative to examine the 2006 DoD Pandemic Plan in order to truly fill these gaps. Key to these initiatives is a successful integration of interagency and the continuity of the document.

Although future policies centered around increasing defense readiness through a pandemic bring about good intentions, the glaringly obvious problem with overzealous planning is the lack of pragmatic economic and spending considerations when building these frameworks. Initially, many experts were led to believe that the effects of COVID-19 on the Armed Services would drastically reduce the authorized amount of funding in the FY22 Defense Bill due to a multitude of factors stemming from the looming recession it created. However, the national defense bill total ended up being $782 billion, which was about a four percent increase over the administration's initial request for FY22 and almost a six percent increase over the 2021 appropriations. With this in mind, the U.S. Armed Forces must use a policy that leverages a framework of realistic spending in order to bring pragmatic solutions for future issues.

"Germ Gaming." Germ Gaming can be defined as the process of executing strategic and operational virtual exercises in which the Armed Forces must respond, mitigate, and assess how a pathogen will affect DoD's readiness and ability to achieve its strategic objectives and commitments. The refurbished policy must include the concept of Germ Gaming in order to counter-balance risk and decision making in the event of a future pandemic. Although the DoD's greatest minds are doing so at some extent within the Pentagon, there should be further emphasis on all potential pathogens that could lead to a pandemic. Key to this initiative is the external validation from an outside agency such as the World Health Organization (WHO) in order to establish an objective assessment.

"Supply Management (Pandemic Personal Protective Equipment)." Although social distancing and teleworking were leveraged by corporate America to keep its employees safe, the U.S. Armed Forces did not have this luxury despite pandemic spikes and local guidance for civilians. Instead, the DoD relied heavily on social distancing and protective masks. Unfortunately, most Service Members needed to purchase their own masks due to the lack of masks available.

Additionally, the military faced a cleaning supply shortage, leading to more risk being assumed in workspaces that were not properly sanitized. In an effort to prevent such an issue from happening again, a standard of units properly storing and accounting for masks and cleaning supplies in a central storage location must be implemented. Annual inventories should be taken in order to mitigate the expiration of supplies.

Maintaining Strategic Tempo. The next pandemic will likely happen at the most inopportune time, just as COVID-19 did. Current geopolitical atmospherics are not promising and therefore the U.S. Armed Forces must be prepared to operate strategically in large-scale combat operations (LSCO) during a pandemic. Countless Active-Duty Service Members were called to assist in crisis control of the pandemic in high-risk locations. This cannot be the case in the future and the leveraging of DHS, National Guard, and civilian vaccination support teams must be used in order for the U.S. Armed Forces to maintain lethality and hedge against both known and unknown threats in the conflict space.

Furthermore, in order to embrace the concept of planning for operations in an uncertain pandemic environment, future strategic operational concepts and plans should be briefed with no less than two trajectories. One for routine operations in a low-risk environment, and the second for executing operations during a pandemic.

Vaccine Administering Teams. United States Marine Corps General Alfred M. Gray once said that "Every Marine is, first and foremost, a rifleman". Moving forward in a pandemic-stricken world, an addition to that should also be "Every service member is trained to support the administration of medical countermeasures vaccines". As eccentric as this may sound, it will play a crucial role in future preparedness. If conditions are set and Active-Duty Service Members must be allocated to assist in process used for administering vaccines, then it is only appropriate that all are properly trained instead of having to leverage in order to augment only military medical personnel. This could be considered for future program of instruction (POI) integration within a service member's advanced individual training (AIT) with annual certifications.

Additionally, the certification and training the service members receive will have continuity beyond the Armed Forces. If the service members decides to transition out of the military, their skill set, and certification can be leveraged for a civilian vaccine administering team concept.

Intergovernmental Agency Interoperability. Key to all things happening within the proposed initiatives is the communication, sharing of information, and relationships between all agencies involved. With such a robust agency makeup within the proposed response plan, there should be no reasons for future responses being more seamless.

Annual Germ Gaming will be the most ideal platform for these agencies to reexamine any modifications or revisions to the plan. Moreover, innovative solutions and recommendations must be collected annually in order to ensure the policy maintains updates and continues to be applicable as the operational environment evolves through uncertainty.

Counter-Argument

Although one could make the argument that the blame should not solely fall onto the DoD for its lack of preparedness in the face of a pandemic, the fact remains that if "readiness" is its number one priority, then there should be a multitude of policies and "playbooks" for handling key events that threaten "readiness."

When examining the proposed initiatives that will assist in future DoD pandemic response, there must also be room to observe potential gaps and shortfalls in order to reassess and refine. For example, Germ Gaming and the Vaccine Administering Teams would place an additional strain on the DoD to not only add an additional validation exercise, but also implement annual vaccination training. Additionally, budgeting is forecasted and allocated an entire Fiscal Year prior, with proposed defense budgets being shaped years out. However, neither of these propositions would require a vast amount of money, but rather software and analytics for Germ Gaming and time allocations within training schedules for Vaccine Administering Team training. With these considerations in mind, there is certainly room to at least begin the blueprints for these initiatives in order to be implemented in the years to come.

Conclusion

The COVID-19 pandemic's unpredictable and unforgiving effects challenged and stretched the U.S. Armed Forces' ability to respond accordingly while also sustaining strategic readiness through an unstable international system. Not only were service members expected to assist at friction points within the U.S. but there were also the complications of the Afghanistan withdrawal in addition to enduring world-wide commitments. Because of this, the service members deserve a sense of predictability and understanding of what the future holds when planning, preparing, and responding to a pandemic. The execution will always be fluid due to each pathogen's biology, but nonetheless, the recommended initiatives will provide an adequate framework for RPF estimates to US Army planners. These vehicle RPF predictions were frequently benchmarked against physical experiments, typically utilizing simplified surrogate military vehicles.7,8 Experiments such as these proved critical in quantifying the degree of uncertainty associated with radiation transport code assessments of RPF. ■

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Utilizing the System Engineering Trade Study Analysis Method to Analyze Patient Aeromedical Evacuation

By: Sara Shaghaghi, Dr. Jeremy Slagley, Dr. Michael Miller, and Dr. Gaiven Varshney

Introduction

The US Air Force has gone through many aeromedical patient isolation transport system designs. The first designs were developed in response to the Ebola outbreak in 2014 and, more recently, the COVID-19 pandemic [1, 2]. The trade study analysis part of the system engineering design method was used to analyze the historic and current aeromedical patient contamination control transport systems. A trade study is a process that evaluates alternatives based upon various "-ilities", such as reconfigurability, flexibility, durability, cost, and more, and performs a systematic analysis to aid designers in producing a 'good' design alternative given the large set of possible solutions.The analysis of these historic and current systems, in addition to speaking with stakeholders, resulted in design requirements for a new system. This article will discuss the findings from the analysis of the historic and current aeromedical patient isolation transport systems.

The legacy systems that were analyzed during this investigation were the Patient Isolation Unit (PIU), Transport Isolation System (TIS), and the Portable Bio-Containment Module (PBCM), also referred to as the Portable Bio-Chemical Module and the Portable Biocontainment Care Module [3, 4, 5]. The PBCM was previously known as the Containerized Biocontainment System (CBCS) [6]. Each system had its respective benefits and drawbacks.

The PIU was lightweight, allowed single patient transport, and ensured staff protection. However, the unit was costly, communication between the patient and staff was difficult, emergency medical treatment was limited, temperature and fluid regulation presented an issue, and a psychological barrier was discovered during training simulations [7]. The specific PIU initially purchased by the Air Force is unknown, at the time of this publication. However, a similar one CAPSULS™, Patient Isolation Unit produced by ISOVAC Products LLC, is available for $9K for government contracts [8, 9]. The PIU produced by ISOVAC Products fits a standard North Atlantic Treaty Organization (NATO) size litter and compacts down to fit inside a bag that measures 24" x 20" x 18" and weighs about 30 lbs [8].The PIU was never operationally used by the Air Force in patient transport.

The TIS, shown in Figure 1, Figure 2, and Figure 3, was developed to ensure better aircraft integration (C-17 Globemaster III and C-130 Hercules) and increased the number of patients transported from single patient transport to two litter mounted patients. Figure 1 demonstrates how litter-mounted patients are loaded into the unit. The TIS is describe as a minivan, such that two fully configured units can fit within the C-17, as shown in Figure 2 [10]. However, the TIS was not applicable for aerosol-transmissible biologicals and large-scale patient transport [1, 4]. Additionally the plastic which encased the unit caused communication issues. Figure 2 and Figure 3 show the TIS with and without the plastic encasing, respectively. These communication issues, in conjunction with the temperature regulation issues and the fact that the medical staff felt that the unit was unstable, increased the risk of adverse effects on the medical staff [11, 12]. The TIS had a 20-week production lead time when built from scratch when initially presented to the Air Force, with approximately two units that could be produced per week [13]. Estimated costs for the production of the TIS was said to be approximately $100K. The initial requirement included was to have twenty-five units for a total cost of $2.5 million [13].

Figure 1: Airmen Inside Transport Isolation System [14]

Figure 2: Transport Isolation System inside of a C-17 [15]

Figure 3: Transport Isolation System Unit without External Plastic Covering [4]

The Portable Bio-Containment Module (PBCM), shown in Figure 4 and Figure 5, was developed for the Ebola outbreak and was a viable alternative for patient aeromedical transport during the COVID-19 pandemic. Like the TIS, the PBCM was integrated with the C-17 and C-130 and increased the number of transportable patients to four but the PBCM had a high cost and a 6-month production timeline. However, the PBCM was reported to have both temperature and communication issues, in addition to having limited interior space [16]. The PBCM, formerly named CBCS, has a footprint of 8 feet wide by 44 feet long and reaches a height of 8 feet. The unit weighs 24,000 pounds [17].

Figure 4: Portable Bio-Containment Module (PBCM) is shown being tested for Aerosol Integrity on a C-17 [18]

Figure 5: Portable Bio-Containment Module (PBCM) on a C-17 Globemaster III [4, 5]

In response to COVID-19, the US Air Force developed the Negatively Pressurized Conex (NPC) and NPC Lite (NPCL) units shown in Figure 6-9. The NPC and NPCL are similarly designed units, the only difference being the physical characteristics of each unit and the total number of patients that can be transported. The NPC is a 40-foot-long Conex (7 feet 11 inches in width and 8 feet 6 inches in height), in contrast to its NPCL counterpart, is a 30-foot-long Conex (9 feet in width and 8 feet in height) [1]. The NPC and NPCL weigh 19,500 pounds and 13,000 pounds at delivery, respectively [1]. The NPC and NPCL further increased the total patient capacity to eight and two litter mounted patients, respectively, and added a separate anteroom, allowing staff rotation. Figure 6 shows the inside of the unit during the initial testing while a graphical depiction of the unit is seen in Figure 8 including the antechamber and patient area. The disadvantages for NPC and NPCL were their expense, communication issues, temperature regulation, storage issues, aircraft integration, and the ability to respond to in-flight aircraft emergencies. In-flight emergencies include the effects from sudden maneuvers causing the unit to shift, personnel loss of balance or breaking the glass windows of the unit. Aircraft integration issues included the size, as well as access to onboard electrical power and oxygen supply [12, 1]. The NPC and NPCL cost approximately two million U.S. Dollars to prototype and test. The current cost per unit has not been released.The production time has not been released. However, the total time it took the NPC and NPCL to be operational was 95 days [1].

Figure 6: Negatively Pressurized Conex (NPC) being used for Training at Ramstein Air Base, Germany [19]

Figure 7: Negatively Pressurized Conex Lite (NPCL) Set-Up for Training at Ramstein Air Base, Germany [20]

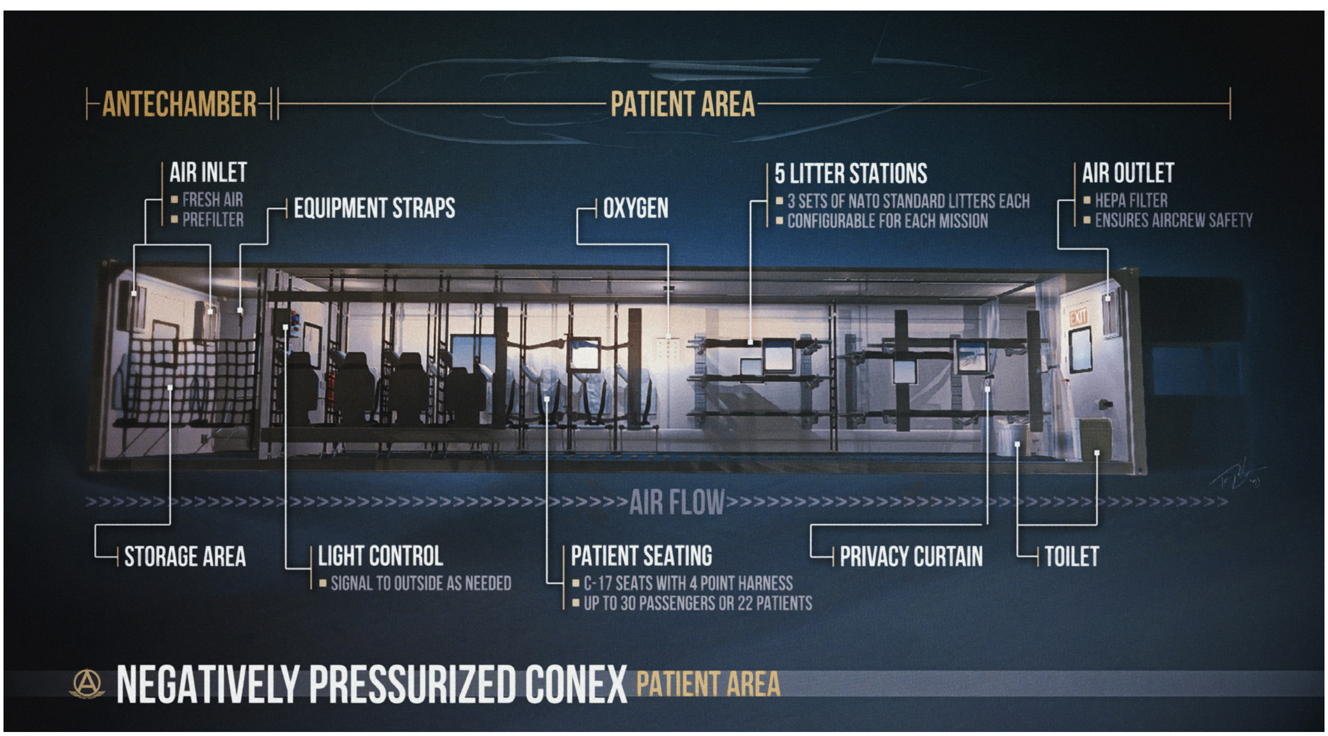

Figure 8: A graphic demonstrating the layout and main patient area of the NPC [21]

Figure 9: Negatively Pressurized Conex (NPC) (Left) and NPC Lite (NPCL) (Right) with Members of the Test Team [22]

Based on the review of these historical and current systems, many recurring design deficiencies exist. For example, every unit has temperature regulation and communication issues, as seen in Table 1. These two factors are essential for patients and staff, as communication and temperature are vital to ensuring safety during transport. Table 1 depicts the ability of each system to achieve the design requirements.

Comparing the legacy systems from a cost and production perspective (Table 2), there are different drawbacks and advantages to the systems. The litter-mounted systems, such as the PIU, are commercially available off the shelf and can be purchased for one-time use. The TIS, which transports two litter-mounted patients, can be produced for less than the NPC with a longer production time. In constrast, the NPC and NPCL can be manufactured at a more efficient rate but at a higher cost. However, they can increase the number of patients per transport.

Using the system engineering design process and a trade study analysis, the drawbacks from legacy and current systems can be found and potentially resolved through future design to prevent recurrence. This method, in conjunction with speaking to various stakeholders, allows engineers to step back from the design process and critically analyze the strengths and weaknesses of legacy systems, to ensure the final product fits the customer's needs. Utilization of the system engineering trade study analysis and design method may allow better product development to charter to our aeromedical transport requirements.

The derived requirements from this trade study analysis will be used for the design of a new patient transport system. Analyzing the drawbacks of others and encompassing them into the design decisions. The new system will be analyzed according to the derived requirements in Table 1 and decontamination efficiency. ■

Table 1: Derived Design Requirements for Patient Transport System and Legacy Systems Capability to Meet the Requirements

Requirement	PIU	TIS	PBCM	NPC/NPCL
Communication	No	No	No	No
Temperature Regulation	No	No	No	No
Aerosol Capture	Yes	No	Yes	Yes
Medic Safety	Yes	No	Yes	Yes
Psychological Impacts	No	Yes	Yes	Yes
In-Flight Emergency	No	No	No	No
Integration with Aircraft	Yes	Yes	Yes	No
Storage	Yes	No	No	No

Table 2: Cost and Production Time for Legacy and Current Patient Transport Systems

Requirement	PIU	TIS	PBCM	NPC
Cost	$14, 000	$100,000	N/A	$2,000,000*
Production Time	Commercial Off the Shelf	20 Weeks**	26 Weeks	95 Days

*The cost of the NPC and NPCL reflects the cost of testing and prototyping time for the system overall. It does not represent the cost of each individual unit.
**The information available TIS's production time represents the production time at the onset of the Ebola outbreak in 2015.

