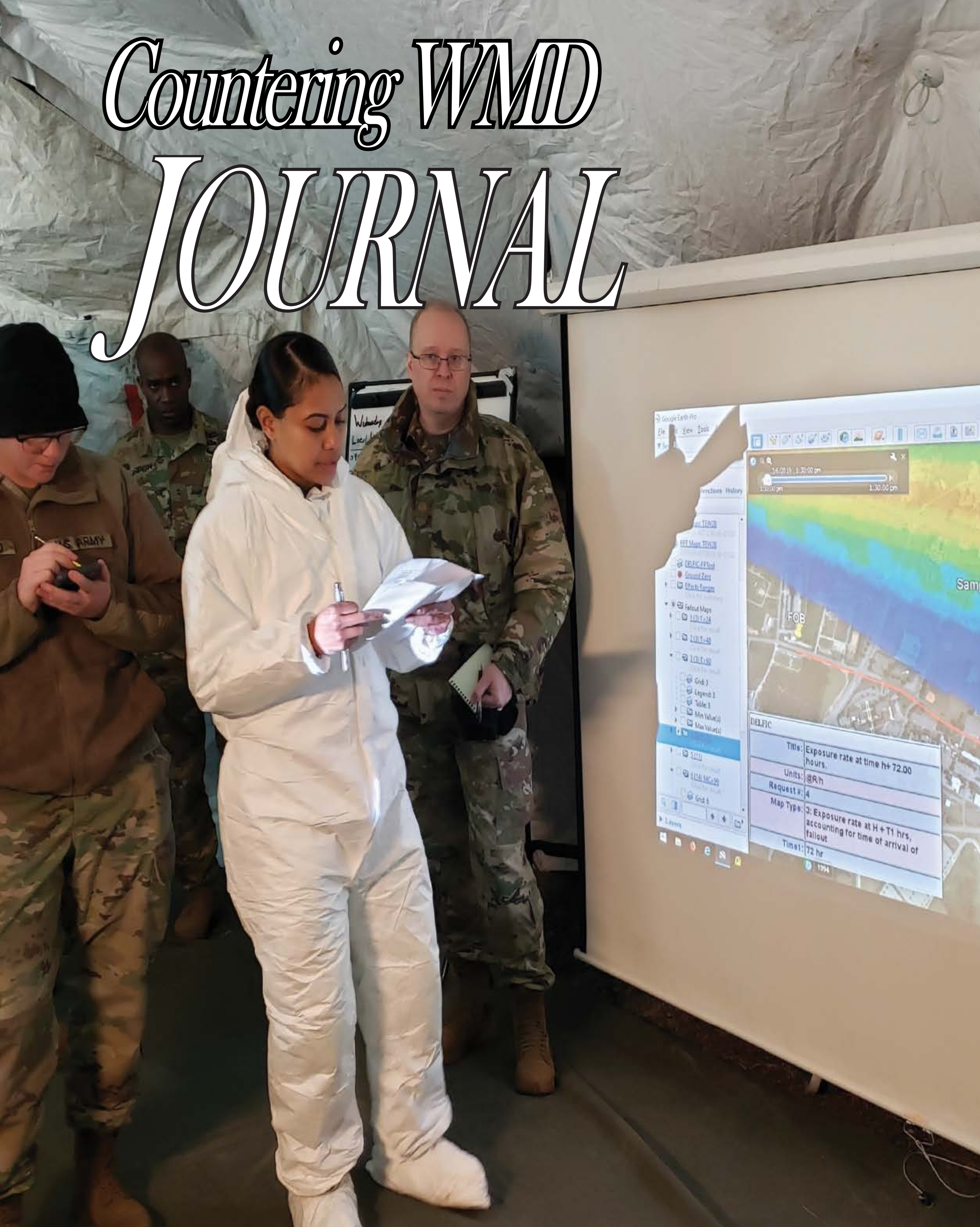
Countering WMD JOURNAL



Issue 19 • Summer/Fall 2019

U.S. Army Nuclear and Countering WMD Agency

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Distribution: U.S. Army organizations and activities with CWMD-related missions, to include all combat and materiel developers and units with chemical and nuclear surety programs, and Functional Area (FA) 52 officers.

Distribution Statement A: Approved for public release; distribution is unlimited.

The Secretary of the Army has determined that the publication of this periodical is necessary in the transaction of the public business as required by law. Funds for printing this publication were approved by the Secretary of the Army in accordance with the provisions of Army Regulation 25-30.

Article Submission: We welcome articles from all U.S. Government agencies and academia involved with CWMD matters. Articles are peer-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 call or 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 http://www.belvoir.army.mil/usanca/.

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About the cover: Soldiers from 110th CBRN Battalion, 9th CBRNE Company (Technical Escort) briefed interagency members of the National Technical Nuclear Forensics (NTNF) Ground Collection Task Force (GCTF) on their nuclear debris fall-out collection mission. This two-week training exercise at Aberdeen Proving Grounds, MD prepared the GCTF's for the task force validation exercise, Prominent Hunt 19-01.

Inside the Journal

Director Notes

COL John W. Weidner
Director, USANCA

Our Nation has entered a period of uncertainty not experienced since the end of the Cold War. Both the United States and Russia have withdrawn from the Intermediate-Range Nuclear Forces Treaty that banned ground launched missiles with ranges between 500 and 5500 km. Furthermore, President Trump has signaled that America's commitments to both the New START Treaty and Open Skies Treaty should both be reviewed. This reevaluation of obligations between our two nations comes in an increasingly competitive and multipolar world. The consequences of changing or abandoning these agreements that are difficult to anticipate. We, as nuclear and countering weapons of mass destruction (CWMD) professionals, must stay current in these complex, evolving issues in order to best advise senior leaders.

New technologies and advancing capabilities in other nations continue to add to instability in the nuclear and CWMD environment. Other nations, such as China, are pursuing more advanced ballistic and cruise missiles. North Korea has continued testing their nuclear employment capabilities in an effort to establish a global nuclear reach. Russia is fielding a hypersonic glide vehicle and is testing nuclear powered cruise missiles to complicate our early warning and characterization capabilities. These developments change the international landscape and our leaders will turn to us for guidance as they make decisions on the best way forward. We must be able to provide technical and non-technical options to mitigate these threats. Our self-education on emerging nuclear, chemical, and biological threats keeps us and our advice relevant.

While current and anticipated developments make leaders and the public anxious, in reality nothing in our mission has changed. We provide the tools and advice to decision makers to deter threats to our Nation and allies and if need be, employ nuclear weapons in time of crisis. The best military advice is our only advice. As professionals, we must not miss this critical opportunity to educate leaders at all levels and provide sound input to training and exercises that can best prepare the Army and Joint force for conflict in a CBRN environment. Success or failure on future battlefields will depend on how well we train our Soldiers to fight in a chemical, biological, or nuclear battlefield.