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Engineering Airflow in Army Command Posts

Reducing the Risk of Exposure to and Transmission of Airborne Pathogens

By: MAJ Gerrit P. Van Ommering

Introduction

This article addresses the question: “How can we engineer airflow in expeditionary command posts to reduce the spread of airborne-transmissible diseases and protect against aerosolized biological and chemical agents in the operating environment?” This question matters for force protection. In peacetime, the answer contributes to preserving the health of the force against a key form of transmission for naturally-occurring pathogens, like influenza and corona viruses. In command post training exercises and Army combat training center rotations, the Tactical Operations Center “(TOC) crud” is a vernacular term used by staff soldiers to refer to sickness that spreads pervasively in an expeditionary command post during training. As a result, staff sections may be incapacitated or perform at a degraded level for several days. In war against a state that possesses a bioweapons capability, the force protection stakes are much higher, and survivability measures may be essential for preserving lives and combat power against the enemy’s use of aerosolized biological agents (bacteria, viruses, or toxins).

This article undertakes a literature review of select science and engineering publications to explain aerosolized biological agents and how to prevent them from accumulating in a structure. First, the article explores the transport phenomena of aerosolized particles—presenting the key variables for airborne transmission of an example pathogen (SARS-CoV-2, the agent responsible for COVID-19), with a focus on particle size distribution, physical forces, and indoor ventilation rates. Second, structure ventilation strategies are considered. The last section of the literature review elaborates the first principles and fluid mechanics behind high efficiency particulate air (HEPA) filters. Finally, the article synthesizes the literature review considerations into a recommended design for command post airflow, accompanied by a discussion of additional design considerations that merit further study.

Literature Review

<u>The Transport Phenomena of Airborne Pathogens</u>

The SARS-CoV-2 virus provides a recent instance of an agent capable of airborne transmission and will serve as this article’s example for an airborne pathogen. Other airborne-transmissible diseases include measles, chicken pox, and tuberculosis (Centers for Disease Control and Prevention, 2016). Bazant and Bush (2021) organize a list of case examples and studies, which clearly demonstrate the spread of SARS-CoV-2 by airborne (aerosol) transmission.

1. In Washington state, during a two-and-a-half-hour choir practice, one primary case infected 53 of the 61 other participants (Skagit Valley Chorale). Many in the choir were line-of-sight shielded from or more than six feet away from the infectious person.
2. During a two-hour bus ride in Ningbo, China, 23 of 68 passengers were infected by a primary case. Many of those infected were more than six feet away from the infectious person.
3. COVID-19 transmission occurred in various rooms of a Korean high rise linked by air ducts, despite the lack of in-person interaction or shared physical spaces.
4. In 7,321 early cases of COVID analyzed in Hubei Province, China, only one instance of transmission was assessed to have occurred outside of an enclosed structure or vehicle.
5. Active virions have been measured in aerosols 16 feet away from infectious patients in a hospital room.

The key factor driving a particle’s classification as an aerosol (and its resulting airborne behavior) is particle size. Figure 1 shows how particle diameter affects the time an aerosol remains in the in the air before falling to a surface.

The label “aerosol” generally applies to particles less than 100 µm (microns) in diameter (although a 5 or 10 µm threshold is sometimes used). The graph in Figure 1 shows that a 1 µm aerosol diameter results in 12 hours of residence time (in a still air column) before falling from a height of 1.5 meters. A 100 µm particle manages only 5 seconds under similar conditions before falling to the surface. This reflects the role that small diameters play in making drag forces near equivalent to gravitational forces. Stokes’ Law defines terminal settling velocity as proportional to the square of particle diameter, when in laminar flow. (Wang, 2021)

The majority of respiratory (exhaled) aerosols are less than 5 µm in effective diameter (with a large percentage smaller than 1 µm in diameter), and normal breathing results

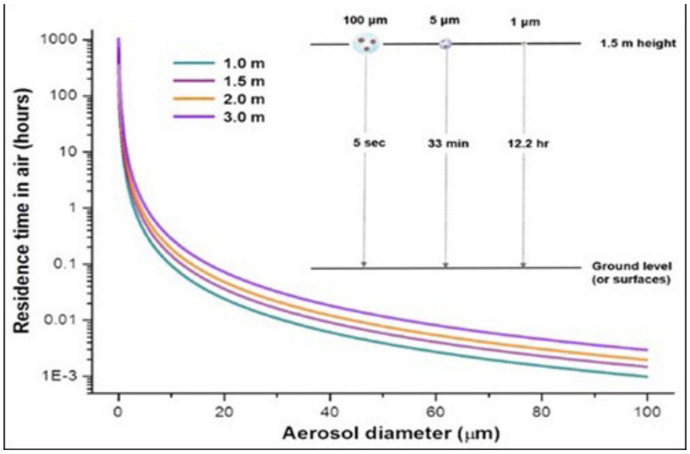

Figure 1. Aerosol Residence Time as a Function of Effective Particle Diameter (Wang, 2021)

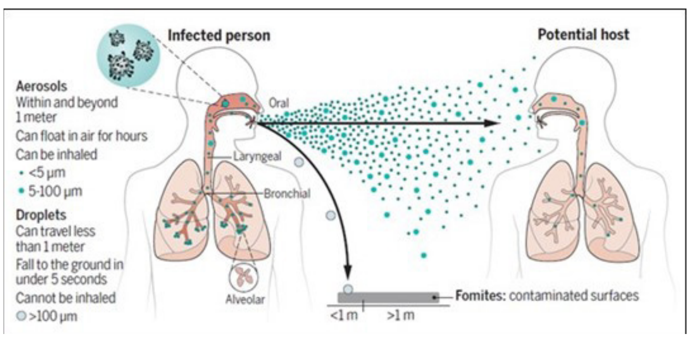

Figure 2. Depiction of Aerosol and Droplet Exhalation (Wang, 2021)

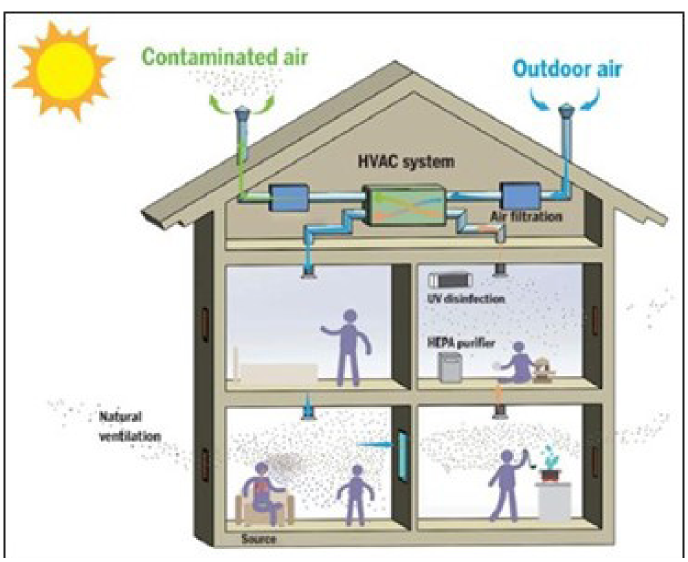

Figure 3. Example of Indoor, Airborne Transmission of SARS-CoV-2 (Wang, 2021)

in 7,200 aerosol particles for every liter of exhaled air. Additionally, larger respiratory aerosols will experience desiccation (drying) that may reduce their size and extend suspension times. Mild turbulence in the air may also result in greatly extended suspension times. Figure 2 depicts a plume of exhaled air and shows the differences in transport behavior between aerosols and droplets. (Wang, 2021)

As a result of aerosols' lengthy residence times, they can quickly accumulate and permeate the air of an enclosed structure. Figure 3 shows how infectious aerosols might transport in a building, given one infectious individual in the lower-left quadrant.

Bazant and Bush's case examples make clear that transmission primarily occurs in enclosed spaces, but Figure 3 depicts how ventilation and other factors may affect transmission.

In the Wells-Riley infection model, the probability of infection (P) via aerosol transmission is a function of the number of infectors in a space (I), the infectious quanta generated per infector per unit of time (q), the breathing rates of susceptible individuals (p), exposure time (t), and room ventilation rate (Q). The equation takes the form:

$$P=1-e^{-Iqpt/Q}$$

Note that this model equation does not account for air filters or air disinfection by means of ultraviolet radiation—these factors will be considered in the final discussion. (Wang, 2021)

Additionally, q varies as a function of activity. Briefing loudly, speaking in a conversation, and routine breathing result in different quanta rates and particle size distributions (Bazant and Bush, 2021).

Interpreting the equation, the probability of infection can be reduced by isolating infected individuals, decreasing high-quanta activities, reducing exposure time, or increasing ventilation.

Ventilation Strategies

Ventilation systems may be either natural, spot (mechanical), or whole-house/structure (mechanical). The whole-house/structure class is further broken down into exhaust, supply, balanced, or energy recovery systems. The exhaust system pumps air out of a structure, which creates a decrease in pressure in the structure and draws fresh air in through vents. The supply system pumps fresh air into a structure, creating an increase in pressure internal to the structure and driving stale air out. The balanced system has two pumps to achieve near-neutral pressure by equalizing air inflow and outflow rates. The energy recovery system uses heat exchange to transfer heat between outgoing and incoming air. (Department of Energy)

First Principles of High Efficiency Particulate Air (HEPA) Filters

High Efficiency Particulate Air (HEPA) filters trap particles using electromagnetic forces (Van der Waals forces). The transient surface fluctuations in molecular charge for both the filter fibers and the aerosol particles create a weak binding force effective at very short ranges. Three mechanisms are responsible for these short ranges, as depicted in Figure 4 and detailed below.

Interception occurs when a particle follows the streamline of fluid (air) around a filter fiber but adheres to the fiber due the radius of the particle impacting the fiber. This occurs when the particle occupies a compressed streamline that passes within particle-radius proximity of the fiber. Inertial capture occurs when a particle's greater momentum causes it to break with the fluid streamline and impact the fiber. This effect is enhanced for larger particle sizes and higher fluid velocities. Lastly, diffusion-mediated impact occurs when a particle impacts the filament surface due to diffusion (Brownian). This diffusion-driven behavior is dominant in the case of smaller particles and lower velocities. Figure 5 gives an example of how one variable (particle size) affects particle penetration of a filter, and how the three mechanisms outline the curve. (First, 1998)

Even at the peak of the penetration curve, HEPA filters achieve 99.97% or greater particle removal from air (Dietz, 2020).

Assessment of Extant Literature

The literature reviewed in this article makes a compelling case for the risk posed by airborne-transmissible agents, looking through the lens of SARS-CoV-2. Mitigation measures that reduce the risk of transmission are identified, and clear physical principles explain their function. However, the literature reviewed thus far fails to account for a broader biodefense strategy that emphasizes positive pressure within structures to prevent the ingress of biological agents aerosolized in the environment by hostile actors. Additionally, the reviewed literature fails to consider the impact of air distribution (mixing versus displacement) as part of a protective ventilation strategy.

Conclusions for Engineering Airflow in Command Posts

Mitigating Risk from Biological Agents in the External Environment

All expeditionary command posts should maintain a HEPA filter at their fresh air inlet(s) to prevent aerosolized biological agents from entering the structure. To increase the life expectancy of the filter in high-particulate environments, coarser filters should be used as a pre-filter and changed out regularly. A particle-saturated filter results in a large pressure drop across the filter, which reduces ventilation rates, strains the mechanical system of the air flow unit, or results in bypass of the filter through gasket leaks.

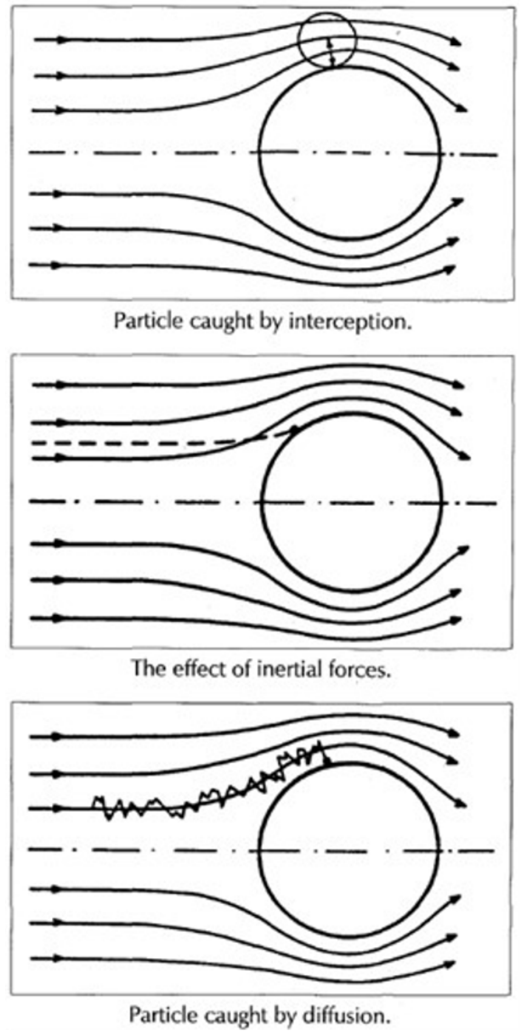

Figure 4. Streamlines Around a Filter Fiber (First, 1998)

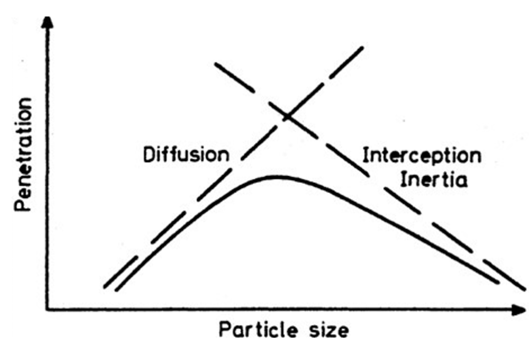

Figure 5. Interception, Inertia, and Diffusion Effects, Varying Particle Size (First, 1998)

Despite higher energy costs, the ventilation method should be a supply-driven system to create increased pressure within the command post, preventing unfiltered air (potentially laden with aerosolized chemical or biological agents) from seeping in through seams and cracks of the structure. This article posits that the energy recovery system is a modifier that can be applied to any of the exhaust, supply, or balanced systems. Command posts should therefore use a supply-driven system that incorporates energy recovery. Persily (1982) measured residential air-to-air heat exchangers as achieving heat recovery on the order of 50% of outgoing heat or cooling. Heat exchange should match or exceed this threshold.

Mitigating Airborne Transmission of Biological Agents within the Command Post

To mitigate against the risk from an infected person in the command post inadvertently aerosolizing a biological agent from within, ventilation rates should be maintained at 10 liters per second per person, in accordance with World Health Organization recommendations (Wang, 2021). Of the variables in Wells-Riley infection model equation, ventilation rate is one that can be engineered and implemented with the greatest reliability. Close-fitting mask wear may offer additional protection against aerosol transmission by reducing spread of larger-sized exhaled aerosols containing biological hazards by an infectious individual. However, unless properly fitted and used, risk from accumulated respiratory aerosols within the structure may persist. Degradation in communication by mask use must also be considered.

contrasts the carbon dioxide profiles for the two strategies, holding ventilation rates constant. The smallest aerosol particles will follow the path of the exhalation breath (traveling up, away from others in the room).

The EPA (2022) recommends consideration of displacement as an air circulation strategy. However, most Army command post tents do not have the ceiling-height geometry to support displacement circulation. Exhaled air will pool at head level in low-ceiling tents. An additional consideration is that the up flow of air within rooms may extend suspension of aerosols, potentially increasing the concentration of hazardous aerosols in regions of the room. These air circulation effects merit further analysis, and a displacement-supportive command post design should be considered in future fielding.

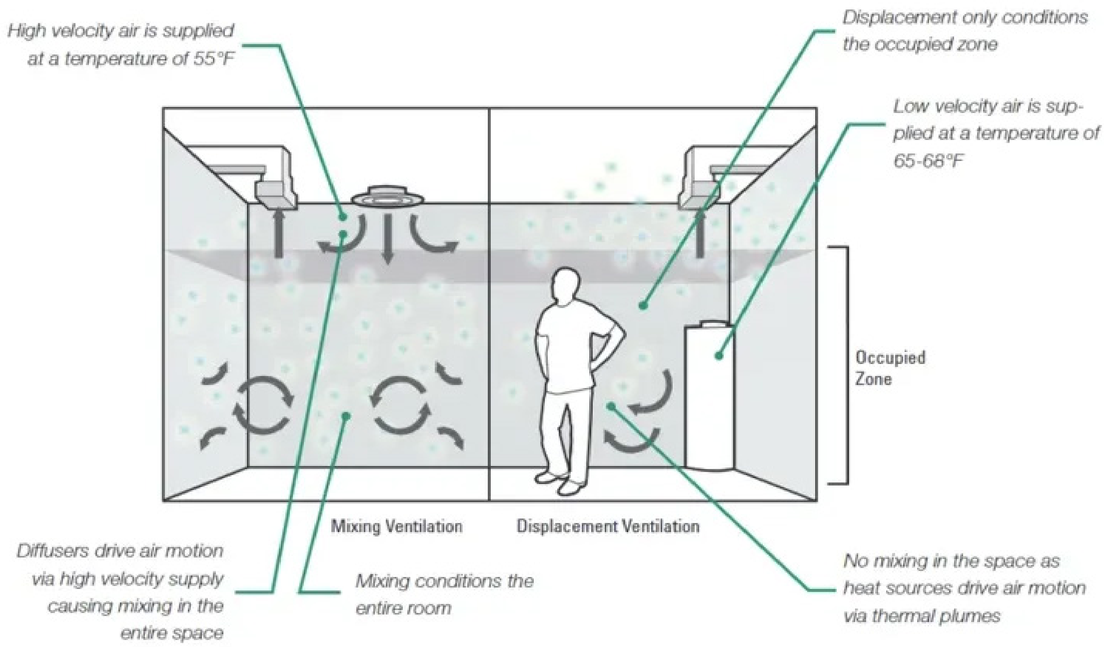

Figure 6. Air Flow for Leading Air Circulation Strategies (Price Industries, 2023)

For multi-room command posts, air circulated between rooms should be filtered as it moves between rooms to further reduce the risk of aerosol transmission. Any air recirculated (for air conditioning purposes) must also be filtered.

Additional Design Considerations

Mixing and displacement are the two leading air circulation strategies employed in structures (Yi, 2009). Mixing creates a bulk flow of air throughout the room, while displacement targets airflow around people via a slow-moving layer of cold air at the floor. This cool, floor layer results in a rising plume of cold air around a person, driving exhaled breath upward. Figure 6 shows the contrasting airflows for mixing and displacement strategies.

The benefit of displacement is lower ventilation rates required to achieve fresh air around individuals. Figure 7

Air conditioning energy costs (required to manage temperatures for personnel and electronics) are significant, especially when conducting long-duration operations in extreme climates. Increased air ventilation rates will drive up energy consumption, increasing logistical demands and risks. HEPA filters operating inside the structure (recirculating rather than venting air) will reduce infective quanta, with a much smaller impact on air conditioning energy costs. However, the air will remain stale (lower in oxygen and higher in carbon dioxide), so a balance of filtered ventilation and recirculating filters will optimize the balance of air quality and energy efficiency. Ultraviolet (Band C) treatment of recirculated air—using high-energy light to kill aerosolized pathogens—also can serve as a substitute for HEPA filtering of the recirculated air. (Wang, 2021). ■

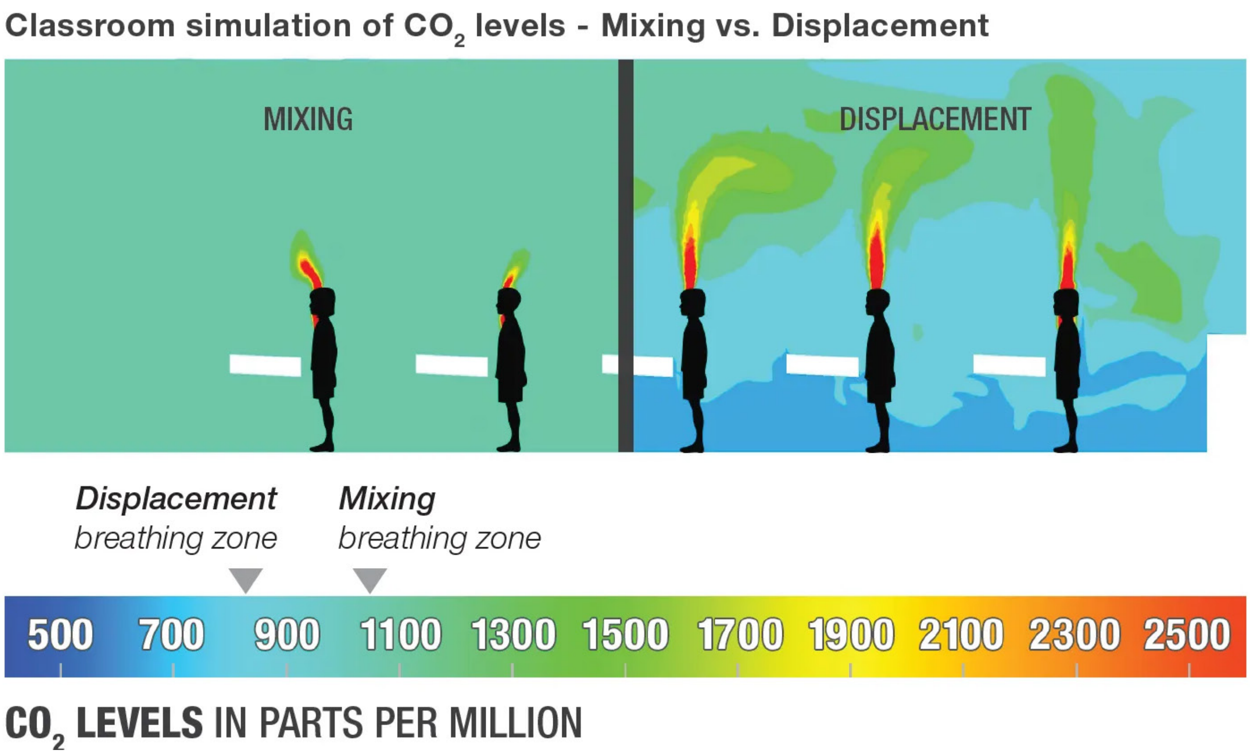

Figure 7. Air Flow for Leading Air Circulation Strategies (Price Industries, 2023)

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A Cautionary Tale of TNOP

By: Dr. Behzad Salimi

Introduction

One of DTRA's nuclear effects simulation tools is the Theater of Nuclear Operations Planner Tool (TNOP), a web-based software that requires registration and request for access on DTRA's Integrated Weapons of Mass Destruction Toolset (IWMDT) web site (https://iwmdt.dtra.mil/). This article offers a perspective on the results of a sample scenario, and a calculational attempt to model the fallout aftermath of the first atomic test–Trinity. The objective is to offer a few inquisitive, cautionary suggestions on the usefulness of this tool and the scope of its applications for the nuclear effects modeler and the greater DOD planning community. This article is a redacted version of the article by the same title (AD1191977) archived in DTIC, Defense Technical Information Center (https://discover.dtic.mil/).

TNOP Overview

The information page of the software nomenclature describes it as a "Planning" tool while the main IWMDT page designates it as a "Planner" tool. A brief description of this tool, by direct quote from its help page is:

> "The purpose of the Theater Nuclear Operations Planning Tool (TNOP) is to provide planners and commanders with a capability to rapidly generate modeling graphics for the purpose of conducting preclusion analysis. It has a requirement to enable planners to be capable of using the TNOP tool with no more than 4 hours per quarter of sustainment training."

The capability to "rapidly" generate any kind of visual graphics is highly dependent on the nature and simplicity of the graphic, and skillful knowledge of the software that generate the graphic element. The quoted time-investment requirement could be met if the user is satisfied with all of the default settings in the tool and minimal settings of a scenario. Otherwise, four hours is likely too optimistic because learning and remembering all of the steps to depict the preclusion analysis, fallout, and uploading of No Strike List (NSL) or Restricted Target List (RTL) collateral damage data in the required particular tabular format, with the level of detail usually included in USANCA's models, is a daunting task for infrequent users. In a recent visit, under the "Help" menu, "TNOP Tool/Things to Remember" there is a 20 bulleted list including 394 words. This many "things to remember" would be possible in 4 hours per quarter for users exceptionally gifted with memory, or for typical users running at least weekly detailed scenario exercises with this tool.

Under the "Strike" menu, only certain combinations of yield and height of burst (HOB) are available, so it is difficult, if not impossible, to run a large variety of strike scenarios to perform scoping calculations or to compare prompt results with other software tools in a wide range of scenarios. When creating a strike, the user can either enter the coordinates of the strike location or use a drag-and-drop feature. If entering the coordinates manually, the user should check the location on the map to ensure the user's coordinates match the convention in the tool. Ready familiarity with international and TNOP conventions of at least two different coordinate systems is a prerequisite knowledge.

TNOP's main menu includes: Creating a Project, Targets, NSL/RTL Targets, Geometries, Minimum Safe Distance (MSD), Collateral Damage Distance (CDD) and Least Separation Distance (LSD), Strikes, Fallout, and Reports. Its current version, however, does not include a tutorial for the impressively large number of tabs, menus, submenus with numerous options throughout the tool's graphic user interface (GUI). Some acronyms are not clearly defined, and the user is either forced to search for or expected to know the meaning and the purpose/effect of some of these options. There is no printable complete user manual. Most of these deficiencies would be immediately apparent to a new user. However, the intent here is not to criticize the user-friendliness of this software tool, but to offer caution and suggestions for the interpretation of the calculated fallout and raise awareness of the inherent assumptions in TNOP and the relatively large uncertainty associated with (and exasperated by) extrapolating any weather model, a key factor in predicting nuclear fallout for realistic preclusion analyses.

Weather Forecasting and Models

The National Oceanic and Atmospheric Administration (NOAA) typically operates three types of environmental satellites that monitor Earth's weather–Geostationary, Polar-orbiting, and Deep space satellites. Additionally, forecasters use weather radar, balloons, barometers, and thermometers. A seven-day forecast can accurately predict the weather about 80 percent of the time and a five-day forecast can accurately predict the weather approximately 90 percent of the time. However, a 10-day—or longer—forecast is only reliable about 50% of the time. In numerical models, extremely small errors in initial values double roughly every five days for variables such as temperature and wind velocity. The inaccuracy of forecasting is due to the chaotic nature of the atmosphere. Human intervention is always required to pick the best possible forecast model to base the forecast upon, which involves pattern recognition skills, teleconnections, knowledge of model performance, and knowledge of model biases. Moreover, weather forecasts are usually reliable for significant (large) climate conditions such as progression of large storms, hurricane, heavy rain or snow, or steady conditions such as partly cloudy, or sunny. The advance of such significant turbulent conditions, however, are not always reliably predictable.

TNOP calculations of nuclear fallout are, necessarily, highly sensitive to the choice of weather model. The tool has a built-in "historical" weather model that is routinely used by consequence modelers to predict nuclear fallout. These modelers are admonished to study TNOP fallout calculations as representative of the consequence, and they should not be considered valid at face value for military operations. TNOP also has the capability to choose (from several options) and download from its homepage alternative, more current, weather models. These "current" weather models only have predictions for a few hours, so the substantive part of calculations is based on built-in extrapolation models, which may not be much better than the historical weather model. While this option of downloading current weather may seem to be a preferred choice for weather input in the calculations, these attempts are severely hampered by exceedingly long download time over the internet. The user who needs a timely calculation is usually compelled to give up the weather download and revert to the historical weather model. In many cases the internet connection is lost without a warning to the user, leaving the user waiting with the false hope of eventual file download. The user could download the "current" weather model in advance to be prepared for a calculation in the near future, but there is no assurance that the calculations using this model would be any "better" than using the historical model, beyond a few hours post nuclear detonation. Furthermore, TNOP also suffers from occasional runtime crash either during a weather download or during a routine calculation. Software runtime crash is not unusual, but in this case there is no system or software reporting (traceback) of what caused the crash.

All of the TNOP calculations are done remotely on a remote server, so the GUI application simply runs an interface between the user and the actual remote software. Therefore, the user must be aware of being always at the mercy of the reliability of user's internet connection especially in field operations. In abundance of caution, one would admonish the deployable or planning officers to request and obtain a stand-alone version of TNOP software and whatever weather model desired well in advance of operational planning activities.

Sample Calculations

To demonstrate the sensitivity of TNOP calculations to weather models, we used one hypothetical scenario and one actual, measured fallout aftermath of the first atomic test Trinity. The hypothetical scenario compared the TNOP fallout calculation result of a 100 kt surface detonation in a port city, for 8-hour delay, 8-hour stay time post detonation on the same day of the month from January to December using the historical weather model. While certain geographic locations have consistent seasonal weather patterns, these calculations illustrate that variability in local (within 5 km) conditions have a significant effect on the fallout pattern. The interested reader could run the same or similar calculations to observe that the calculated fallout pattern changes even with only hours apart, sometimes slightly and sometimes drastically.

As a second, more realistic example, we compared the TNOP calculated fallout pattern for the same setup as in the above scenario, but for a nominal 20 kt surface explosion at the precise ground zero location of the 1945 Trinity test.

An interesting observation in the calculated results of Trinity fallout is that only some of the weather models predict the general direction of the fallout correctly. However, none of the calculated results show the dispersion pattern correctly. The following figures show the actual Trinity fallout pattern. Figure 1 is a reproduction drawing of the actual, measured fallout zone of the Trinity test in a 1945 beta-gamma survey reported in Los Alamos report LA-10256-MS. Figure 2 is another perspective of the Trinity fallout.

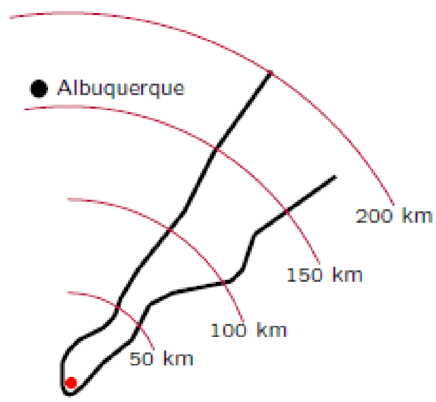

Figure 1. Trinity test fallout zone measured in 1945.

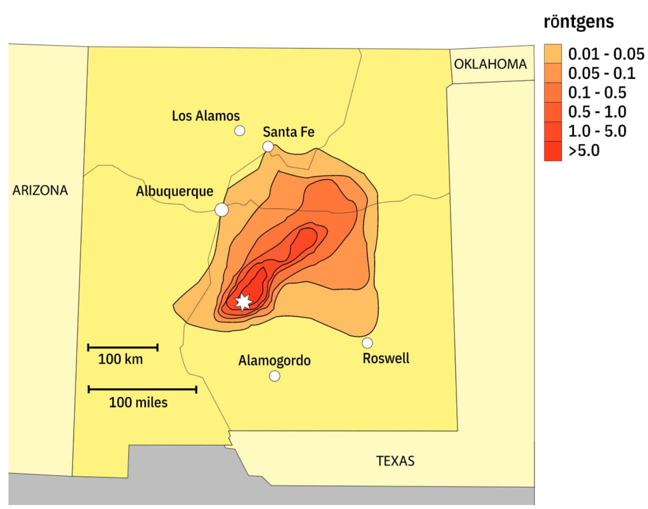

Figure 2. Trinity test fallout, source: atomicarchive.com.

Conclusion and Recommendations

TNOP is a useful computational tool for general analysis of nuclear weapons effects post detonation. It computes some of the prompt effects, which may be much easier to obtain using other software if only prompt effects are desired. Its distinct capability is computation of fallout pattern superimposed over actual geographic map so the prompt and possible delayed effects of fallout could be observed beyond ground zero, and in perspective of distance to other significant land features such as cities or large facilities in the vicinity of ground zero.

TNOP includes many assumptions and gross approximations. While TNOP can produce visually attractive color geographic pictures in several different formats, the user should consider due caution to carefully interpret the calculated results for delayed nuclear fallout. Even if the user applies the current weather model, if the download over the internet is successful and timely (usually it is not) the fallout calculation is not likely to be predictive beyond a few hours after detonation. The user should be cognizant of the wide variations possible in estimating the actual fallout effects on the battlefield. Actual local weather patterns can change very quickly and the best predicted weather models can have large uncertainties. Therefore, TNOP fallout calculations are not predictive. Nevertheless, TNOP may be used for scoping the magnitude of a radiation dispersion problem in consequence analysis and planning process. It might be useful, however, to run a large set of calculations, in advance, with prevalent weather patterns over a geographic region of interest for planning purposes. This type of analysis could be helpful in predicting the worst-case scenario in populated areas or help with scoping "What if…" questions in advance of military operations.

Finally, planners and combatant commanders are well advised to keep in mind a few important facts when considering any fallout model:

• The action of wind and weather cause significant irregularities in the overall fallout pattern.

• Fluctuations in the wind speed and direction can cause significant change in the location and spread of lethal fallout.

• There are very likely to be unpredictable "hot spots" of radiation.

• Some areas receive much lower radiation than predicted and other areas receive much higher radiation than predicted.

• Active, continuous survey and radiation monitoring is necessary to obtain a reasonably accurate picture of the radiation environment. ■

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Review of Compton Backscatter Imaging and Modulation Transform Functions Applied to Explosive Detection

By: MAJ Travis R. Barker and Dr. James E. Baciak

Introduction

Energy interactions with matter are the basis for the application of x-ray imaging techniques. The density of the target material directly affects the way energy moves from a source to a detector, allowing the user to adjust brightness, contrast, and clarity of the image by altering the resultant image, detector response, or source collimation. While transmission radiography in its various forms and applications is well understood due to its relative simplicity, backscatter radiography continues to develop in terms of its applications, capabilities, and potential. The purpose of this paper is to outline the basics of Compton Backscatter Imaging (CBI), past application and system development, and finally, identify areas where it could be expanded.

Basics of CBI

With transmission imaging, the photon scatters are relatively minimal, in that the darkened and lightened regions of the image are due to the intensity of scattering as the x-rays traveled through the target medium. In the case of Roentgen's 1895 experiment using his wife's hand, the darkened portions of the image reveal the scattering effects of her metacarpals and ring when compared to that of her skin. However, in 1928 Klein and Nishina derived their formula that proved Compton Scattering would allow photons to not merely pass through a target x-ray medium, but rather scatter towards the initial source as a result of the electron interactions. This relationship in scattering is best demonstrated in Figure 1.[1]

The benefit of the scattering effects Compton, Klein, and Nishina observed is that unlike traditional transmission imaging techniques, backscatter imaging allows for the possibility of placing the source and the detector on the same side of the target medium. This configuration is commonly referred to as CBI. While numerous researchers have experimented with different techniques to use CBI imaging with greater precision, speed, and image quality, the foundation of the techniques rely on the same scattering effects.