While this recent focus is on nuclear forces, nations and groups also continue to develop chemical and biological weapons of mass destruction. As our adversaries seek to asymmetrically counter our superiority, we must continue to support our country’s and the international community's pathway defeat efforts. Our experience and technical expertise can be applied to all aspects of

CWMD and the disruption of other malicious use of technology. We must keep ourselves informed of development of fourth generation agents and niche bioweapons to best counsel commanders.

Thank you for your continued service, and your families for their support. As members of the Nuclear and CWMD community you maintain the substantial knowledge base and skill sets required by our nation. I commend your steadfast commitment to maintaining our CBRN expertise, developing critical nuclear and CWMD policies, ensuring a safe and secure stockpile, and supporting CWMD efforts across the federal government. The work you do is often overlooked but absolutely 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 *CWMD Journal.*

Singular Command Moves Into New Headquarters and Celebrates Birthday

BG James Bonner
Commanding General, 20th CBRNE Command

The 20th Chemical, Biological, Radiological, Nuclear, Explosives (CBRNE) Command celebrated its 15th anniversary on October 16, 2019 and cut the ribbon on its new headquarters complex October 18, 2019 on Aberdeen Proving Ground, Maryland. The creation of the command in 2003 began when U.S. Army leadership recognized the need for a singular command to meet the expanding threats from CBRNE dangers both at home and abroad. The new, two-building $88 million complex is the realization of that vision by senior Army leaders. To those leaders here and beyond, the 20th CBRNE Command offers its sincere thanks for your vision and perseverance.

Command Formation

On May 1, 2003, then LTG Richard Cody, Headquarters Department of the Army (HQDA) Deputy Chief of Staff G-3/5/7, codified the command as the "organizational solution for an operational command to gain efficiencies, better focus, coordinate, and employ Army [CBRNE] response capabilities." The command was constituted on May 6, 2004 and activated on October 16, 2004 as the 20th Support Command (CBRNE). Nine years later on October 16, 2013, the command was re-designated as the 20th Chemical, Biological, Radiological, Nuclear, Explosives (CBRNE) Command to better reflect the command's unique mission. In a September 2019 interview, GEN (Ret.) Cody said "We needed a full spectrum capability against these threats with a headquarters that could deploy units." Locating the command at Aberdeen Proving Ground (APG) in northeast Maryland, provided several advantages according to GEN (Ret.) Cody, "APG was in close proximity to some of the places where they would train such as A.P. Hill [in eastern Virginia]." This also placed the garrison close to Dover Air Force Base in Delaware to facilitate deployments.

The former commander of the Army's Research, Development and Engineering Command, MG (Ret.) John Doesburg, worked with senior service leaders on the creation of the command. An important operational need for the U.S. Army was characterization and identification of what was

Brigadier General James E. Bonner assumed command of the 20th CBRNE Command on July 19, 2017. Brigadier General Bonner is the 7th commander of the U. S. Army 20th CBRNE (Chemical, Biological, Radiological, Nuclear, Explosives) Command. As the commander of the Army's and Department of Defense's sole CBRNE organization, he is responsible for the manning, equipping, and training of more than 3,800 Soldiers and civilians assigned across two Explosive Ordnance Disposal Groups, one Chemical Brigade, and a CBRNE Analytical and Remediation Activity.

produced at suspected weapons of mass destruction (WMD) industrial facilities. "The key, both in Iraq and Afghanistan, was someone who could go into these different facilities and sites and make a determination whether or not WMD was present." He also affirmed locating the command at APG because "The 20th required equipment that was out of the norm. They had to be close to the laboratories responsible for the technology."

MG (Ret.) Doesburg summarized what has happened since 2004, "In the world we sit in, there are many countries that are pursuing weapons of mass destruction of all sizes. You need an organization like the 20th CBRNE Command to protect the force, be able to determine if WMD exists [at a site] and in what amount and capability, and you've got to be able to be on the ground with the Soldiers you are supporting."

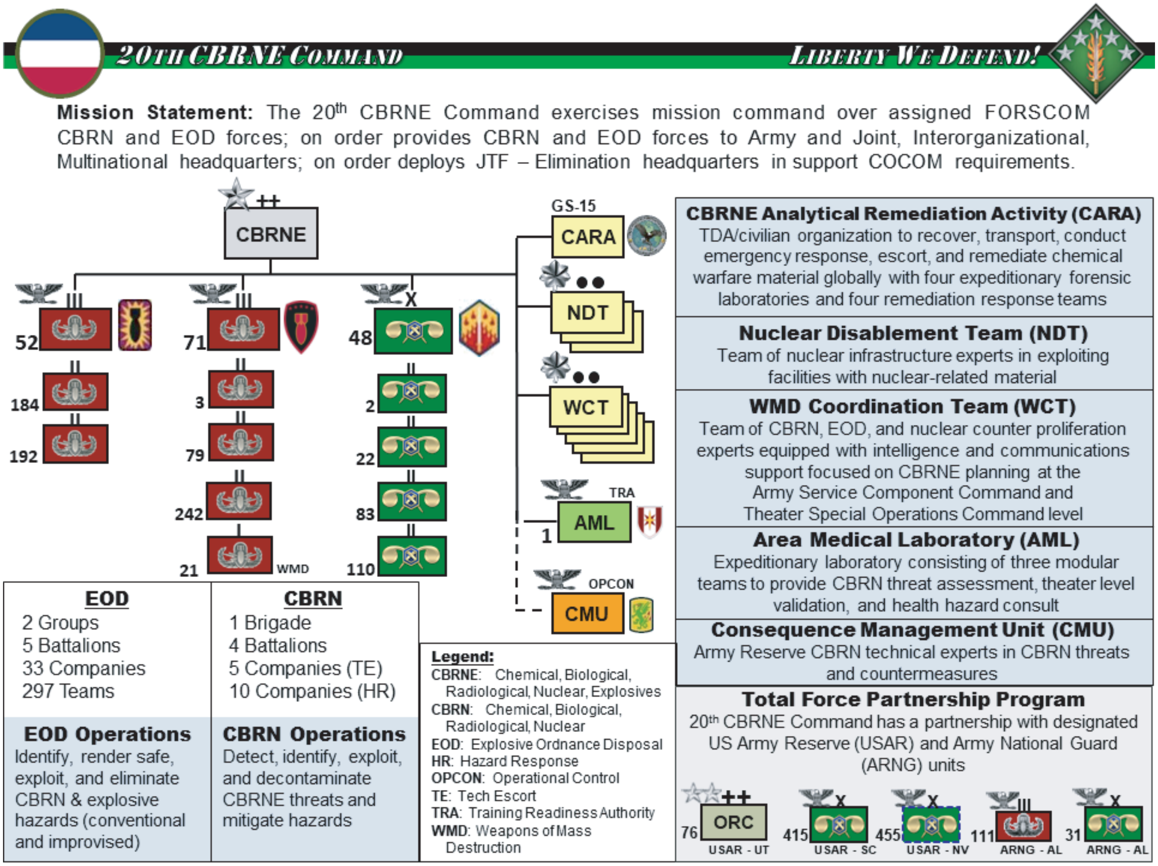
The first commander of the 20th Support Command (Chemical, Biological, Radiological, Nuclear and High Yield Explosives), MG (Ret.) Walt Davis, had many challenges to overcome transitioning from operational concept to a functioning command and headquarters. He reflected, "We had a double-wide trailer on APG Edgewood Area and some other office space. What I did have in place was a great nucleus in structure. We had great support from APG in terms of establishing the command and moving forward." Then COL Davis served as the commander for 10 months, "I enjoyed every minute of it. It was a tremendous privilege to say that I was part of something that was really important to the Army at that time which was to bring these capabilities together."