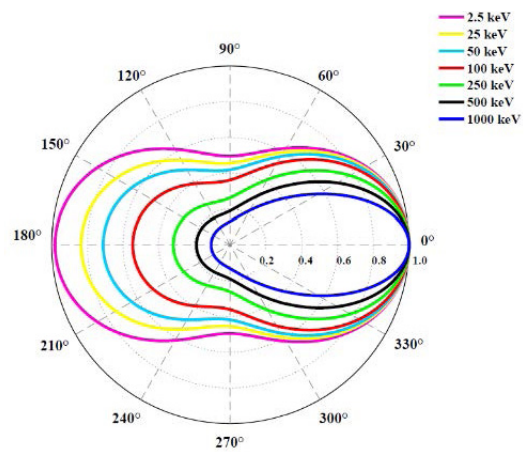

Figure 1. Dependence of the Klein-Nishina cross-section on scattering angle for incident photon energies. Cross-sections have been normalized to the squared electron radius. Image Courtesy of J. Kelly, 2016.

Past Research in Government and Academia

Beginning in 1967, in conjunction with Texas Nuclear Corporation, the US Army began experimenting with the application of a 2 in x 2 in collimated photon beams and NaI detectors to test the potential of using single side source and detector as a means to detect land mines.[2] The findings of the study determined that with 200keV photons, because explosives have a lower atomic weight, they tended to scatter photons more so than the surrounding soil, thereby making detecting mines possible. While the technique was successful in demonstrating a single sided source and detector could detect mines, the limited speed of the process provided an operational constraint that ensured this method of landmine detection, justifiably, did not move past the experimental phase. However, the benefits of CBI in environmentally constrained applications, like landmine detection, remained a subject of interest for researchers who saw its potential.

In 2004, researchers at the University of Florida investigated the application of a pencil beam source with four detectors in two novel approaches to imaging. These novel approaches included Radiography by Selective Detection (RSD) and a subset of RSD, Lateral Migration Radiography (LMR). Both RSD and LMR utilized a 1.5 to 2 mm pencil beam, similar to previous work.[3] However, unlike the previous research efforts, Dr. Shedlock, Dr. Addicott, Dr. Jacobs, and Dr. Dugan utilized a series of four collimated detectors, consisting of either YSO, NaI, or both. Their approach provided a middle ground solution between highly collimated and uncollimated approaches, providing images of land mines as well as tools and cracks within space shuttle foam. By using the four detectors in series, they were able to gather in-depth information not available with previous CBI designs. Later applications attempted to develop an image of the landmine under the surface instead of simply the presence of altered soil.[4]

For his dissertation, Shedlock went on to test Snapshot Backscatter Radiography (SBR) and Shadow Aperture Backscatter Radiography (SABR). SBR is based on the concept of using film and a single pulse exposure to take a snapshot of the target area with a 50kVp and 2.85mA exposure.[5] Unprocessed, the results from an experimental nylon and lead target demonstrated the possibility of using SBR in a more operational setting. Furthermore, Shedlock's efforts with SABR laid a grid pattern over the target object which collimated the source signal and the return signals. Rather than collimate the detector or the source, his method collimated the target, thereby collimating both and sharpening the image in its entirety. The approach does result in an image that contains a series of grid lines across the final image as shown in Figure 2, from saturation Computed Radiography (CR) phosphorus plates; however, the image clarity is improved over that of SBR. While the ideal optimized pattern would be a uniform grid of collimation, Shedlock demonstrated that using a variety of geometries would work as well. Shedlock experimented with optimization geometries, finding that rectangular geometries tended to lend themselves to better imaging prior to processing.

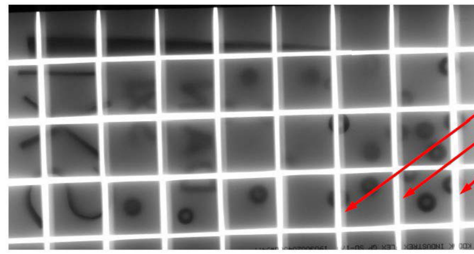

Figure 2. SABR image courtesy of D. Shedlock. ACR induced lines refer to the regions that are highly saturated regions in the target area.

Following Shedlock's work, Chris Meng published his proof of principle in Computed Image Backscatter Radiography (CIBR). CIBR differs from RSD in three main ways: it uses a fan beam x-ray source instead of a pencil beam, uses a rotational motion instead of a rastering, line-by-line, technique, and requires specific reconstruction technique.[6] Normal CBI reconstruction techniques are based on a filtered back-projection method to reconstruct the images. This reconstructed image technique is most used in tomography methods, like Computed Tomography (CT) scans. However, CIBR utilized separate images, reconstructed and overlayed on top of each other, as shown in Figure 3. Unlike RSD where each voxel is its own independent voxel, CIBR requires all the scan data to be reconstructed into a complete image, but at the benefit of an increase in scan speed and a reduction in image acquisition time on the order of minutes to hours faster. Following the success of CBIR, Olivier Bougeant began testing fan beams with segmented collimation arrays on a Linear Detector Array (LDA). The resulting collimation of the return signal to the LDA allowed for simultaneous imaging of the target object along the pixel lines.[7] The speed of scans increased even more dramatically what would have taken RSD eight minutes to image only took two minutes.[8]

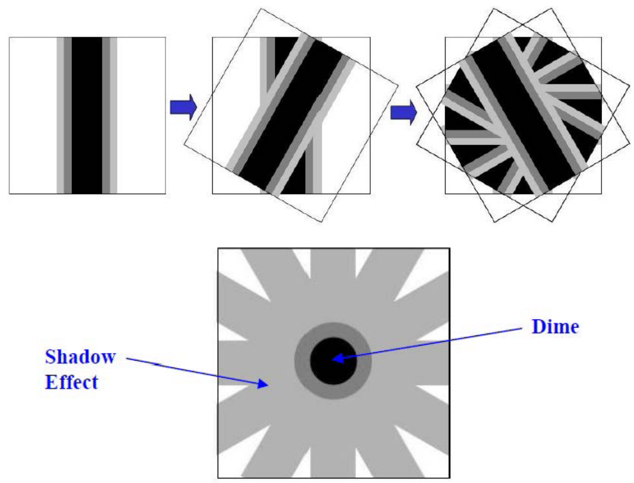

Figure 3. CIBR image scanning process. Top: Series of scans captured from 365 degrees around the target of interest. Bottom: Combination of the images to show a dime target in the center with shadowing effects on the edges. Images courtesy of C. Meng.

Capitalizing on the speed of fan beam geometries, Dr. Jessica Kelley went on to demonstrate success in applying fan beam geometry through a unique approach known as a push-broom design to test rail tie integrity. Kelley's

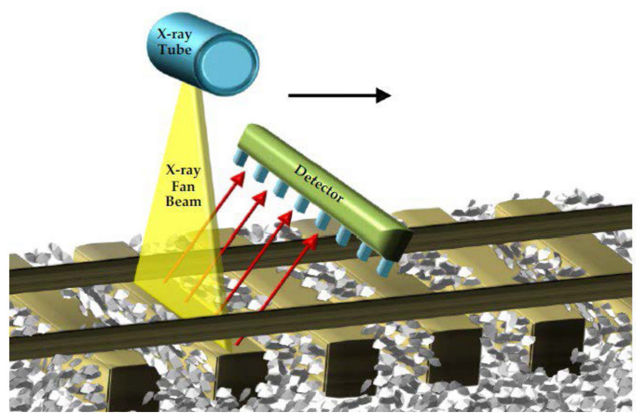

Figure 4. Push-broom concept design. Image courtesy of J. Kelley.

research capitalized on the fact that fan beam geometries have a clearer resolution at greater distances than pencil beam geometries. As a result of her push-broom design, Georgetown Rail was able to inspect rail ties by driving a truck with a detector and x-ray source along the rails in excess of 25 mph.[9] At 15 mph, her system could detect voids in wood cross ties as small as 1.5 cm.[10] By characterizing the Modulation Transform Functions (MTF), or contrast function, of the detector array, the system could determine the voids within the rail ties, comparing the wood density to air gaps, water, and gravel.

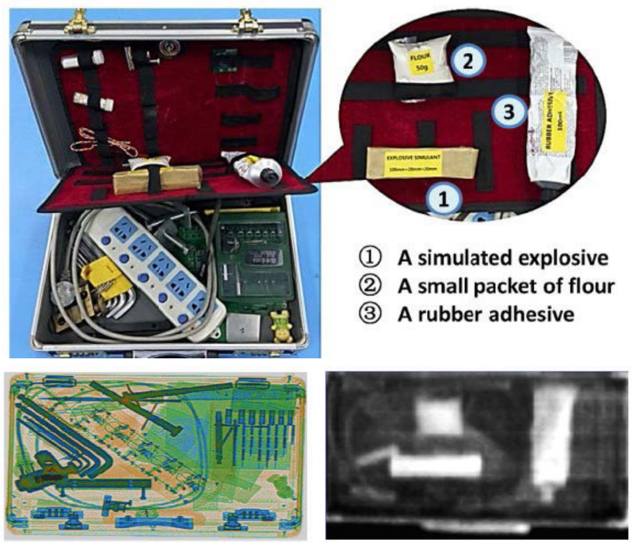

Figure 5. Scans of a brief case containing wires, explosive and organic contraband. Top: Photo of a target briefcase for their experiments. Left: Transmission image of the target. Right: CBI image highlghting the low Z explosive and organic contraband simulants. Image courtesy of Xiong et. al.

The characterization occurred using two methods, edge and bar pattern. Bar pattern relied on a series of bars that were pre-scanned in regions of interest to acquire and characterize the relative brightness of the system, while the edge method relied on 3 separate scans that were combined to create a pre-sampled MTF unique to the spatial domain of the specific linear detector array. It is important to note that the bar pattern is a course, but quick method of obtaining a detector MTF, while the edge method provides a more precise method. However, the relative speed at which the push-broom design worked inspired follow-on research in land mine detection, which saw success in detecting a lightly buried pressure plate under 3.81 cm of sand or 7.62 cm of water.[11]

In 2019, the researchers at the Chinese Academy of Science tested the development and application of a Y2SiO5 fan beam design, with a linear detector array similar to the push-broom design. Their final design consisted of a fan beam geometry with a linear detector array for the purposes of “low atomic number and high-density materials such as explosives, drugs, and other organic materials.”[12] Their work focused on the use of CBI imaging for explosive and contraband detection, with the majority of their success in low z materials, as shown in Figure 5.

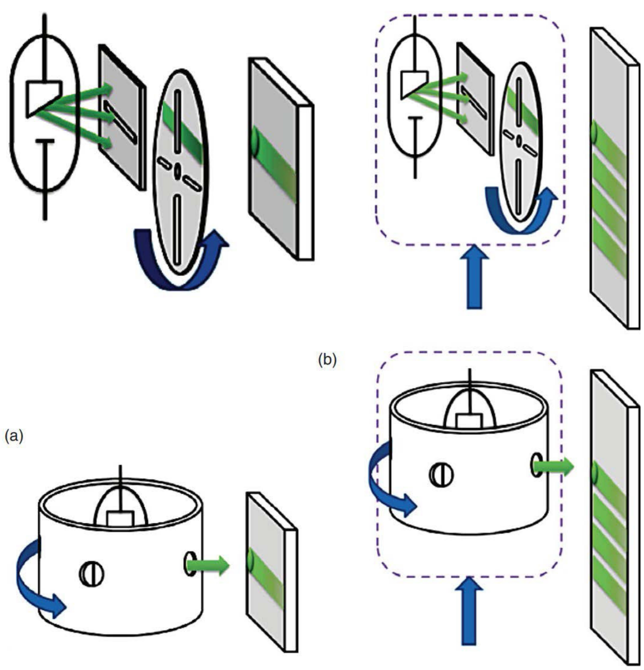

Figure 6. Top: Rapiscan 1000 pencil beam rasting technique using a rotating collimator. Bottom: AS&E rotating and lifted collimator rasting technique. Images courtesy of Erik Svedberg and the Committee on Airport Passenger Screening.

Commercial Developments for Law Enforcement Applications

With the increase in homeland security and law enforcement check point screenings, backscatter imaging offers a complimentary capability to traditional transmission imaging methods. Two predominate applications of back scatter imaging include personnel (passenger) check points and cargo inspections. For backscatter imaging of personnel, the three primary systems fielded operationally are manufactured by Rapiscan Systems, American Science and Engineer, Inc. (AS&E), and Tek84 Engineering Group, LLC.[13]

The first personnel system, the Rapiscan 1000, uses a rotating pencil beam that is collimated to raster the set target individual at a rapid pace. This rotating collimation allows for rapid collection of scattered X-rays into large area detectors positioned around the person of interest. This Advanced Imaging Technology (AIT), utilizes a posterior and anterior unit to rapidly scan an individual in three to six seconds.[14] The large area detectors coupled with the exposure location generate an image of anything concealed on the individual being scanned.

By comparison, the AS&E smart check uses a different approach, but still maintains a relatively similar scanning speed while still using a pencil beam. Unlike the Rapiscan 1000, the AS&E moves a canister of pencil beam collimation and detectors vertically along the scanning axis, allowing for a rapid acquisition with single lines of scanned area at a time. The total scan time of the AS&E systems, like its Rapiscan AIT counterpart, is approximately three seconds.

The final system was developed by TEK84. It is most closely related to the Rapiscan 1000 in terms of collimation and image acquisition with an average scan time of approximately six seconds. However, unlike the Rapiscan 1000, TEK84's user software does not have automatic target recognition and therefore is not in use in the United States, but is in use in other countries, like Israel.

The benefit to these personnel AIT scanning systems is not only do they provide a high degree of confidence as to any hidden items or threats under a passenger's clothes, but they're also relatively safe. Because of the precise nature of backscatter imaging relative to other x-ray technologies, collimation of the source photons limits the exposure to a small beam and small area of effective dose as a result. To prove this, Johns Hopkins University Applied Physics Laboratory (JHU/APL) conducted a test using an ion chamber both internal to the scanning system to represent the individual undergoing the scan, and external to the system to calculate bystander and operator dose. Their calculation methods were based on the ANSI/HPS N43.17-2009 calculation methods.[15]

Their experiment and calculations concluded that the average dose per scan for the individual within the system was 14.6n Sv per screening.[16] They went on to determine that the average by-standard received approximately 7.14 nSv per scan, with a maximum of 1,285 nSv per hour, based on the assumption of 180 scans per hour. The importance of these distinct measurement values is whether the bystanders is another passenger passing by the scanner as they move through the security check point or a system operator or checkpoint security officer. The system operator or checkpoint security officer would remain close to the system for the 180 scans per hour, whereas a passenger passing through the check point would get a minimal amount of bystander exposure.

The National Institute of Standards and Technology (NIST) conducted a similar test to that of JHU/APL and found that the bystander exposure was an order of magnitude less. Because the exposure rate of the Rapiscan ATI was so low, it only reached a maximum of one-twenty-fifth to one-eight of a person's maximum dose contingent upon the scanned person's positioning within the system. While the Committee on Airport Passenger Screening noted that there may be construction differences between units or scanned individuals who position themselves improperly within the scanning area, the calculated dose values could vary slightly, but the dose is still below the threshold of known medical impacts, such as cancer, on an individual.[17] By comparison, a chest x-ray averages 0.1 mSv (100,000 nSv), while a hand x-ray averages 0.001 mSv (1000 nSv).[18]

While personnel screening using backscatter technology is relatively safe, equipment scanning techniques that Rapiscan has developed demonstrate promise as well.

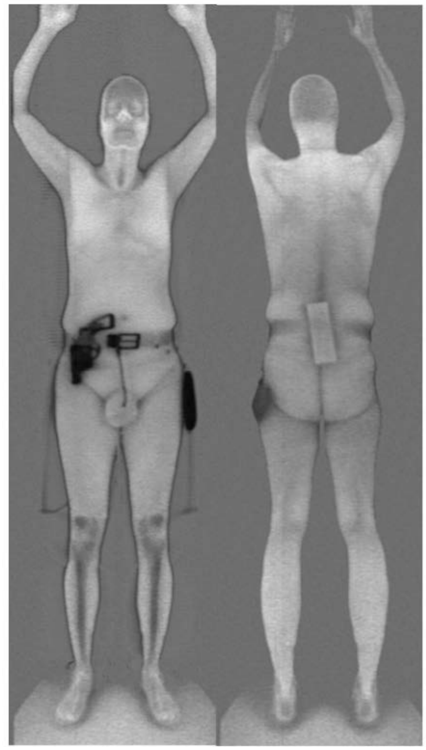

Figure 7. Anterior and Posterior scans of individual concealing firearm and contraband under their clothes. Image courtesy of TEK84 engineering group and Committee on Airport Passenger Screening.

Figure 8. Top Left: Rapiscan Mini Z. Top Right: Hidden contraband currency. Bottom Left: Transmission Scan of Vehicle with rifle and propane tank. Bottom Right: hidden drugs. Images courtesy of Laurus Systems.