The unit's history began in 2003 with the mission to find and eliminate Iraqi WMD. Because there was no standing Army capability, the 75th Field Artillery Brigade was tasked to form the 75th Exploitation Task Force. Recognizing the challenges of this unit as an ad hoc organization, HQDA directed the establishment of a single headquarters to establish unity of command for worldwide CBRNE response. Initially called the Guardian Brigade, later renamed the 20th Support Command (CBRNE), and now the 20th CBRNE Command supports missions around the globe.

Command Missions

Today, the 20th CBRNE Command is a highly-technical, special purpose formation of approximately 3,800 Soldiers and 225 civilians in 16 states on 19 different installations. The organization includes: both the 52nd and 71st Ordnance Groups (EOD), the 48th CBRN Brigade, the CBRNE Analytical Remediation Activity (CARA), the 1st Area Medical Laboratory (1st AML), the Consequence Management Unit (CMU), Nuclear Disablement Teams (NDT), and WMD Coordination Teams (WCT). Overall, the 20th CBRNE Command provides the Army with highly skilled, trained and equipped CBRNE forces capable of operating in a contaminated environment. It is the Army and DOD's only integrated command with Explosive Ordinance Disposal (EOD), CBRN, and lab capabilities.

The 20th CBRNE Command continues to provide the Army and the Nation a scalable response to counter CBRN and explosive ordnance threats and hazards. It strives to meet its mission statement: "The 20th CBRNE Command exercises mission command over assigned FORSCOM CBRN and EOD forces; on order provides CBRN and EOD forces to Army and Joint, Interorganizational, Multinational (JIM) headquarters; on order deploys Joint Task Force



20th CBRNE Command Mission Statement and Task Organization

– Elimination headquarters in support combatant commander requirements." The command has diverse mission sets, in support of both the homeland and overseas.

The command has over 90 military occupational specialties including CBRN specialists, EOD technicians, nuclear research and occupational specialists, chemical and biological engineers and scientists, nuclear physicists, biologists, health physicists, and chemists. These highly trained individuals, many with advanced academic degrees, enable the command to maintain a full-time focus on countering weapons of mass destruction (WMD), and explosive ordnance threats and hazards.

Teams, and teamwork, accomplish the diverse, and sometimes dangerous, missions of the command. Several homeland response missions include: support to the Defense CBRN Response Force (DCRF), the National Technical Nuclear Forensics (NTNF) Ground Collection Task Force (GCTF), EOD emergency response, recovery of chemical warfare material, and Very Important Person Protection Support Activity (VIPPSA) missions. EOD Soldiers work closely with the Secret Service providing protection support to the President, Vice President, senior Federal government officials, and visiting dignitaries during VIPPSA operations.

Additionally, the command supports Federal, state, and local authorities on a daily basis by providing CBRNE capabilities. CBRNE teams respond to incidents on and off military installations involving explosive munitions, IEDs, recovered chemical munitions, and other CBRNE material found throughout the United States.

While deployed, 20th CBRNE Command operations consist of: counter improvised explosive device (IED) operations, military-to-military operations in support of theater security cooperation strategy, special operations, recovered chemical warfare material, nuclear facility disablement, and sensitive site exploitation (SSE). The 20th CBRNE Command routinely works with special operations forces and possesses multiple capabilities vital to their countering WMD mission set.

The Chemical Response Teams are specially trained Soldiers deployed to provide advice, assessment, detection, sampling, verification, render safe, packaging, and escort of chemical and biological devices or hazards.

The Hazard Response Companies provide CBRN reconnaissance, surveillance, assessment, and decontamination. EOD teams are capable of detecting, identifying, rendering safe, conducting limited sensitive site exploitation, disposal, and disposition of explosive ordnance, IEDs, WMDs including enemy ammunition, unexploded ordnance, and CBRN munitions.

The command's five WCTs are rapidly deployable teams of Soldiers and civilians with specialized CBRNE training and experience. Each team is organized with CBRN, EOD, nuclear and counterproliferation officers, intelligence analysts, and communication specialists. They deploy to support combatant commanders on countering WMD operations, CBRNE and counter IED operations and intelligence, consequence management, and SSE.

NDTs are small teams of nuclear experts equipped and trained to perform missions in support of theater and strategic nonproliferation and counterproliferation objectives. NDT competencies include the ability to characterize, exploit, and disable nuclear infrastructure or sites. They also package, transport, and safeguard nuclear and radiological materials.

SFC Joshua Tygret, assigned to 744th Ordnance Disposal Company, 52nd Ordnance Group (EOD), uses a metal detector during the 5th annual EOD Team of the Year competition. (U.S. Army photo by SSG Lance Pounds, 71st Ordnance Group (EOD), Public Affairs)


Soldier-scientists from the 1st Area Medical Laboratory's Biological Team study a blood plate for bacterial growth during a field training exercise at Fort Indiantown Gap, Pennsylvania. (U.S. Army photo by Angel D. Martinez-Navedo)

The CARA conducts remediation, provides mobile analytical laboratory support for theater validation analysis of chemical, biological, and explosive agents/materials, and conducts technical escort of chemical surety and non-surety material. CARA is also the lead for recovered chemical warfare material emergency response and supports DOD CBRNE defense initiatives by providing safe and secure hazardous material escorts throughout CONUS with organic aviation assets and specially trained escort teams. CARA technicians are the only civilians authorized to escort chemical surety material in the Department of Defense.