Rapiscan sports a suite of backscatter imagers to include portable vehicular checkpoint scanners, fixed vehicular checkpoint scanners, and handheld scanners. Their vehicular checkpoint scanners not only offer backscatter imaging capabilities that highlight the low Z composition of explosives and narcotics, but work in conjunction with transmission imaging in order to develop a more holistic understanding of any potential threats within a scanned target vehicle. Furthermore, the Rapiscan and AS&E handheld scanners have the ability to get more precise scans in areas of interest that may register as potential threats from a large-scale vehicular scan. Their advertised scanning depth allows for near skin contact of a car door, with penetration imaging up to 4mm of steel or 17mm of aluminum.[19]

Conclusion and Future Work

CBI has progressed dramatically since its first inception as only a land mine detection method. While initial concepts were slow and cumbersome, despite accuracy, the potential advantage to single sided imaging is worth research given advances in computing capabilities. With each success in the application and development of approaches both in academia and commercial applications, more opportunities for further development are presented. The approach of SBR and SABR using phosphorous scanning plates similar to equipment already in use by some EOD teams presents an opportunity for image generation that may offer teams a doctrinal advantage when transmission imaging is constrained. Combining the speed and accuracy of systems through collimation and spatial image refinement demonstrated by Meng and Kelley may require additional software materiel capabilities. Although it currently lacks the accuracy of transmission imaging, the benefits of layered imaging, as well as the decreased risk to force, make CBI a relevant and necessary research field. ■

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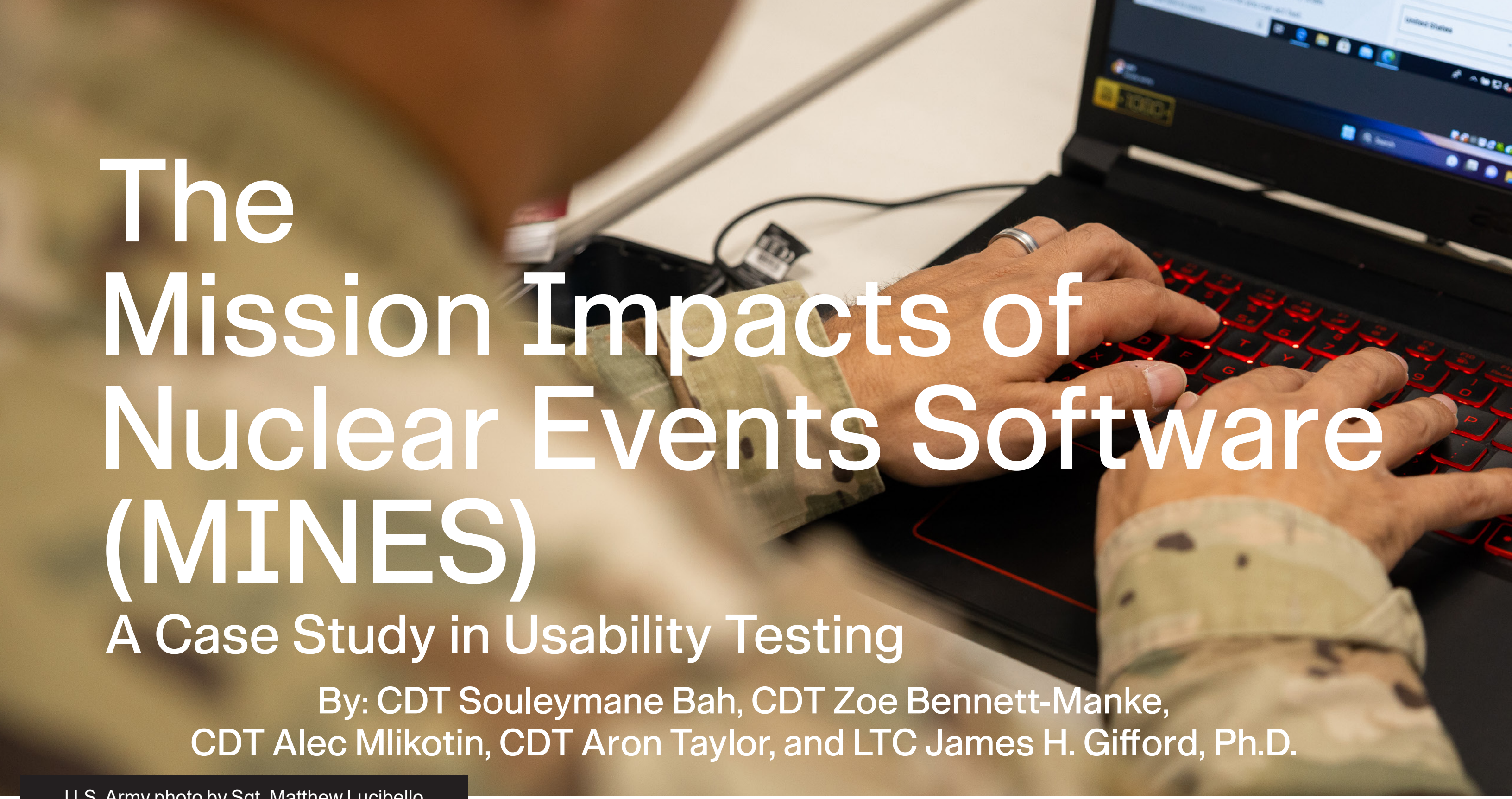

The Mission Impacts of Nuclear Events Software (MINES)

A Case Study in Usability Testing

By: CDT Souleymane Bah, CDT Zoe Bennett-Manke,
CDT Alec Mlikotin, CDT Aron Taylor, and LTC James H. Gifford, Ph.D.

U.S. Army photo by Sgt. Matthew Lucibello

Background

Many organizations develop nuclear weapon effects codes. For the Department of Energy/National Nuclear Security Administration it is the National Laboratories, such as Sandia National Laboratories and Los Alamos National Laboratory, and for the Department of Defense (DoD) it is the Defense Threat Reduction Agency (DTRA). Most nuclear effects codes are designed for technical subject matter experts (SMEs) who are familiar with other technical codes and processes. For these technical nuclear codes the priority is the technical capability with little investment toward usability during development, with many usability upgrades limited by the legacy interfaces or architectures used to originally develop these codes. Typically the main users for technical software are the SMEs who provide the specifications to the developers, so the code is built to fit the SME needs. New users typically require a week or longer training course to learn the software, and then they still often rely on a checklist to ensure they are properly setting up and running calculations. A new DTRA nuclear wargaming tool, the Mission Impacts of Nuclear Events Software (MINES), aims to break that mold and is targeted at users outside of the typical nuclear SME community. Once MINES was ready for its first non-technical users, it became apparent that designing for usability is vital to the success of this software, since most of the users are unfamiliar with traditional SME tools. A software's usability is not a single quality, but rather a set of attributes. Nielsen listed those attributes as learnability, efficiency, memorability, errors, and satisfaction.[1] Each of these attributes is now considered when any changes are proposed for MINES.

MINES is the primary nuclear wargaming software application programming interface (API) currently in development by DTRA's Research and Development Directorate (RD) Nuclear Technologies Department (NT). DTRA RD-NT facilitates deterrence through resilience by supporting the integration of low yield, non-strategic nuclear weapons (NSNW) into DoD conventional wargaming architectures and advocating for, and incorporating, potential enemy use of NSNW vignettes/events into Service, Joint, and Combatant Command (CCMD) wargames. This ensures the Joint Force can plan, prepare, fight, and win in a nuclear environment. The MINES tool is a significant part of DTRA RD-NT's efforts toward ensuring deterrence through resilience.

MINES is designed to provide operational impact from a nuclear detonation to support planning and adjudication in a wargame environment.[2] Most nuclear software codes model nuclear environments (airblast, prompt radiation, thermal, fallout, electromagnetic pulse (EMP), etc.) and their effects to buildings, underground structures, and/or the civilian population. The limited number of nuclear software tools that include military units, focus on determining the minimum safe distances (MSDs), least separation distances (LSDs), or other forms of how far away from ground zero friendly troops should be when conducting a friendly nuclear strike. MINES is designed for the opposite, to look at the damage when military units are in the vicinity or the target of an adversary's nuclear strike. It provides operational impact, by calculating the effects to military equipment and personnel resulting in a degradation to combat power, including time based degradation resulting from acute or prolonged radiation exposure. MINES is unique among nuclear effects codes in that it can estimate the causalities to combat units from nuclear detonations, taking into account the shielding and radiation protection factors of military equipment. Figure 1 depicts the basic design of

MINES.

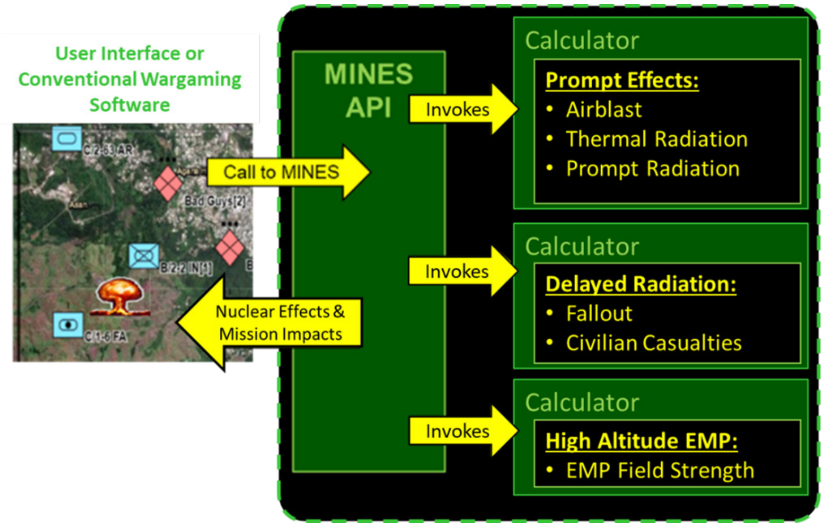

Figure 1. MINES architecture design

The MINES API began development in November 2020, with the first prototype made available in November 2021. For the prototype, the initial workflow for running a scenario in MINES was created by the developers and provided to DTRA without input from future users. In other words, the typical nuclear SME code procedures were the basis for the MINES workflow. Using this initial prototype, the DTRA RD-NT team provided multiple demonstrations to potential customers of the MINES tool, always sticking to the same script and using that initial workflow. Little thought was given to the completeness or accuracy of this workflow during these demonstrations. With no other users the workflow seemed adequate.

In April, MINES was granted functional interim authorization to test (IATT) on Amazon Web Services Government Cloud (AWS GovCloud) through https://mines.dtra.mil. This IATT allowed for beta testing of MINES by users outside of DTRA. Within the first few hours it was clear that a tutorial needed to be developed to walk new users through the MINES workflow. For these new non-nuclear SME users, the workflow was unclear or confusing. Many of these initial users were not able to figure out how to change key inputs, such as the nuclear weapon's yield, height of burst, or change the echelon of units. DTRA RD-NT quickly developed a stopgap user guide with screenshots to explain the designated workflow. This user guide later became an interactive tutorial within the MINES tool. As the number of users increased, the DTRA team realized more effort was needed regarding usability. The remainder of this article considers the lessons learned from the initial MINES usability testing, prescribing a framework for future software development in the nuclear community.

User Testing Methodology

Usability evaluation methods (UEMs) are ways to evaluate human interaction with software intended to identify areas of improvement in this interaction to increase the software usability. Layla Hasan, a preeminent researcher in user testing, lists the possible UEMs as: user testing, think-aloud method, constructive interaction, questionnaires & interviews, and eye tracking.[3] DTRA chose three of these methods for its initial usability testing: user testing, co-participation, and questions & interviews. Both think-aloud and co-participation require users to verbalize what they are doing with the software, DTRA chose co-participation over the think-aloud method due to hardware limitations. Eye tracking was also not used because it required equipment that was not available. Just as important as the UEMs chosen, the correct users must also be selected for a successful usability test.

The users chosen for the usability testing were three cadets from the United States Military Academy and one ROTC cadet from Southern Illinois University. These cadets were conducting a summer internship with DTRA in June and July 2022 and were the perfect candidates for non-technical users. None of these cadets have experience with nuclear weapons codes, or even with nuclear weapons effects. They do have some limited experience with military operations and could provide an unbiased assessment of MINES usability for non-SME warfighters. DTRA provided the cadets with a list of nuclear wargaming scenarios and asked to work through them using MINES. As the cadets worked through these scenarios they utilized the previously selected UEMs to determine usability improvements.

User testing is defined as "collecting information about the specific ways in which the product is easy or difficult for" users.[4] This was the main method used to garner feedback from the cadets. When the first two cadets started working on MINES, they were only given the interactive tutorial to learn the software. This walked them through the initial workflow and how to create and calculate a simple scenario. After a week of the cadets working on MINES alone, the DTRA lead for MINES met with the cadets and provided some additional training on the application, showing the cadets some of the advanced features. These cadets then spent an additional two weeks working with MINES and documenting issues with the software. The next two cadets arrived with a few days overlap with the first group of cadets before they departed. This allowed the first cadets to train the newer cadets with everything they had learned about MINES and their findings. As the second set of cadets began their user testing, they were able to expand on the work of the first two cadets and look at new issues, not just find the same issues as the first group. The second set of cadets felt they were able to become advanced users of MINES within a few days of being shown how to use the software by their peers.

Constructive interaction or co-participation "involves two participants working together to explore the test object and perform tasks."[5] Due to MINES account access requirements, the cadets had to share a single computer with MINES access. MINES contains Controlled Unclassified Information (CUI) data, requiring both a common access card

(CAC card) and a connection to a DoD Non-Secure Internet Protocol Router (NIPR) for access. The lack of NIPR access required the cadets to work from a standalone laptops. This single laptop necessitated the use of co-participation, which actually provided great feedback on MINES. With only one laptop, the cadets had to work together and talk through what they wanted to do in MINES, causing them to discuss their differences in understanding and functionality in MINES. Had they been working on the software individually, they might not have realized each other's interpretations or perceptions of the software, which lead to some key findings related to entity movement.

Questionnaires and interviews was the final user testing method employed with the cadets. Unlike the first two methods that relied on the cadets' working on MINES without DTRA influence, this method directly focuses the users on answering questions from the designers/developers to better understand the users' views. The cadets were provided with a 21-question questionnaire about the tutorial and its usefulness in understanding how to use MINES. This survey asked users to compare their knowledge and experience with MINES before and after running through the tutorial in order to determine the usefulness of the tutorial and anything to add or delete. Also, the DTRA team conducted at least one interview with each group of cadets in the middle of their time and again at the conclusion of their internship. These interviews allowed DTRA to ask detailed probing and follow up questions to really understand the issues the cadets discovered with MINES and their recommendations on how to improve the software.

User Testing Results

The testers uncovered and identified many issues with the MINES software that have since been corrected or improved. Because the DTRA team previously stuck to the same SME-based workflow for their demonstrations, this was the first time users went off script and tested the full capabilities of MINES. The main usability findings can be grouped into calculation errors, movement anomalies, and workflow improvements.

The testers discovered multiple calculation errors through some very inventive methods. One scenario arrayed each possible unit type, over 50, in a ring at a set distance from ground zero. This allowed for quick comparison of the various unit types or entities in MINES to ensure the proper radiation protection factors and damage thresholds were applied. As a result, multiple heavy armored units were identified with incorrect radiation protection factors. Another scenario was created where one entity would move toward ground zero and another move away from ground zero before the detonation. This scenario showed that the thermal and damage probability was calculated using the initial entity location, but the air blast and prompt radiation were calculated using the current location at the time of detonation. This is a significant error, as all calculations should be based on the entity location at the time of detonation. Another error identified occurred in the prompt radiation calculations for some recently added yields, where no prompt radiation was calculated. Finally, testers noticed that all radiation contours above 1,000 cGy had the same radius. (cGy is centi-Gray. Gray is the international standard unit of measure of radiation exposure dose. cGy is the unit of measure used in Army doctrine for tracking radiation exposure, 1 cGy = 1 rad.) By default, MINES shows radiation contours of 1,000 cGy, 3,000 cGy, and 8,000 cGy; however, none of the developers or DTRA team members had noticed that the 1,000, 3,000, and 8,000 cGy rings were displaying with the same radius, see Figure 2. These calculation errors would likely never have been noticed with the standard demonstration script used by DTRA, and are all substantial issues that are now being corrected.

MINES allows entities to move around the battlefield before, during, and after the detonation in a scenario. This movement function had not previously been rigorously tested by DTRA; only a single entity moving in a straight line stating at the time of detonation was used to demonstrate the capability. It was found that trying to move entities prior to the detonation caused an error in the results visualization and the entities not moving correctly on the screen. It was also noticed that if entities moved at or after the detonation, at the final time step the entity icons would jump back to a previous location along their path. Also, while drawing a movement

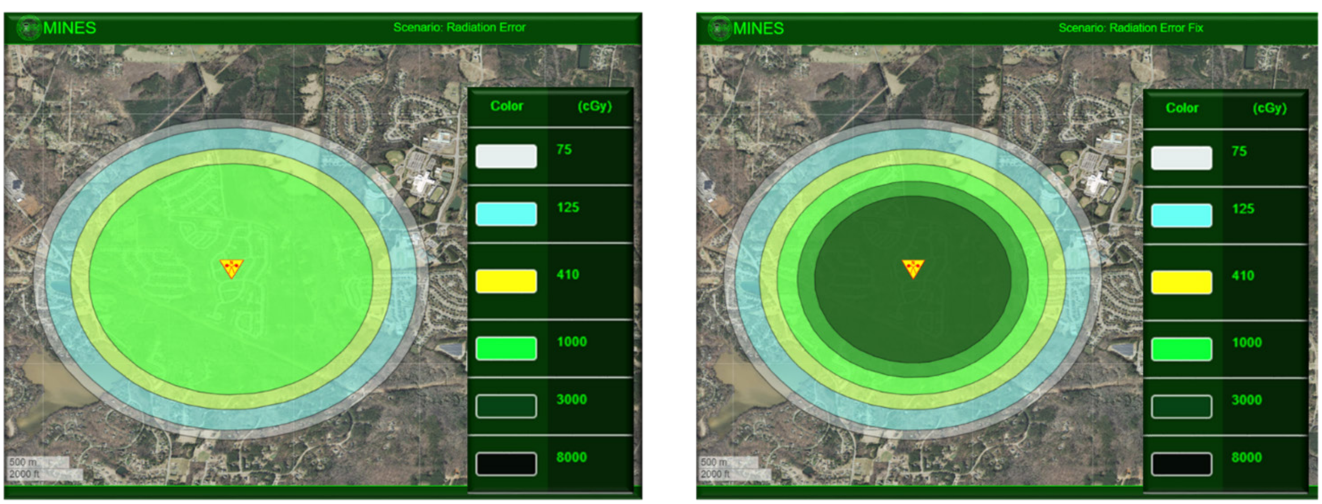

Figure 2. Prompt radiation contour rings above 1,000cGy missing (left) and corrected code providing all correct contours (right).

path is simple using MINES, the testers found that editing a point in a pre-drawn path was difficult. In fact, they found it easier to delete the entire path and start over rather than trying to change a single point along the path. Movement is a functionality in MINES that has not been used much prior to the usability testing, and the extent of the errors related to movement was not understood. These movement issues, once brought to light, have been address in MINES.

The characteristic of MINES that the usability testers had the most feedback on was its workflow. They found the typical technical SME workflow created by the developers to be confusing and did not follow the logic of military operations. Figure 3 depicts both the current and recommended MINES workflow. Currently a scenario is built from bottom to top, starting with units (1), then nuclear weapons (2), then the weather (3), and advanced calculations (4), before going to back to the very bottom of the menu to run the calculation. Running from bottom to top is counter-intuitive for new users and it was suggested to reorder the workflow to run from top to bottom.

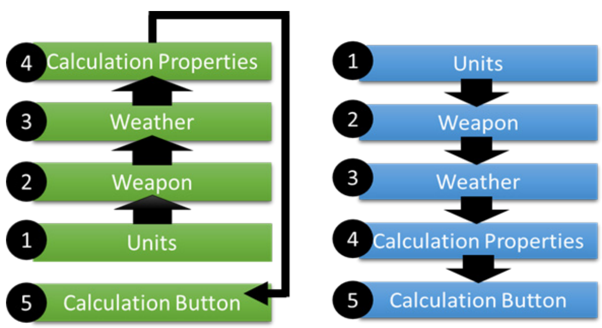

Figure 3. Depiction of current MINES workflow (left) and recommend new workflow (right)

It was also found to be counter-intuitive to have to double click a placed weapon icon in order to access the menu to change the weapon's yield and/or height of burst. The testers suggested having the weapon properties menu automatically display anytime a weapon is dropped on the map to simplify the workflow. Another confusing aspect of the MINES menus was the advanced options in the calculation properties. Most of what was confusing was old buttons or selections that are now obsolete and had not yet been removed from the software. Since these are not used in the scripted demonstrations, these outdated selections had been skipped over and ignored. Removing them will prevent any future user confusion or workflow breakdown. Finally, the need for a displayed legend explaining the visible nuclear environment contours was identified. It is possible for a user to open a settings menu to view the contour settings; however, that menu requires a few button clicks and once on screen it covers the majority of the map and contours. Having a specific legend visible automatically upon displaying calculation results and set off center, so as not to cover the results, would be very helpful to users interpreting and understanding the calculation results. Similar to the other tester feedback, these changes are being implemented to improve MINES for current and future users.

Conclusion

MINES is a nuclear weapons effects software tool that provides a unique capability, to adjudicate effects to military units and get the resulting degradation to combat power from nuclear detonations. Unlike other nuclear codes, MINES is intended for use by warfighters, not only technical SMEs. As such, MINES has a simple interface and should be very user friendly. However, MINES was developed primarily by nuclear SMEs who are used to the other more technical and complicated nuclear codes. The engrained workflow approaches and predispositions of traditional nuclear software made its way into the development of MINES unintentionally. Once non-SME users started to use MINES, a shift in the development mindset was required. A focus on improving the usability for non-SME users was necessary, and dedicated user testing was conducted. Through the effort and dedication of four future Army leaders, the user testing of MINES was able to identify many needed changes and cause a shift in perspective towards user focused development. Usability feedback was able to catch errors that had gone unnoticed for months and provided insight into refining the workflow processes to significantly improve the usability of MINES. As the DoD begins to consider operations in post-detonation nuclear environments, it is vital that the technical nuclear SMEs adjust their thinking and methods to be more accessible to non-SME warfighters.

The MINES nuclear wargaming tool is currently available on NIPR at https://mines.dtra.mil. MINES has authority to operate on NIPR at the CUI level and anyone with a CAC card and NIPR access can get an account. If interested in MINES access, please email dtra.belvoir.rd.list.mines-help-desk@mail.mil. ■

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Army Officer Corps Science, Technology, Engineering and Mathematics (STEM) Foundation Gaps Place Countering Weapons of Mass Destruction (CWMD) Operations at Risk - Part 3

By: MAJ Bryan Lagasse, MAJ Patrick Bowers, LTC Andrew R. Kick, LTC Matthew Gettings, MAJ Jeffrey Chin, MAJ Nicholas Calangi, LTC Robert McMahon, and COL F. John Burpo

Background:

This is the third and final article of the series where the authors have outlined potential risks the Army may face in future Joint operations due to the shortage of STEM competencies in the Army Officer Corps. To assess this risk, we utilized the Joint Operational model, Notional Phasing for Predominant Military Activities, from JP 3-0, Joint Operations as the framework. In parts 1 and 2 we described how the current efforts in Phase 0 (Shape) and Phase 1 (Deter) were insufficient to develop the STEM competencies in the Army Officer Corps at large. As the United States Army is not directly engaged in a direct or decisive action conflict, our assumption is that we are currently in Phases 0 and 1. During these phases, the focus is on the ability of military leaders to understand the operational environment and develop competencies in preparation for offensive operations. In this article, we shift to address the potential future conflicts and how the lack of STEM competencies could impact the Army's ability to win our Nation's wars. During Phase 2 (Seize the initiative) and Phase 3 (Dominate) the focus for military leaders is on executing offensive operations and the abilities of those leaders to develop an operational plan leading to mission accomplishment. In Phase 4 (Stabilize) and Phase 5 (Enable Civil Authority) the focus shifts to stability operations and the leaders' abilities to use information to enable local leaders to re-establish authority and control of the operational environment. With the continued introduction of innovative technology, it is critically important that military officers at echelon have foundational STEM competencies in order to effectively integrate the technology into operations.

Introduction:

In concluding Parts 1[1] and 2,[2] we recommended several courses of action to address the shortfalls in the STEM competencies across the Army Officer Corps. These included:

- implementing a requirement for greater than 50% of all ROTC scholarship awardees and service academy graduates to earn an undergraduate degree in STEM

- allowing additional opportunities for company and field grade leaders to earn a graduate-level degree (M.S. or Ph.D.) in STEM-related fields

- including CWMD operations as part of planning and operational objectives during every training center rotation

As seen over the last year of the Russo-Ukrainian War, the rapid advancement of technology over the past decade continues to play a critical component in modern combat operations. Ranging from personal-use unmanned aerial vehicles to conduct attacks on remote locations, to the ability to deny an adversary use of satellite systems such as GPS or even communication, it is unlikely the next major conflict for the United States will not have similar technology used by all sides.[3,4] In order to leverage the capabilities that this ever-advancing technology provides, leaders at all levels should have a familiarity with a broad range of STEM fields and concepts. Having this familiarity allows leaders to recognize and capitalize on opportunities and minimize significant risks to their operations and forces. While leaders may not be the subject matter expert on the technology or scientific challenge, the ability to process and distill the most important information from data in less time than their adversaries will be a critical component in future conflicts. Given the increased prevalence of technology within the military at all echelons it would follow that there would be a focus on developing the technical competencies and understanding of trending technology at echelon within the formalized military development and education system. Unfortunately, this assumption is not true under the current Army accessions mission and professional military education structures. On the contrary, there is a significant lack of development of STEM competencies at any level of the formalized military leadership education, with the exception of specialized roles such as Medical Service Officers or Functional Area officers. Furthermore, the lack of STEM competencies in the military leadership education domain places the burden of STEM competency development on the undergraduate education program. While this does fulfill some requirements for STEM competencies, there are several concerning trends that elevate the risk of this approach. First, the percentage of newly commissioned officers with undergraduate degrees in STEM has decreased over the past 20 years. Second, looking only at the graduation requirements for the United States Military Academy at West Point, the number of required STEM courses to earn a Bachelor's of Science degree has decreased by 10% over the past 40 years (See Table 2). While this does not necessarily indicate a decrease in understanding or competency, it does present a probability that graduates have less depth of understanding of STEM concepts and competencies. Due to the varied programs ROTC graduates can attend it is more difficult to quantify the prevalence of general STEM courses in this population. These trends indicate a potential major risk during future operations, especially during the offensive and stability phases where commanders will need to understand and implement US and allied science and technology (S&T) while countering adversarial S&T, in order to make timely and accurate decisions. This risk further elevates when considering CWMD operations, which historically is not a priority during combat training center (CTC) rotations, leading to further erosion of the Soldier-level skills that are critical during these engagements. Without a significant effort to introduce more STEM-related competencies into the military officer education system at echelon the US Army risks being woefully unprepared for the conflicts ahead.

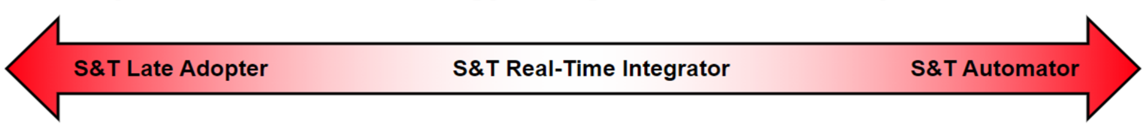
Assessing this risk requires an assessment of the technological complexity facing the Army and an acknowledgment of potential domains the Army faces in future conflicts. The recently published FM 3.0, Operations, details the ambiguity and complexity the Army faces in what it now calls Multi Domain Operations (MDO). Senior leaders recognize the complexity and ambiguity that future conflict can and likely will contain. Of note, Army leaders at every echelon must recognize the interdependency of domains within the operational environment, specifically recognizing that effects from the air, space, cyberspace, and maritime domains affect land operations, and vice versa.[5] Some prominent examples include the land domain's ability and/or responsibility to destroy physical nodes executing enemy cyber operations, and the ability of enemy cyber operations to disrupt communications and collect intelligence on ongoing land operations. How does an Army leader, at echelon, recognize the presence of a physical location for an enemy cyber node? A STEM-educated leader could potentially recognize the presence of additional power infrastructure, network equipment, and the difference between a multi-directional, line-of-sight or satellite communications array. While only a small example, many similar thought experiments exist between the interrelations of these four domains.

Spectrum of Science & Technology model

Understanding that S&T will continue to occupy an increasingly greater influence in our military necessitates that leaders understand, at least on a fundamental level, what various technologies can provide them on the battlefield. As a framework for analyzing the broad range of abilities for officers we propose the following spectrum of technology integration for military leaders as a tool to assess leaders at echelon. On the far ends of the spectrum are S&T Late Adopters and S&T Automators. These are defined as most sub-optimal for the conflicts of the future. Leaders who trend as a late adopter are at risk due to a tendency to not utilize the resources available or inability to integrate new systems into the decision-making process and, therefore, will be behind the decision-making cycle and likely achieve sub-optimal results. This is not to say those officers will be completely ineffective, but rather that they will fail to reach their full potential both as individuals and for the organizations they lead.

An emerging technology that is expected to have the greatest impact on future conflicts is the integration of artificial intelligence (AI) and machine learning (ML) systems. While these technologies are closely linked, there are some discrete differences in their application. Briefly, artificial intelligence leverages the abilities of computers to rapidly analyze data streams with pre-determined algorithms to provide specific information or to take a predetermined action. Machine learning is similar to AI in that it also uses algorithms to analyze data, but instead of taking action it recognizes patterns in the data stream and then adjusts the algorithms to make better assessments of future data.[6] With the development of artificial intelligence and machine learning system (AI/ML) it follows that these systems will eventually integrate into the myriad of sensors and battle tracking systems at the military's disposal. A late adopter will likely not take advantage of how these systems can rapidly analyze and synthesize this large pool of data to identify patterns and present potential courses of action. For example, through AI/ML it would be possible to quickly analyze a wide data set collected from a variety of forward positioned sensor systems. The AI/ML system could then analyze the information, detect patterns, and propose potential future operations or targets. Officers who are late adopters of this technology in favor of a more traditional analysis may still recognize this opportunity, but it would likely be well after the AI/ML system. This suggests these leaders could miss valuable opportunities against the enemy and delay the achievement of the overall mission. An important

Spectrum of Technology Integration for Military Leaders



S&T Late Adopter — Characteristics:
- Delays integrating new systems
- Late to recognize technology advancements
- Relies on personal experience in decision making, generally ignores "Big Data" or AI/ML
- Lacks understanding of STEM foundations and applications

S&T Real-Time Integrator — Characteristics:
- Effectively integrates new systems into operations
- Distills useful information from large data streams to identify most important data
- Solid foundation in STEM foundations
- Able to rapidly assimilate new knowledge and technology

S&T Automator — Characteristics:
- Integrates all new systems rapidly, but with limited efficiency due to ongoing development
- Recognizes value of "Big Data" and AI/ML systems; struggles to discern pertinent from noise
- Understands STEM foundations at surface level; lacks depth of knowledge

Figure 1. Spectrum of Technology integration for military leaders and associated characteristics of leaders along spectrum.

recognition is that these officers may see the value of this new technology, and may even praise it, but may be delayed integrating it due to their unfamiliarity with the technology or supporting infrastructure and lack the fundamental STEM competencies to understand it.

On the opposite end of the spectrum are S&T Automators, officers who rapidly integrate new technology into their operations without fully understanding how the technology operates. These officers implement new technology readily, but generally to suboptimal efficiency. One trait of officers on this end of the spectrum is they may not be able to discern the useful data from the large amount of information available to make effective decisions. They are also susceptible to information paralysis, or inability to decide due to the overwhelming amount of data at their disposal. Another risk of the S&T Automator is the potential to be ineffective at communicating their intent to subordinates due to reliance on digital systems. This disconnect could arise due to issues or flaws with the actual systems, or from the subordinates' lack of understanding of the system. While the physical act of running the system seems straight forward, to truly leverage these systems requires officers with an understanding of algorithms, probability, and computer systems. Without this ability, the officer could blindly trust the system, and its recommendations. If applied to the Army writ large, the Army officer corps could end up either abdicating its decision-making in combat to algorithm-based systems or miss the advantages and opportunities available due to an inability to implement and understand these new powerful tools. This is further exacerbated by the nature of the Army acquisition process which tends to trail behind the develop of new technologies as a necessity of determining how to properly integrate new technologies into the military operational structure and environment.

Another concern pertaining to officers who tend towards the S&T automators region of the spectrum is they may tend to engage passively with their units through the digital realm, versus actively with their subordinates. While these officers will incorporate many of the new systems, it will likely be desynchronized and create the potential that the leader and the subordinate are not able to share a common operating picture and assist in the decision-making process. This is a significant risk as most contemporary models of the innovation process include multiple iterative cycles requiring implementation, analysis, and re-evaluation before arriving at a final product.[7,8] By breaking the links between analysis and re-evaluation it lowers the potential that the organization will be able to develop an effective solution or to take advantage of opportunities on the battlefield. While innovation is necessary and will eventually lead to new possibilities, it requires STEM-competent leaders to reduce risk while implementing in combat. These risks set conditions for the S&T Automators to be generally ineffective and behind their adversaries in the decision-making cycle. While these officers may still achieve success, it will likely be at a greater cost both in terms of equipment and manpower.

The most optimal position on the spectrum for an officer to trend is the S&T Real-Time Integrator. These officers can both understand the benefits of the systems and technology, while also understanding the limitations or shortfalls. To truly weigh the benefit against the risk and implement effectively, the officer must understand the foundational concepts behind the system. With the ever-increasing complexity of the systems developed and the wide range of tasks they can perform, this means the officer must have a solid foundation in STEM competencies. An S&T integrator is able to absorb data from the various systems, identify the most pertinent for the decision, and then coalesce the information into actionable orders or recommendations. Unlike the officers who tend towards the ends of the spectrum, the technology integrator leverages the systems available for maximum efficiency and can seize advantages and opportunities in real-time. While all three types of leaders may ultimately be successful in a battle, campaign, or effort, only the technology integrator achieves these ends with the most efficient route. One of the defining skills an S&T integrator has compared to the other two types of officers is the solid foundation in STEM competencies which enable the officer to better integrate and understand the systems. Without these skills, the officer can only rely on others, which at best will only serve to further slow the decision-making process, and at worst leave the officer susceptible to misinformation or inability to recognize risks. Having a solid foundation in STEM will be critical in future conflicts to properly leverage the new and increasingly advanced systems that the Army fields. Currently, however, the Army's formalized educational system has a severe lack of STEM education for the Army officer corps and is overly reliant on the undergraduate STEM courses to provide officers the STEM competencies they will need throughout their career.

Argument 1: STEM Education is not significantly included in any echelon of professional military education (PME) (BOLC, CCC, ILE, War College)

Under the assumption that S&T will continue to progress and will play an increasingly important role in future conflicts, it follows that STEM competencies and proficiency would be included in the military officer education system. This system encompasses the required courses that all officers, regardless of branch, must complete to be eligible for promotion or leadership roles at the next rank. For the purposes of this article we define PME as the Basic Officer Leader Course (BOLC), Captain's Career Course (CCC), Intermediate Level Education (ILE), and the Army War College. Currently, there is almost no STEM competency education or evaluation in any echelon of the formalized military leadership education model. The formalized military education system lacks the content to effectively train current and future generations of senior leaders to make decisions in an MDO environment. The increase of S&T in Army systems will not be integrated effectively in the future because senior leaders will lack the foundational understanding of STEM concepts, forcing future leaders to trend as either S&T Late Adopters or Automators.