The 1st AML is the DOD's only analytical laboratory with a robust expeditionary diagnostic capability to detect and identify a wide range of accidental or intentional environmental contamination with chemicals, microbes, and radioisotopes. The 20th CBRNE Command has training and readiness authority of 1st AML. The mission of 1st AML is to deploy worldwide to perform surveillance, analytical laboratory testing, and health hazard assessment of environmental, occupational, endemic disease, and CBRNE threats in support of Soldier protection and WMD destruction missions.

The CMU is a U.S. Army Reserve unit with CBRNE subject matter experts tasked to provide risk analysis and technical advice on countering WMD, CBRN response management and defense support of civil authorities (DSCA). These citizen-Soldiers possess high-end technical and professional CBRN defense related skills with professional licenses and advanced civilian education.

The 20th CBRNE Command Headquarters is a deployable Joint Task Force Headquarters which provides mission command of Army and Joint CBRNE forces conducting WMD-elimination and other CBRNE related missions.

New Headquarters

The new headquarters complex consolidated numerous facilities from APG Edgewood Area and has more than 186,000 square feet of space with 492 work stations. At the headquarters entrance, the Memorial Glass Display honors the ultimate sacrifice of 31 Soldiers since the command's inception in 2004. Most recently it showcases the dignified transfer of SGT Joseph Collette, 71st Ordnance Group (EOD), at Dover Air Force Base, on 24 March 2019. The other side of the display highlights the command's history with pictures from Task Force McCall in Tuwaitha in addition to early EOD operations in Iraq. The 20th CBRNE Command's Meritorious Unit Commendation for Task Force McCall is displayed along with pictures of the former headquarters, Building E2400 on Edgewood, and the new headquarters, Building 5016. The main hallway highlights facts about the command and its subordinate units while also honoring former commanding generals and command sergeants major. Throughout both buildings, images highlight the multiple missions of EOD and CBRN Soldiers and civilians.

The new facility also hosts the Command Operations and Information Center (COIC), a state-of-the-art operations center enabling mission command of daily operations including: chemical surety escorts, remediation operations, EOD emergency response, and VIPPSA missions. The COIC also compiles daily situational reports, tracks key leader movements, and Serious Incident Reports across 19 installations.

A Memorial Garden inside the headquarters serves as a place where individuals can take a break to reflect on the sacrifices our armed forces make every day. At its center, a piece of granite has the command's symbol and inspiring words from President John F. Kennedy from his inaugural address on January 20, 1961:"*Let every nation know, whether it wishes us good or ill, that we shall pay any price, bear any burden, meet any hardship, support any friend, oppose any foe, to assure the survival of liberty.*"

During the headquarters ribbon cutting ceremony, the 20th CBRNE Command inaugurated the "Defender of Liberty Award." This annual award honors individuals deemed to represent the greatest support for the concepts of liberty. The first recipient, GEN (Ret.) Richard Cody, 31st Vice Chief of Staff of the Army, said "Where the command has gone today is remarkable. In terms of relevancy, they are more relevant today than when we stood them up. I am absolutely amazed and proud of where they are and what I know they will do in the future to keep us safe."

The command also unveiled a Pentagon Memorial in front of the new headquarters. Constructed by the APG Department of Public Works, the memorial centerpiece contains limestone from the Pentagon following the attacks on September 11, 2001. The inscription, carved into the granite base, reads: *The 20th CBRNE Command dedicates this memorial to those who lost their lives in the attacks on September 11, 2001. This surviving piece of limestone symbolizes the strength of our will. LIBERTY WE DEFEND!*

Iranian Breakout Time Post-JCPOA

MAJ Christopher Mihal
Air Force Institute of Technology

The Joint Comprehensive Plan of Action (JCPOA) is an agreement reached by Iran and the P5+1 (China France, Germany, Russia, the United Kingdom, and the United States) on July 14, 2015 to limit Iranian nuclear capabilities. The deal was endorsed by UN Security Council Resolution 2231 and adopted on July 20, 2015. Iran's compliance with the nuclear-related provisions of the JCPOA is verified by the International Atomic Energy Agency (IAEA) according to certain requirements set forth in the agreement. The agreement required Iran to eliminate 98% of its low-enriched uranium (LEU), in Iran's case uranium enriched to 3.67% U-235, and to eliminate all medium-enriched uranium, uranium enriched to about 20% U-235. Highly enriched uranium (HEU) is uranium enriched to contain approximately 95% U-235. Additionally, Iran had to remove two-thirds of its gas centrifuges for a period of fifteen years. Iran pledged not to process uranium beyond 3.67% enrichment, as well as to close all but one of its uranium enrichment facilities and cease construction of heavy water facilities. On 8 May 2018, the U.S. withdrew from the JCPOA, citing Iranian intentions to only pursue peaceful nuclear power was demonstrably false based on prior history, even though to date Iran had been in compliance with the treaty's obligations.

The JCPOA significantly set back Iran's break out timeline for uranium enrichment. Break out time is the amount of time it would take for a state or non-state actor to have a functional nuclear weapon, including a design and all necessary nuclear components. If Iran has properly declared all of its nuclear-related facilities and materials, break out time is approximately eight months to one year from when Iran begins to construct a bomb. The JCPOA affected a number of Iran's potential nuclear weapons program areas: uranium enrichment, centrifuge capacity, and International Atomic Energy Agency (IAEA) access, increasing a timeline that could have been as short as two months to at least four times as long.[1] Given recent revelations that Iran already had a design for a U-235 bomb – though it is unknown if it would have worked since it descended from A.Q. Khan's design[2] – the sole limiting factor was a sufficient quantity of HEU. The JCPOA directly addressed this issue by limiting Iran's enrichment capability and stockpile, as well as increasing IAEA oversight of Iran's declared facilities. If Iran is transparent about its nuclear program, the break out time should be sufficiently long enough to intervene beforehand. However, given revelations from an alleged Iranian

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document archive obtained by the Israeli intelligence agency, Mossad, there may be more to Iran's nuclear program that is undeclared and unknown.

The JCPOA achieved much to enable Iran's peaceful pursuit of nuclear capabilities, as well as, simultaneously undercutting any nascent nuclear weapons program. This is primarily due to the fact that Iran voluntarily surrendered approximately 98% of its (declared) enriched uranium stockpile, leaving it with just 300 kg of uranium hexafluoride or similar uranium chemical composites in its stockpile.[3] This is down from the roughly 22,000 pounds of LEU it maintained prior to the deal – including 20% enriched research reactor fuel and the 3.67% enriched power reactor fuel which Iran utilizes.[4] Given the chemical composition of UF_6, this translates to just over 200 kg of uranium currently in Iran's possession.[5] The goal of JCPOA is to prevent Iran from having a sufficient quantity of U-235 to produce a nuclear weapon. Iran's current uranium stockpile, enriched to 3.67% U-235, is only sufficient for nuclear reactor operations. While it is not technically difficult for Iran to enrich uranium to the level required for a bomb, the supply of uranium currently inhibits these efforts. The major hurdle Iran currently faces to completing a nuclear weapons program is a distinct lack of HEU.