In a survey of the current programs of instruction for the military officer education systems at each echelon there were only two blocks of instruction dedicated to STEM-related fields. In both ILE and the War College, there is a block of instruction related to nuclear weapons and nuclear operational planning.[9,10] While understandably neither of these educational programs are designed to educate officers on the effects or an in-depth understanding of nuclear weapons or their effects, the concern arises from the lack of general STEM competency education for the senior leadership in the Army. Considering most officers have 10-12 years of service prior to attending ILE and more than 17 years prior to attending the War College, the conclusion is that the last formalized education most field grade leaders in the Army receive on STEM competencies was likely in their undergraduate education. At the lower echelon schools, BOLC and CCC, there is essentially no formalized education or assessment of STEM competencies. Some branches, such as Field Artillery and Engineers, have STEM-related points of instructions, but even in these fields these blocks of instruction account for less than 20% of the total hours of the course. While arguably both BOLC and CCC focus more on the development of tactical level skills for the positions their graduates will fill, this continues to widen the gap in STEM competencies for military officers upon graduation from their undergraduate commissioning source.

Further exacerbating the gap between STEM competencies and the development of other competencies is the formalized process for officers at both ILE and the War College to earn graduate degrees in various focus areas during their enrollment. All graduate degrees currently offered at both institutions, however, focus on history, politics, or international relations. The primary routes for an officer to obtain a graduate level degree in a STEM field currently is through selection for a functional area which requires a STEM degree, selection to be a rotating faculty member in a STEM department at the United States Military Academy, or through electing for a Graduate School Additional Duty Service Obligation (GRADSO) prior to commissioning as a second lieutenant. All three of these options are extremely selective, and in some cases potentially prohibitive towards an officer's career advancement. The end result is the vast majority of field grade officers have minimal formal STEM education or competency development throughout their military career.

With most military officers only having an undergraduate level education in STEM competencies the potential risks in future operations are most heavily prevalent during phases 2 (seize the initiative) and 3 (dominate) of the military operations model. During both phases, the focus is predominantly on offensive operations and leaders being able to exploit weaknesses and opportunities during the conflict. During these phases, however, there is also the greatest risk for the unknown as situations develop rapidly and there is a high degree of uncertainty in the developing conflict. FM 3-0 Chapter 1 highlights that the "proliferation of space and cyberspace capabilities further requires leadership who understand the advantages those capabilities create in their operational environment" and that leaders at echelon must be able to integrate and synchronize these capabilities to create and exploit advantages.5 The formal integration of these highly S&T related capabilities into the operations process underscores the need for officers with a solid foundation in STEM competencies in order to achieve the optimum results on the battlefield.

As a vignette, consider the threat the Army faced from improvised explosive devices (IEDs) during Operations Iraqi Freedom and Enduring Freedom throughout the early 2000s and 2010s. While conventional conflict was a major component of both of these conflicts, estimates of casualties from IEDs range from 40-50% across both of these campaigns.[11,12] When the US entered Phase 2 of these operations in the early 2000s, forces were generally not equipped or prepared for IED attacks and the number of casualties gradually increased over the first 10 years of conflict. This unexpected threat prompted a response from the military to continue to seize the initiative and enter Phase 3 of each operation. The enemy, however, did not remain static and continued to develop new methods of employment to evade US protection efforts. By comparison, the S&T employed to develop IEDs is considerably less complex than the technology being employed currently in the conflict in the Ukraine. In future conflicts, it will be increasingly important for military leaders at echelon to have a foundation in STEM competencies in order to attempt to stay ahead of the development of countermeasures or unknown threats.[13] This importance further amplifies by considering the employment of potential chemical or nuclear threats on the battlefield by combatants. Without a solid foundation in STEM competencies, officers at echelon will lose valuable time developing the skills, knowledge, and understanding to effectively analyze the environment and either make decisions on the battlefield or provide meaningful recommendations to senior leaders.

Argument 2: Officers with STEM degrees are pre-dominantly developed during undergraduate education; however, STEM courses have been decreasing in education.

Since graduates from ROTC programs have a wide range of requirements and variability between institutions it is difficult to assess the number of core STEM courses that ROTC graduates are required to complete in order to earn an undergraduate degree. While the core course requirements at the United States Military Academy (USMA) have changed over the years, the core courses have generally remained the same and serve as an effective control to assess the changes in STEM background for newly commissioned officers. Conducting a crosswalk of the core course requirements to earn a Bachelor of Science degree from the United States Military Academy revealed a trend that the number of required STEM courses for USMA graduates decreased over the past 40 years.

From 1985-1992 all cadets, including those in history, philosophy, or arts (HPA) focus areas, completed 16 core STEM courses out of the 32 required core courses (50.0% of the core course requirement). Cadets in a math, science, or engineering (MSE) focus were required to complete 18 core STEM courses out of the 32 required core courses (56.3% of the core course requirement).[14,15] Beginning in 1993-2007 the core course requirement decreased to 26 common courses for all cadets and the number of courses in a major ranged from 10-18 courses. Of the 26 core courses there were 14 core STEM courses required (54% of the core course requirement). It is important to note two of the core STEM courses were related to information technology/systems and both electrical and mechanical engineering were dropped from the core course sequence. Furthermore, the core engineering sequence reduced from five courses to three courses for all cadets regardless of major or focus area.[15,16]

Table 1: Cross-walk of Core STEM Courses Required to Graduate USMA[14–17]

1985-1992 Core Courses	1993-2014 Core Courses	2015-Present Core Courses
Chemistry x 2	Chemistry x 2	Chemistry x 1
Computer Science x 1	Computer Science x 2	Cyber/IT x 2
Math x 4	Math x 4	Chemistry/Physics/Biology x 1
Physics x 2	Environmental Science x 1	Math x 3
Electrical Engineering x 1	Physics x 2	Physics x 1
Mechanical Engineering x 2	Engineering Sequence x 3	Environmental Science x 1
Environmental Science x 1		
Engineering Sequence x 2 (HPA focus)		Engineering Sequence x 3
Engineering Sequence x 3 (MSE focus)		
HPA Required Electives: EV365		
MSE Required Electives: Math x1, Electrical Engineering x1, Physics x1		
Total STEM: 16 HPA / 18 MSE Focus	**Total STEM: 14 courses**	**Total STEM: 12 Courses**

In 2015 the United States Military Academy conducted a review of the academic program and restructured the core course sequence yet again. Under the new structure, cadets complete 26 core courses with 12 core STEM courses (46.2% of the core course requirement) and academic majors now have a standardized number of 13 courses including 3 electives which relate to the major field of study.[16,17] A summary of the core STEM courses cross-walk from the past 40 years is shown in Table 1.

While the average percentage of core STEM courses remained generally consistent across the years evaluated, the total number of STEM courses consistently decreased. Furthermore, West Point has gradually decreased the number of overall courses required to complete the academic program. From 1985-1992 cadets were required to complete 44 academic course to graduate.[14] In 1993 the number of required courses was decreased to 40 courses required to graduate.[15] It is important to note during this time period several majors, primarily in the STEM fields, required their cadets to complete more than 40 courses to earn their degrees. In order to normalize the values, the 40 course minimum was applied as the requirement to graduate and compared to the number of STEM courses required for all cadets. The requirement to complete 40 academic courses has remained constant through the present graduates, however the number of required STEM courses decreased to 12 courses in 2015.[17] The decrease in the number of overall courses compared to the number of STEM courses is shown in Table 2. While this data does not include an assessment of cadet performance across the last 40 years, nor their performance as officers upon graduation, it does reveal the general trend of the institution to focus less on STEM education for the officer corps, especially for officers who do not major in a STEM field.

In addition to requiring graduates to complete both less overall academic courses and less STEM courses there were several important changes to the STEM course requirements that are worth highlighting during this 40-year period. Beginning in 1993 the STEM course requirements focused on including more information technology courses to the curriculum decreasing the number of engineering courses from 5 courses to 3 courses.[14,15] Following the 2015 restructuring of the academic program cadets were only required to complete one semester of general chemistry and one semester of physics. The final physical science course was an option between general chemistry II, physics II, and a general biology course.[17] This is a significant change in the depth of knowledge for graduates that is not evident upon a review of the number of courses required, but is worth consideration when assessing the STEM competencies gap.

As the current model for officers to develop STEM competencies is almost solely reliant on undergraduate education, the officer corps is at significant risk to not possess the skills necessary to integrate or synchronize the technology of future conflicts. This leads to the potential that both current and future military officers will tend towards the extremes of the spectrum of S&T integration, rather than being S&T real-time integrators.

Table 2: Normalized Percentage of Academic Course Requirement at USMA 1985-Present[14–17]

	1985-1992	1993-2014	2015-Present
Academic Course Requirement	44	40	40
STEM Course Requirement	HPA Focus: 16 MSE Focus: 18	14	12
% STEM Courses Required	HPA Focus: 36.4% MSE Focus: 40.9%	35.0%	30.0%

Argument 3: Future operations in MDO will require leaders to make decisions rapidly in ambiguous situations. These operations will require leaders to effectively integrate multiple systems and data streams simultaneously in order to make optimal decisions.

During Phases 2 and 3, when offensive operations are the primary focus, the understanding of the operational environment will develop rapidly and will likely contain large amounts of ambiguity. During these periods, the most effective officers can analyze ill-defined problems into actionable components to make recommendations and decisions to maintain momentum. With the increased prevalence of AI/ML systems and other technological breakthroughs, those who can integrate technology in real-time will have an advantage of leveraging these information streams to make more timely and effective decisions. One of the tenets of MDO is that these conflicts will contain "ambiguous or uncertain operational environments" and that leaders will need to execute judgement to "distinguish between risk acceptance…[for] successful operations and potentially disastrous rashness."[5] Military leadership in MDO and the understanding that effective decision making in ambiguous situations will be a spectrum of a leader's ability to integrate the varied sources of information, to rapidly make decisions, and to achieve success on the battlefields of the future. Comparative research proposes that senior-level leaders with STEM education make better decisions in highly competitive and developing fields when facing ambiguity and in increasingly technological fields or environments.[18,19]

These periods of ambiguity can be correlated to the experiences that CEOs of companies have when guiding their companies through ambiguous business environments. Both senior leaders in the military and in corporations make decisions that impact a large number of individuals. Research suggests that STEM-educated business leaders are better able to navigate their businesses through these ambiguous situations and create new value for their organizations.[18,19] Research into businesses who were faced with ambiguous environments found that "STEM leaders are able to make better decisions when innovation is crucial and there is a high level of ambiguity."[18] This result was also shown to be more important for companies that specialized in technology or STEM-related industries. The study found CEOs with robust STEM competencies not only better understood the technology of their company, but also understood the broader impact of the technology across the industry and created significantly more value for their organizations and the shareholders.[18] These STEM educated leaders are able to make a preferred decision due to their ability to "recognize, evaluate, and execute real options crucial to innovation."[18] While the military does not have shareholders in monetary terms, the shareholders impacted by the decisions of the senior leaders are the Soldiers, civilian support staff, family members and the broader American people; all of whom expect our senior leaders to make decisions that will help win our Nation's wars and protect our Nation. With the increasing prevalence of technology in the military, it follows that senior leaders in the military would benefit by increased understanding of STEM competencies and the foundations behind the technology they are employing to win future conflicts.

Research confirms STEM educated CEOs are better able to navigate a company through ambiguous situations to achieve success. Compared to non-STEM educated business leaders, STEM educated leaders are able to break down ambiguous situations into actionable decisions and then determine a potential course of action.[18] It follows that the education these leaders receive during their formal education enables them to make better decisions. A significant competency of STEM education develops individuals who can think analytically and identify the variables that are controls versus variables that can be affected. While a detailed education in humanities allows leaders to understand the human and cultural dimensions of conflicts, the ability to think analytically is a characteristic of STEM fields. Since Phases 2 and 3 of the JP 3-0 operations model highlight the ambiguity of these phases, it follows that STEM-educated leaders can make more effective decisions compared to their humanities educated peers. Layering the increased emphasis on the necessity for STEM leaders in order to effectively integrate technology into the decision-making process, the need for STEM educated officers becomes increasingly important for resolving future conflicts with efficiency.

One important finding from the study of the differences between STEM and non-STEM educated leaders was that "complex technical information cannot be conveyed cheaply, quickly, or easily to a non-STEM educated leader."[18] When applied to the model of the US military and combat operations in a potential presence of either chemical or nuclear attacks, the ability of senior leaders to understand and process data and models is critical to making effective and timely decisions. As a vignette, consider if there was a threat of a detonation of a low-yield nuclear weapon during an engagement. As part of the planning for the operation the staff would consider the potential impacts of a detonation and the post-blast effects on the environment as part of the planning for future operations. This can be accomplished by the computer-based effects modeling software that is currently in development within the United States military. These models can predict both the immediate post-detonation effects, such as thermal, blast damage, and prompt radiation, as well as the residual radiation effects. These models allow the operations planners to both consider the casualty evacuation plan following a detonation as well as the follow-on operations for the unit. While the staff and subject matter expert, i.e., FA-52 officers, would be the proponents to make recommendations to the commander, if the commander cannot quickly process the provided information, then there will be a delay in the decision making process. Based on the findings in business, it follows that STEM educated leaders would be able to process and understand the information faster than non-STEM educated leaders and therefore arrive at a decision sooner.

Another aspect that FM 3-0 focused on with the introduction of MDO is that the battlefield is no longer three dimensional. Adding in the presence and capabilities of space and cyberspace and their impacts on the battlefield adds additional strain on the intelligence preparation of the battlefield (IPB) prior to and during operations. Leaders will be expected to utilize the various systems and capabilities in their organizations to develop “timely, accurate, relevant, and predictive intelligence” in forming courses of action and identifying mission objectives.[5] This suggests that AI/ML systems will likely play a significant role in future operations and leaders need to be able to rapidly discern which data streams and recommendations are most relevant to understanding the operational environment. Two of the tenets of MDO are agility and convergence. Agility describes the ability of an organization to act faster than the enemy especially in the offensive phases of conflict.[5] Convergence is the ability to create exploitable opportunities from the “employment of capabilities from multiple domains and echelons against combinations of decisive points” and enable mission accomplishment.[5] Both of these tenets rely heavily on the ability of leaders to integrate and synchronize a variety of systems and intelligence sources into actionable mission orders. While leaders who tend towards the ends of the S&T integration spectrum may be able to identify and achieve success, there is a greater probability that leaders who can integrate the systems in real-time will have a better understanding of the operational environment. This understanding of the complete operational environment across multiple domains is the key to successfully exploiting the opportunities on the battlefield and achieving the mission.

Recommendation Summary

- **STEM integrated with Professional Military Education (PME) at echelon.**
- **STEM/Data analysis assessment during Battalion Command Assessment Program.**
- **Programs to allow for MS/PhD focused studies for officers.**
- **Quota of commissioned officers with STEM degrees/focuses.**

The United States is currently in Phase 0 and 1 of the joint operations model: this means there is time to adjust the model in preparation for the next conflict. However, understanding that making a STEM-educated battalion commander takes over 20 years it is evident that the longer the Army waits to begin closing the gap the greater the risk becomes. The planning horizon demonstrates the need to evaluate our officer development models immediately as making STEM-competent battalion and brigade commanders takes even longer than weapons procurement timelines. We propose the following recommendations to begin closing the STEM education gap and to shift more leaders towards the Technology Real-Time Integration section of the spectrum.

1. STEM competencies should be taught and assessed at each echelon of PME. This should be tailored to the specific level of warfare the officer is expected to predominantly engage: i.e., officers attending the Army War College receive in-depth training on the effects of nuclear and chemical weapons, while officers in CCC receive training on the various communication systems and the theoretical framework behind how the communications work.

2. STEM competencies and data analysis included in the assessment portion of the Battalion Command Assessment Program (BCAP). As Battalion Commanders are likely the first level of command where the staff would be able to obtain “big data” using AI/ML systems, these future commanders should be familiar with how the data is consolidated and be assessed on their ability to discern useful information from the data set. This would help to determine the leaders who possess the pre-requisite skills to be successful in future conflicts with the high degree of technology integration.

3. Programs that allow officers in ILE and the Army War College to obtain certifications in STEM related fields. These could be provided in concert with the currently established humanities related graduate degrees that are currently offered. One major consideration is that these degrees would likely not include the experimental design portions of these types of degrees but would include the course work associated with these degrees to provide the theoretical STEM competencies the leaders would need to understand a broad range of fields. From a review of current graduate programs there is no current model for this to be adapted, but would be an Army initiative specific to help cover the STEM gap in the officer corps. While these programs are not equivalent to the knowledge gained through a traditional MS or PhD program due to the lack of individual novel thinking and synthesis of ideas, it could provide a mechanism to ensure officers at echelon continue to develop their competencies in STEM related fields.

3a. Implementation of a Naval Post Graduate School (NPGS) or Air Force Institute of Technology (AFIT) type of graduate school in the Army through USMA with research internships at Army research centers. Regular Army officers can obtain STEM degrees and conduct a year of Army research at either an Army Research Lab (ARL) or at one of the centers under U.S. Army Combat Capabilities Development Command (DEVCOM) structure. An alternative pathway in the short term is to utilize the current graduate level programs in place from sister services. Both the US Air Force and Navy already have post-graduate level educational systems built into their structure and officer development models. While on the surface there is inherently more technical aspects associated with both of these branches of the military, that gap is rapidly narrowing as the Army becomes more reliant on technology and the integration of systems. In the short term, the Army should seek to obtain allocations at both NPGS and AFIT for officers to obtain graduate level degrees, either following or while attending ILE. A model is already in place for some functional areas, such as FA-52, which has allocations for officers to attend AFIT graduate certificate courses of Nuclear Weapons Effects Policy and Proliferation (NWEPP) and Countering Weapons of Mass Destruction (CWMD).[20] These courses are generally completed remotely, and similar to distance learning ILE, officers could complete alongside their current assignments. This model should be expanded to include the other AFIT graduate certificate courses aligned with branch specific skill sets and more broadly for officers to seek self-development.