Unless Iran is able to procure HEU from a proliferating nation, it would have to restart uranium enrichment. JCPOA forced Iran to dismantle all but 5,060 IR-1 centrifuges at its Natanz and 1,044 IR-1s at its Fordow enrichment facilities, plus a few ancillary, more advanced IR-4, IR-5, IR-6, and IR-8 centrifuges used for research.[6,7] This was a significant decrement from Iran's original, almost 20,000 centrifuges, drastically increasing enrichment time. The JPCOA also halted Iranian advancements of the IR-8 and limited Iran to just 33 of the machines.[9] The IR-8 centrifuge is significantly more advanced than the IR-1, with cascades sixteen times faster than what Iran currently possesses.[10] Producing 95% enriched weapons-grade uranium (WGU) requires 220 kg-SWU (Separative Work Unit (SWU) is a common measure of separation done by centrifuges) per kg of U-235. A typical 10,000 SWU per year facility can produce about 45 kg of WGU annually.[11] Since IR-1 centrifuges operate at about 1 SWU,[12] Iran can only produce approximately 22 kgs of WGU annually with current facilities, but doing so would provide them almost no uranium for power generation.

However, this is only based on Iran's declared assets; Iran may have much hidden. Israel claims it obtained information on hidden facilities in a recent raid on an alleged Iranian nuclear archive.[13] Though the archive's dates end around 2003, it demonstrates that Iran had a large hidden facility at Parchin. These documents also revealed that Iran conducted more advanced testing than previously thought by the international community. This included hydrodynamic testing and neutron testing of shock-driven uranium deuteride initiators.[14] The IAEA has tried and failed to get access to the entire Parchin facility, but did note when visiting the site in 2015 that there were "recent signs of internal refurbishment, a floor with an unusual cross-section, and a ventilation system which appeared incomplete," along with external renovations including wall and roof replacement and demolishment of certain buildings.[15] This could indicate that the facility had been used for something related to the nuclear program and was hastily renovated when discovered.

While it appears Iran certainly had hidden facilities, it is not clear if they still use them, or to the actual extent of how many sites there are. If Iran no longer maintains hidden facilities, Iran's breakout timeline is approximately one year, given the low quantity of usable uranium and the small number of older, less-efficient cascade centrifuges it currently possesses. However, if Iran secretly has a large number of more advanced centrifuges or a hidden uranium stockpile, the timeline could be much shorter. Critical to determining this is the access and ability of IAEA inspectors to determine the presence of both declared and undeclared stockpiles and make assessments. The IAEA's ability to operate within the JCPOA is unquestioned, the main document outlines several tasks:

> Long-term IAEA presence in Iran; IAEA monitoring of uranium ore concentrate produced by Iran from all uranium ore concentrate plants for 25 years; containment and surveillance of centrifuge rotors and bellows for 20 years; use of IAEA approved and certified modern technologies including on-line enrichment measurement and electronic seals; and a reliable mechanism to ensure speedy resolution of IAEA access concerns for 15 years.[16]

Unfortunately, if the seized Iranian nuclear archive is authentic, it reveals that Iran is very capable at hiding facilities from the IAEA and the international community. Some facilities, such as centrifuge enrichment facilities, lack distinct nuclear thermal and effluent signatures and can be hidden underground, making detection extremely difficult.[17] Historically, Iran is very adept at building underground facilities and engineering tunnels. The IAEA itself in 2015 noted that it needed to work with Iran on a separate agreement regarding Parchin for fuller access.[18] Given Iran's ongoing deceit with the IAEA, one thing is apparent: where the IAEA has access, the IAEA scheme is working. Iran is keen to avoid letting the IAEA know about facilities where nuclear weapon program activities occur. While one can thus infer that the IAEA's inspection teams are very capable at site exploitation and technical analysis, intelligence collection could potentially be a larger issue if the Mossad-acquired documents are legitimate.

One risk in dismantling JCPOA is that it has emboldened Iranian Principlists, the mostly conservatives and members of either the military or Iranian Revolutionary Guards Corps who were sidelined by Iranian President Hassan Rouhani when he signed the deal. Iran's economy has not improved as much as promised under the deal, and in fact has only gotten worse since the U.S. withdrew from the JCPOA and re-imposed harsh sanctions; Rouhani's rapprochement for cash plan has failed.[19,20] The Principlists have warned to never trust the United States; they are likely the main force pushing for a nuclear-armed Iran. With the moderate Rouhani humiliated and possibly sidelined, Principlists in government may decide that pursuing nuclear weapons is their only available response to deter perceived U.S. aggression and regional threats. This may lead Iran to accelerate timetables by whatever means necessary, shortening break-out time to acquire a nuclear weapon. One year is an optimistic but currently reasonable estimate, but significantly shorter break out times are feasible given the factors noted above. The international community must tread carefully to ensure Iran remains nuclear-weapons free in an already volatile region.

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Red Teaming China's Strategic Nuclear Options

COL Paul Sigler

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For most of its history as a nuclear power, China's nuclear policy has focused on maintaining a "minimum deterrent", with just enough capability to assure a second-strike, but also an overtly stated no-first-use policy. China has never sought to establish nuclear parity with the United States or Russia, and only within the past two decades has China finally begun strengthening its nuclear deterrent capability and creating a three-dimensional system that combines offensive capabilities, space warfare, and missile defense capabilities.[1] By 2013, China fielded upgraded road-mobile Intercontinental Ballistic Missiles (ICBMs), new nuclear-capable Intermediate-Range Ballistic Missiles (IRBMs), and Submarine-Launched Ballistic Missiles (SLBMs). China announced later that year that its Second Artillery Corps (SAC) had tactical nuclear weapons, and also conspicuously failed to mention its no-first-use doctrine in its Defense White Paper. Many scholars speculated that China might be moving to a more aggressive nuclear posture which would eventually place it into more direct confrontation the United States and/or Russia.[2] If true, a Sino-American nuclear rivalry would seem inevitable, and an arms race quite likely.

Modernization of China's nuclear deterrent– which, even after two decades of modernization, can still best be described as a monad[3] – does not necessarily mean that the United States and China are destined to compete head-to-head in a nuclear arms race. Such a strategy would be counter to the traditional Chinese strategy of asymmetric competition,[4] and it would place China into a classic "security dilemma"[5] where its efforts to secure itself would paradoxically lead to counteractions from its adversary (the United States) that actually decrease its security. Yet, while an arms race would likely be counterproductive, China also cannot ignore U.S. policy statements which call out its "growing and diversifying" nuclear arsenal as an arena of great power competition,[6] especially given increasing internal pressure for China to abandon its long-standing "peaceful rise" approach and take a more aggressive stance on security.[7] Considering these external and internal forces, China would thus be wise to maximize its technological advantages, unitary decision-making structure, financial resources and uncertain nuclear doctrine in order to asymmetrically compete with the United States. By doing so, China would minimize both the threat of nuclear coercion and

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the threat of a costly arms race which would detract from its economic centenary goal of "moderate prosperity" for all citizens by 2021.