4. At least one writing assignment specifically tailored to current developments in STEM related fields integrated into each echelon of the military education system. This assignment would serve to introduce leaders to the STEM foundations behind the equipment and or resources available to them at their specific level of warfare.

5. A quota on the number of commissioned officers with STEM degrees for each year group. Increasing the percentage of newly commissioned officers with degrees in STEM related fields will help to contribute towards closing the STEM gap in the officer corps and will help set the conditions for the future leaders of the military to have the necessary skills and ability to succeed in future conflicts.

6. Provide a reward structure for officers who earn a graduate level degree in STEM related fields. As proposed in Part 2 of this sequence, at promotion boards consideration will be given to those officers who receive a graduate level STEM degree should be viewed as the equivalent of receiving a “Most Qualified” (MQ) officer evaluation report (OER) at their current rank.[21] This would help to both increase the interest in these programs, while also recognizing the contribution these officers are making towards preparing for the future conflict. It is important to note this should only be for graduate level STEM degrees which include a thesis based on experimentation, vice the broad overview at the graduate level outlined in recommendation 3 above.

Conclusion

In conclusion, the Army officer corps is currently at risk to successfully integrate the wide variety of systems in development to prepare for future conflicts. The current professional military education system relies, almost exclusively, on an officer’s undergraduate education to set the foundation for STEM competencies. As technology continues to rapidly develop and S&T capabilities are being introduced into all echelons of the military it is paramount that the current PME model is re-evaluated to include more development of STEM competencies. Just as the knowledge and skills gained from in-depth studies of military history and science are critical towards an officer’s professional growth, the abilities of officers to understand the STEM concepts that enable these new systems will be critical towards successfully integrating them into the operations process. While no one leader is going to be the subject matter expert in all systems, aligning STEM training against the various staff and war fighting functions will allow for leaders to gather a more in-depth understanding of the operational environment. Commanders who are then able to synthesize and determine courses of action that yield the highest probability of success will be able to seize and maintain the initiative in future conflicts. The successful integration of capabilities introduced by the emerging technology ensures that our Army is prepared for the next conflict. To achieve this end, officers at echelon need to consistently develop their understanding and depth of STEM competencies so we can continue to meet our mission and win our Nation’s wars. ■

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Beta Decay as a Model for Understanding Risk Shared from Two Strategic Competitors

By: MAJ Luke Tyree

Nobel laureate P.W. Anderson made the profound observation in a 1972 issue of *Science* that "More is Different."[2] He made the argument that as you increase in scale and complexity, the constructivist approach to building upon fundamental laws begins to break down. Anderson asserts that there is a broken symmetry that occurs as a system grows in scale and complexity, and the principles that governed the smaller system must be exchanged for other principles to understand the larger and more complex system. This is an important point to keep in mind when considering a tripolar international system as opposed to a bipolar international system: *more is different*. Certain principles will cross over, but to understand a system that has significantly grown in scale and complexity, such as a tripolar international system as opposed to a bipolar one, the theoretical system needs to be revised as new principles dominate.

In the 2022 National Security Strategy, the People's Republic of China (PRC) and Russia are identified as significant challenges to American interests. The 2022 NSS states, "The PRC and Russia are increasingly aligned with each other but the challenges they pose are, in important ways, distinct."[3] During the Cold War, the United States played the role of one half of a two-party system. With the fall of the Soviet Union and the end of the Cold War, the world entered an era where the United States was the sole hegemon. We are now in an era of great power competition with both Russia and China challenging the global rules-based international order that the United States seeks to lead. There is significant uncertainty and risk involved in a system like this. With this shift in polarity towards a three-party system, the risk dynamic has also shifted. While acknowledging the age-old adage that all models are wrong, but some are useful – alpha and beta decay can serve as useful models to visualize how the risk dynamic within a bipolar system as opposed to within a tripolar system behaves and how to consider the level of risk in a complex tripolar system.

Before delving into this risk dynamic, it would be worthwhile to spend time exploring and defining risk to establish a baseline of common terms and definitions. There are three main bins regarding what is meant by the word "risk" which will be considered. In some contexts, risk is a word to describe uncertainty. In some contexts, those things that are valued by a person, organization, or country that could potentially be lost are described as being "at risk." In other circumstances, risk is the word used to describe the level of chance of not achieving a particular goal or objective.

In his landmark text *Arms and Influence*, Thomas Schelling devotes the third chapter of this book on "The Manipulation of Risk." Schelling describes brinksmanship as "manipulating the shared risk of war."[4] Schelling argues that the risk involved in approaching the brink of war is that the two countries involved in brinksmanship do not know where the brink exactly is – the nature of the brink is uncertain. Physicist John Taylor describes the discipline of error analysis within the fields of science and engineering as the "study and evaluation of uncertainty in measurement."[5] Taylor makes a point to differentiate between the terms error and uncertainty. He defines "error" in the measurement of some quantity as "the difference between the measured value and the true value."[6] He defines "uncertainty" in a measurement as "the scientist's attempt to estimate how large the error is likely to have been."[7] This uncertainty measurement is important because it is never truly possible to fully know how much the error is in determining how far off the measurement of some quantity was from its true value. Similarly, Schelling points out that the unknown location of where the brink of war is from where the countries are that are engaged in brinksmanship is a source of risk.

Another prominent deterrence theorist, Herman Kahn, talks of risk in terms of that which is valuable might be lost. For example, how many people are at risk to die based on a course of action or a state of affairs. In Kahn's discussion about a Doomsday Machine, he talks about "how many people we would be willing to risk."[8] This line of thinking is what is often described in deterrence strategy as holding assets at risk. Keith Payne points out that adversaries seek to protect what they value. He cites Defense Secretary Harold Brown who emphasizes that U.S. deterrence threats should be able to "hold at risk those assets valued by the opponent."[9]

Another way of considering risk is the construct put forth by Arthur F. Lykke and his strategy stool. He posited that the three legs of strategy are ends, ways, and means. Like the three legs of a stool, if these three legs of strategy are imbalanced, they create an unstable stool and introduce risk. This risk is that the desired ends and national objectives may not be accomplished.[10] On the tactical and operational level of war, the Army published Army Technical Publication (ATP) 5-19: Risk Management. In ATP 5-19, risk management is defined as "the process of identifying, assessing, and controlling risks arising from operational factors and making decisions that balance risk cost with mission benefits."[11] Risks are those things that result in failure to achieve objectives or accomplish the mission. Ultimately, the strategic environment in which states operate is informed by that inherent uncertainty where those things that a state values and those critical national interests and objectives are threatened.

The strategic environment from a deterrence perspective has changed with the shift towards a multipolar world, with significant risk for the international body as a whole. The national security strategy specifically identifies both China and Russia as strategic competitors that challenge the interests of the United States.[12] Sometimes, the physical world with its predictable laws and principles can serve as a basis to visualize complex ideas and relationships that exist in the human domain and characterize a fundamentally anarchic international system. To understand how a bipolar world differs from a multipolar world, the alpha and beta radioactive decay processes can serve to illuminate certain aspects of the bipolar as opposed to the tripolar dynamic.

There are four fundamental forces under which all known forces can be grouped. In order of increasing strength, these forces are gravitation, the weak interaction or weak force, electromagnetism, and the strong interaction or strong force. While gravity is very important at a macro scale, it is negligible at the subatomic level. The three forces that are of concern for radioactive decay are the strong force, electromagnetism, and the weak force. The strong force is responsible for the binding of nuclei. Electromagnetism competes with the strong force within the nucleus to determine its resultant structure and stability as the all the positively charged protons are repelling each other. The weak force is responsible for nuclear beta decay, but it does not play a significant role in the binding of the atomic nucleus.[13]

Radioactive decay occurs when there are either too many or too few neutrons for a given number of protons. If there are not the correct number of neutrons, then the given atomic nucleus is unstable and undergoes radioactive decay.[14] There are several different methods of radioactive decay, but the ones that this paper will concern itself with are alpha decay and beta decay. Beta decay tends to be the predominant decay mechanism in atoms that are lighter than lead while alpha decay tends to be the decay mechanism in heavier atoms.[15]

Alpha decay occurs when an unstable nucleus emits an alpha particle which is a helium-4 nucleus consisting of two protons and two neutrons.[16] Alpha emission is due to the disruptive Coulomb repulsion effect overcoming the strong nuclear force that binds the nucleus together.[17] An example of an alpha decay process is uranium-238 decaying to thorium-234.[18]

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

Beta-plus decay occurs when a nucleus that has too few neutrons emits a positron and a neutrino. The number of protons is reduced by one as one of the protons becomes a neutron with the emission of a positively charged positron and an electrically neutral neutrino – making the resulting daughter nucleus more stable. An example is the decay of oxygen-15 to nitrogen-15.[19]

$$^{15}_{8}O \rightarrow {}^{15}_{7}N + \beta^{+} + \nu$$

Beta-minus decay occurs when a nucleus that has too many neutrons emits an electron and an electrically neutral antineutrino, decreasing the number of neutrons by one – as one of the neutrons becomes a proton – making the resultant daughter nucleus more stable. An example is the decay of oxygen-19 to fluorine-19.[20]

$$^{19}_{8}O \rightarrow {}^{19}_{9}F + \beta^{-} + \bar{\nu}$$

In both beta-plus and beta-minus decay, the emitted positrons/electrons are detected along a continuous energy distribution. The x-axis of this continuum is the energy of the emitted electron, and the y-axis being the number of measured beta decays. This distribution is bounded by an upper characteristic maximum energy above which no positrons/electrons are emitted at a higher energy. This distribution also has an average energy, $\bar{E}$. For beta-minus decay, $\bar{E} \cong 0.3E_{max}$. For beta-plus decay, $\bar{E} \cong 0.4E_{max}$.[21] This continuous energy distribution was a confusing observation in the 1920s as it contradicted the law of conservation of energy. To contrast the distribution of energy for beta decay, alpha particles were detected with discrete, well-defined energies that equal the mass-difference between the initial and final states (not counting the small recoil corrections). All alpha decays have exactly the same kinetic energy corresponding to the same initial and final states.

This is not the case for beta decay. An initial attempt to explain this continuous energy distribution was that all beta particles were initially emitted with a certain energy (the maximum energy mentioned previously) but lost energy due to collisions with other atomic electrons on the way to the radiation detection medium. This theory was ultimately ruled out due to very precise calorimetric experiments that did not indicate the expected heating that would have been expected as a result of the proposed kinetic energy loss by these beta particles on the way to the radiation detector. This showed that the detected beta particle energy distribution was inherent to the beta particles at the time of emission. To account for this distribution in beta particle energy, in 1931 Wolfgang Pauli proposed that there was a second particle emitted in beta decay. This second particle was subsequently named by Enrico Fermi as the "neutrino." The neutrino carries the missing energy and is a highly penetrating (weakly interacting) particle that was not stopped by the calorimeter and thereby not recorded during the calorimetric experiments. Conservation of electric charge indicated that the neutrino should be electrically neutral.[22] While the neutrino interaction cross-section is extremely small at ~$10^{-44}cm^2$, making it extremely weakly interacting and difficult to detect, its existence has been proven by the observation of neutrino capture by protons to yield neutrons and positrons. It has also been established with certainty that neutrinos emitted during beta-plus decay are not identical to antineutrinos emitted during beta-minus decay.[23]

There are several corollaries that might be drawn from the alpha and beta decay processes with bipolar and tripolar competition dynamics in terms of the nature of the risk landscape. First, in an environment where either two or three countries are in competition with each other (i.e. the United States interacting either with one or two strategic competitors), this competition strains the relationship of the countries and induces instability. This strain can manifest itself in conflict that does not necessarily manifest itself through the military instrument of national power but can also manifest itself as conflict through the application of the diplomatic, economic, or informational (DIME) instruments of national power. This conflict seeks to resolve whatever tension that the situational conditions are inducing within the rival countries in the bipolar or tripolar system. This is similar to how the unstable atomic nucleus progresses to a more stable state through radioactive decay. The conflict occurs resulting in risk to the United States. All conflicts ultimately resolve themselves – just with some uncertainty and therefore risk to whether that conflict resolves itself in a way that is favorable to American national interests.

In the same vein of *more is different*, alpha and beta decay are governed by two fundamentally different forces. Alpha decay is governed by the strong nuclear force while the weak nuclear force governs beta decay. So too does the strategic environment dramatically change as it shifts from a bipolar to a tripolar international system. Many of the underlying principles of international relations and competition dynamics hold true, but just as alpha and beta decay are governed by completely different fundamental forces, so too is there a fundamental shift in the way that the United States must compete and manage risk in a tripolar system as opposed to a bipolar system.

Another corollary is that the risk posed by the third country in a tripolar competition system is often difficult to assess. This is related to how the weakly interacting neutrino is extremely difficult to detect also. In any given beta decay, the neutrino may carry a certain amount of the decay energy. Assuming that the daughter nucleus is the native country (in this case, the United States), the two rival countries (in this case, Russia and China) are the electron and neutrino. Prior to this conflict (i.e. decay event), the three competing countries all exist together in a tenuous competition environment within the same international system just as the three products of beta decay (daughter nucleus, electron, and neutrino) all exist in the same unstable nucleus prior to the beta decay event. In any particular manifestation of tension through conflict along the DIME, the level of cooperation between the two rival countries may change. In a worst-case scenario for the native country (here – the United States), the two rival countries may be actively cooperating to undermine the native country. This would be a circumstance where in the beta decay model, the emitted beta particle is at the E_{max} level. This might commonly be referred to the most dangerous enemy course of action (ECOA). There is also the chance that the two rival countries may be operating in their own self-interest in competition with the native country but not cooperating with each other. So, when conflict manifests itself somewhere along the DIME with one of the rival countries (a "decay event" in the beta decay model), the other rival country does not necessarily act in concert with the other rival country but continues in the day-to-day competition with the native country. This might be considered the $\bar{E}$ case or also the most likely ECOA. There is also the possibility where one rival country might act in opposition to the other rival country when conflict with the native country and one of the rival countries manifests itself somewhere along the DIME. This would be a situation where a decay event occurred with an energy that was $E<\bar{E}$. Of note, just as the $\bar{E}$ value was not the same for beta-plus and beta-minus decay ($0.4E$ and $0.3E$ respectively), so too would the risk posed by the most likely ECOA for manifestation of conflict with one rival country versus another. Also, E_{max} value (or the risk posed by the most dangerous ECOA) would not be the same for different manifestations of conflict along any particular instrument of power for either of the rival countries.

One example of a manifestation of conflict, or a "decay event", would be the Russian invasion of Ukraine in 2022. This posed a risk to the United States and its NATO allies that manifested itself primarily in the military instrument of national power. The relationship between China and Russia over the course of this conflict remained difficult to ascertain. How the relationship between these two rival countries of the United States played out would drastically alter the level of risk to the United States and its NATO allies. The beta decay construct and associated energy distribution of the beta particle can serve as a qualitative model for visualizing the risk landscape for this "decay event."[24] Trying to understand the entire risk landscape and escalation dynamic posed by both Russia and China at the same time is challenging. For complicated problems, it is often useful to simplify the system. Just as when measuring beta decay events, it is the beta particle that is measured with the understanding that some of the resultant energy is carried by the weakly interacting and difficult to measure neutrino, so too is it useful to focus on the main actor in a conflict – in this case, Russia – and assess the risk posed by that particular actor in the conflict with the understanding that there is risk carried by the third element in the tripolar system (China). Based on how China relates to Russia in various conflicts will change the level of risk posed by a particular conflict creating a spectrum of risk just as there is a spectrum of detected electron energy for beta decay.

Another decay event where the conflict manifested itself through the diplomatic and economic instruments of national power was when China ceased climate talks with the United States in 2022 following Speaker of the House Nancy Pelosi's visit to Taiwan.[25] This conflict manifested itself primarily along the diplomatic instrument of power. Here, the level of risk posed by this "decay event" also would be dictated by China's relationship with Russia. It was possible that China could potentially backtrack on progress and agreements that it had made towards reducing carbon emissions. This backtracking on climate change progress could be influenced by Russia and its ongoing war in Ukraine (cooperation among the two rival countries in this tripolar competition system), which could then increase risk to the United States by setting back climate efforts to reduce global fossil fuel emissions. The nature of Russian involvement in this situation is once again difficult to ascertain from the native country perspective (just as the neutrino is highly difficult to detect) and so visualizing the risk landscape along a continuum (much as the beta particle energy exists on a continuum) makes sense.

Conversely to a tripolar competition environment, the risk landscape posed by a bipolar competition environment as was the case between the United States and the Soviet Union during the Cold War is easier to ascertain as there is not a third rival country to complicate the risk calculus. Similarly, the alpha particle emission spectrum is not a continuous one like the beta decay spectrum. The alpha decay spectrum consists of discrete, well-defined energy peaks.

The current tripolar competition environment that the United States functions within is certainly complex. Managing risk within this environment calls for being able to operate under a certain level of ambiguity. As a model of this ambiguity, the beta decay energy spectrum is a worthy thought construct which reflects some of the key points of this challenging competition dynamic as it represents the shift in the underlying governing principles. *More is different*.[26] ■

Notes

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