Although the People's Republic of China's (PRC) nuclear strategy is not publicly known, it is fair to say that China's interests would be best served by preventing U.S. nuclear coercion and by also avoiding direct nuclear competition with either the United States or Russia.[8] Accordingly, it is likely that China would choose an asymmetric approach that does not arouse an overt reaction from the United States. Such an approach would be most successful if it played to China's strengths, namely:

1. *China is not bound by any bilateral arms control treaties, or compliance regimes (although it did sign the Comprehensive Test Ban Treaty (CTBT) in 1996).* China can thus pursue a variety of nuclear weapons development programs with little scrutiny from the United States and Russia– with the important caveat that the CTBT does prevent China from conducting yield-producing nuclear tests. While the CTBT limitations complicate design of new warheads, it does not prevent China from developing and testing new delivery systems for its existing warheads, to include expanding its Multiple Independently Targetable Reentry Vehicle (MIRV) capabilities.

2. *China follows a state-driven, well-resourced research and development model and its military spending is not subject to public review or comment.* Although the SIPRI military expenditure database estimates Chinese military spending at $228.2 billion– 1.9% of GDP– in 2017, these self-reported numbers are impossible to verify. The Chinese Ministry of Finance reported a budget of only $151.4 billion for that same time period.[9] Both numbers could very well be understated, and there is little public accountability as to how that money is being spent.

3. *China has access to an abundance of dual-use technology/infrastructure– to include an active space and missile program– and a potential advantage in the fields of Artificial Intelligence (AI), advanced robotics and hypersonic glide vehicles.* These assets provide China with the ability to develop autonomous delivery systems, counter U.S. delivery and missile defense systems, and conduct advanced simulations in order to overcome the restrictions of the CTBT. DARPA Director Steven Walker has estimated that China has "two to three times" more facilities built to conduct hypersonic research and production than the United States does.[10] These delivery systems can deliver both conventional "ship-killing" munitions, or they can be used to deliver nuclear weapons that can penetrate missile defenses at extended ranges.

4. *China's nuclear and non-nuclear missile forces fall under a single command, making it difficult to accurately measure its nuclear arsenal, especially with respect to Short-Range Ballistic Missiles (SRBM) and IRBMs.* The Peoples Liberation Army (PLA) Second Artillery Force, which was renamed the Rocket Force in 2015 and designated as a separate branch of service,[11] is responsible for all of China's land-based ballistic missiles and cruise missiles. In 2017, the Rocket Force unveiled the DF-26 IRBM which is capable of delivering nuclear and conventional precision warheads from identical mobile launchers.[12] The DF-26 can easily range the U.S. territory of Guam, as well as any U.S. bases within the first island chain and Korea.

Given these inherent strengths, and mindful of statements within the 2018 U.S. National Defense Strategy specifically identifies the PRC as a focus of U.S. military competition, China would be wise to maximize its technological advantages, capability for unitary action, financial resources and uncertainty about its nuclear doctrine in order to compete with both the United States and Russia asymmetrically.

China's nuclear strategy goals should be twofold. First, it should aim to reduce the ability of the United States to threaten it through nuclear coercion. Many U.S. efforts to counter the North Korean nuclear threat have – by extension – decreased the credibility of China's strategic nuclear deterrent. By surrounding China with robust theater land and sea-based missile defense systems; redoubling investment in U.S-based mid-course interceptors; and continued development of satellite-enabled mobile launcher targeting capabilities and prompt global strike systems, the United States has greatly decreased the possibility of an effective Chinese strike. The success of U.S. and Japanese navies in tracking Chinese missile submarines greatly compounds this problem.[13] As a result, China could reasonably fear that the United States might begin to believe that it can launch a conventional first strike on China's strategic deterrent without serious damage to the U.S. homeland.

To gain the most competitive footing in the most efficient manner, China should invest in capabilities which create multiple strategic dilemmas for both the United States and its Asia-Pacific allies if it should consider a pre-emptive strike on China's nuclear force. These would include:

1. *Hypersonic glide vehicles (HGV).* To fully confound U.S. planning, China should develop HGVs that can be launched from ICBMs, IRBMs and long-range bombers. Such capabilities will serve to decrease the effectiveness of U.S. missile defense systems, increase the range and penetration of IRBMs, and increase the strategic effectiveness of the strategic bomber arm.

2. *Dual-capable, mobile, MIRV-equipped ICBMs and IRBMs.* Much of China's ICBM force is already mobile, which makes it difficult for the United States to track and target each launcher with certainty. China would be wise to invest in making its ICBM force fully mobile and MIRV-equipped, such as the new DF-31AG,[14] and to do the same with its IRBM force, interspersing conventional and nuclear warheads to increase the array of targets that the United States would have to destroy to be assured of a successful first strike.

3. *Autonomous air-and space-based missile defense systems.* A combination of deep pockets, unaccountable money, and legacy Chinese investments in AI and advanced robotics creates opportunities for rapid advancements in missile defense systems that could provide a technological leap beyond the current generation of hit-to-kill interceptors. Systems which can undermine confidence in U.S. nuclear command and control systems would be particularly valuable investments, as they would force the U.S. to invest in costly upgrades.

China's second nuclear strategic goal should be to camouflage these capability investments in order to avoid or reduce a U.S. counter-action. China's ability to act unitarily and its historic lack of transparency helps in this regard, as does the general political reluctance of the U.S. Congress to invest in new nuclear systems while recapitalization of existing systems called for within the 2018 Nuclear Posture Review (NPR) remains underfunded.[15] Additionally, the lack of a bilateral arms-control commitment with the United States reduces the ability of the U.S. policy makers to directly observe Chinese strategic investments. With these points in mind, China should incorporate the following principles to minimize a potential U.S. response:

1. *Ambiguity by design.* Chinese upgrade/expansion of ICBM and IRBM forces should be billed as routine modernization. HGV warheads should be designed to be indistinguishable from conventional warheads. Revelation of emerging missile defense system capabilities should be carefully controlled. Investments in space-based systems should be masked within the Chinese space exploration program.

2. *Unaccountable investments.* The increases in defense spending required to develop these new capabilities should be dispersed and difficult to trace. The large science and technology base already existing in China makes this an achievable goal. China will need additional fissile material production capability in order to support development of new warheads,[16] but should seek to embed these capabilities within the nation's growing nuclear power industry.

3. *Focus on troublesome neighbors*. China shares land borders with four other nuclear powers, of which two (India and Pakistan) are locked in a state of permanent hostility which could quickly escalate to a nuclear exchange, and one (DPRK) has engaged in a series of nuclear threats and stand-offs with the United States. With two of these neighbors, China has had a direct conflict during the Sino-Indian War of 1962 and Sino-Soviet Border Conflict of 1969. Meanwhile, Russia has increased emphasis on nuclear weapons within its security strategy. China has numerous plausible reasons to justify nuclear investments.

Some might argue that China has no need to invest in additional nuclear systems for two reasons: First, it already has sufficient mobile ICBMs to ensure that it can impose a serious cost on the United States in the event of a nuclear first strike. Second, China's economic integration serves as a much more effective deterrent to the United States than any nuclear system that it could develop.

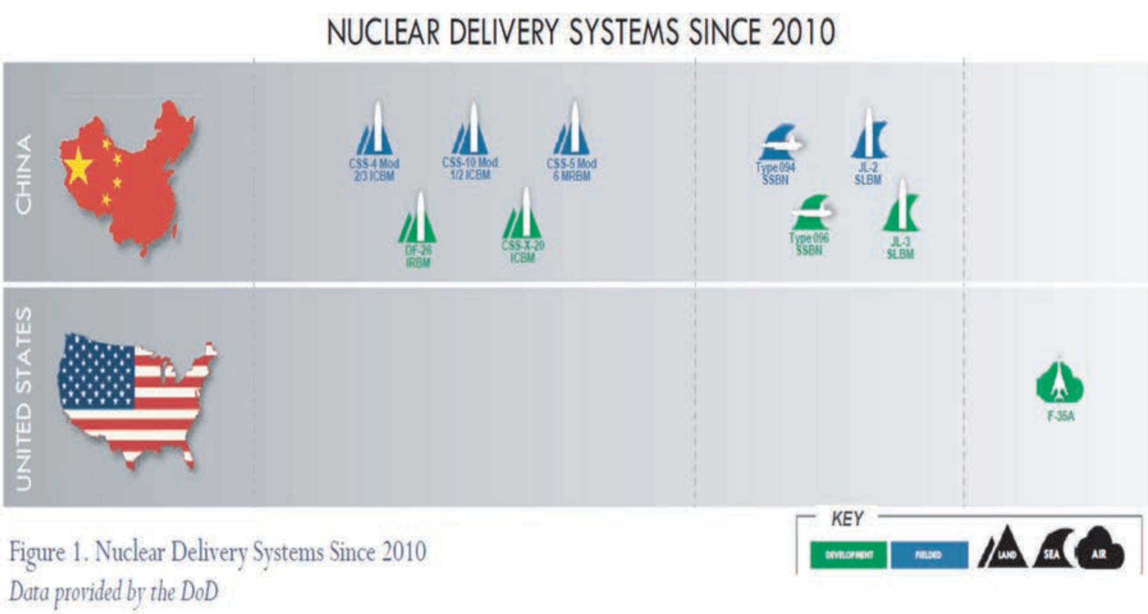

Figure 1. Chinese Nuclear Capabilty - Modified from 2018 Nuclear Posture Review

Both of these arguments have merit, and they bring the conversation back to the initial question of whether an arms race between the United States and China is inevitable. The fact is that some measure of nuclear rivalry between the United States and China is inevitable – the U.S. National Security Strategy and National Defense Strategy paint a clear impression of China as an emerging threat, and China cannot ignore U.S. declaratory policy as it plans its nuclear strategy. However, an outright arms race is less likely. Instead, China has strong incentives to compete asymmetrically, avoiding a head-to-head arms race while presenting multiple strategic dilemmas to the U.S. and its allies in the region which may deter them from considering a first strike on China (conventional or nuclear). Moreover, China can do this in a manner which minimizes the possibility of an overt U.S. response due to its restrictions on transparency, centralized technological investment, and freedom from the arms control restrictions which bind the United States and Russia. Doing this allows China to minimize the risk of both nuclear coercion and a spiraling arms race, while freeing it to focus more resources on ensuring domestic prosperity, which is arguably a more pressing and enduring national interest than nuclear competition with the United States.

Notes:

1. Baohui Zhang, China's Assertive Nuclear Posture: State Security in an Anarchic International Order (London: Routledge, 2015), pp. 42-44.
2. Ibid, pp. 177-180.
3. China's strategic bomber fleet is aging and its nuclear submarine force is both small and has difficulty escaping the first island chain without detection. Thus, the majority of China's strategic nuclear deterrent is bound to road-mobile ICBMs.
4. Lowell Dittmer, China's Asia: Triangular Dynamics Since the Cold War (Rowman and Littlefield, 2018) pp 48-51.
5. Zhang, p.35.
6. National Security Strategy of the United States of America, December, 2017, p.25.
7. Alexander Lukin, China and Russia: The New Rapprochement (Cambridge, 2018), pp.16-29.
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11. Kenneth Allen, Dennis J. Blasko, and John F. Corbett, "The PLA's New Organizational Structure: What Is Known, Unknown and Speculation Pt I."
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16. Eric Heginbotham, Michael S. Chase, Jacob L. Heim, Bonny Lin, Mark R. Cozad, Lyle J. Morris, Christopher P. Twomey, Forrest E. Morgan, Michael Nixon, Cristina L. Garafola, Samuel K. Berkowitz, "China's Evolving Nuclear Deterrent: Major Drivers and Issues for the United States", RAND, 2017.

Concerns Reemerge About Limited Nuclear War

Al Mauroni

This article appeared in the August 2019 edition of *ARMY* magazine, which is published by the Association of the U.S. Army.

The Army is in the midst of a reorientation—planning and preparing for conflict with peer and near-peer adversaries as directed by the 2018 National Military Strategy. This reorientation will involve changes big and small, with the Army embracing both new technologies and concepts—such as unmanned systems and multi-domain operations—and dusting off and updating old ones—such as camouflage and electronic warfare.

But one thing is strikingly absent: Army leaders are not giving sufficient consideration to the threat of nuclear weapons as they develop capabilities and plans to engage future peer and near-peer adversaries.

For nearly two decades, the U.S. military has been focused on combat against non-nuclear nation-states in which post-conflict counterinsurgency operations took significantly more time and resources than planned. As a result of these engagements, U.S. military readiness for conventional operations against a near-peer state has measurably degraded. A 2016 RAND report suggested that Russia could overrun the Baltics before NATO could respond, and Russian President Vladimir Putin has suggested that he would resort to limited nuclear weapons use to stop NATO offensives. The rise of regional tensions on the Korean Peninsula have also caused some consternation as to whether U.S. military forces are prepared for hostilities from North Korea's military, which is believed to have a mature weapons of mass destruction program.

Possible Battlefield

The 2018 National Defense Strategy stresses, as a central challenge to U.S. security, "long-term, strategic competition," by Russia and China in particular. The 2018 Nuclear Posture Review echoes this concern as one of the rationales behind the need to modernize U.S. nuclear forces. The question is, does the Army's leadership recognize the need to train and develop its force to be prepared for a nuclear battlefield?

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In a 2018 article published by the U.S. Army War College's Strategic Studies Institute, Dr. Michael Fitzsimmons states that the Army must pay attention to what will become an integrated conventional-nuclear threat environment, and that the likelihood of an Army maneuver force having to operate on a nuclear battlefield is increasing.

In a similar vein, in a 2018 article published by the Modern War Institute headlined "The U.S. Army Is Wrong on Future War," three Army officers argue that the Army's leadership erroneously believes that an armed conflict with Russia and China can be limited to conventional means, even as those nations modernize their nuclear forces and posture against U.S. national security interests.

Other defense specialists outside of the Army have quietly expressed concerns, as well, that since 1991, when the Army lost its tactical nuclear weapons, it also has steadily lost its ability to understand the consequences of adversarial or friendly use of nuclear weapons within a theater of war. Over the past three decades, the specter of nuclear war has been relegated to a strategic scenario largely limited to attacks against one's homeland and not against military forces.

If that is changing, in this "second nuclear age" where a nuclear confrontation is not limited to a bipolar superpower crisis, is the U.S. Army prepared? A review of the Army's current doctrinal concepts suggests that it is not. Articles in Army professional journals like Parameters and Military Review are bereft of nuclear conflict discussion. Maj. Brad Hardy, in a May War on the Rocks article, says that nuclear education has atrophied in the Army's professional military education pipeline.

Expertise Not Integrated

To be clear, the Army has retained some technical expertise in this field, notably through its Functional Area 52 nuclear and counterproliferation specialists. These officers understand nuclear weapons effects and routinely assist major commands and combatant commands with nuclear weapons plans. But senior leadership and Army maneuver units do not integrate this expertise into their plans or exercises.

So as a thought experiment, what if the Army were to seriously consider the possibility of resurrecting nuclear artillery by designating a field artillery unit with Army Tactical Missile Systems (ATACMS) as a nuclear-capable unit?

As the Army looks to replace the ATACMS with a new system sometime in the next 10 years, this would be an ideal time to examine the requirements for such a capability. The National Nuclear Security Administration could rebuild a small number of W70-3 nuclear warheads, originally designed for the MGM-52 Lance missile, for the Army's future long-range missile system. Or, as an alternative, the W80-4 nuclear warhead, already being developed for the Air Force's Long-Range Standoff cruise missile, might be useful in a ground delivery system.

Such a tactical nuclear missile could be useful in several modes: demonstrations of intent, defensive fires against large conventional formations, or targeting adversary nuclear forces in theater. Given the potential vulnerability of Air Force "dual-use aircraft" fighters carrying tactical nuclear weapons in Europe, this capability would strengthen NATO's nuclear deterrent while reducing the chance of escalating the conflict to a strategic nuclear exchange.

Past Army doctrine examined how to effectively employ tactical nuclear weapons against enemy forces, using airbursts to minimize collateral damage. Today, there may be new uses for precision delivery of low-yield nuclear weapons—for instance, electromagnetic pulse effects to attack enemy communication systems or a penetrating nuclear warhead to destroy hard and deeply buried targets. Unless the Army owns a nuclear weapon, it remains unlikely that its leadership, let alone the rank and file, will feel compelled to prepare to fight conventional-nuclear battles.

Formidable Challenges

There are challenges, of course, to the Army getting a nuclear weapons capability, not least of which are political. The nuclear modernization program is politically charged, and the idea of increasing the budget to bring another redesigned (but not new) nuclear weapon into the active stockpile would be a tough sell. The Army would have to retrain on its nuclear competencies and re-institute its personnel reliability program, and the field artillery community may not like having to make additional room for a capability it may never use.

If the Army does create a nuclear-capable field artillery unit even as a singular "insurance policy" intended to strengthen regional deterrence efforts, would U.S. allies in Europe or Asia be willing to host such a unit? These are formidable challenges, but can the Army afford not to investigate this option? And if such a step is in fact deemed in practical, such a conclusion only reinforces the importance of other actions the Army should take to prepare the service to fight and win on a conventional-nuclear battlefield.

As an example, the Army should incorporate nuclear deterrence education into its intermediate and senior military education. There is plenty of available material in the Air Force's professional military education that could be of immediate use. There needs to be a scrub of all Army and joint doctrine and concepts to acknowledge, at the least, that nuclear warfare will be an operational factor of future conflict. The Army's general officers need to join the Air Force's and Navy's flag officers to discuss strategic deterrence options and how to incorporate nuclear weapons in their plans and strategies.

The possibility of limited nuclear war has re-emerged as a viable concern for political and military leaders. The nation's focus on nuclear weapons as solely a strategic concern has reduced the Army's ability to envision a future battlefield in which tactical nuclear weapons use is a possibility. To be clear, this is not a case of trying to make nuclear war "easier" by deploying nuclear weapons within a theater of conflict. But U.S. adversaries like Russia and North Korea believe that there is a role for limited nuclear warfare. The United States should not be in a position where escalation to strategic nuclear conflict is the only option.

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Nuclear Engineering at the Air Force Institute of Technology

A Unique Graduate School Experience for a Unique Set of Students

LTC Michael B. Shattan
Air Force Institute of Technology

In August 2018, the Air University Commander formed a task force to review the Air Force's Science, Technology, Engineering, and Mathematics (STEM) graduate education programs that are delivered and administered through the Air Force Institute of Technology (AFIT). The study was rooted in strategies to support the 2018 National Defense Strategy, and provided the necessary technologically equipped personnel for the 21st century. The study was commonly referred to as "reimagining AFIT". Several themes emerged from the study, which include reaching a broader community of Airmen through alternate educational modes (e.g. distance learning, short course etc.), forming strategic educational and research partnerships with top universities and government organizations, and ensuring that AFIT provides a top quality, defense focused STEM education. This study serves a critical role in the effort to re-validate, re-think, re-imagine, and re-engineer AFIT's role in providing STEM education for the future Air Force, and will undoubtedly prove to enhance the FA 52 nuclear operations and counterproliferation officers' education as well.

The study's preliminary results revealed that AFIT is essential to the technical education of military officers, particularly in fields of study where the Department of Defense (DoD) has a unique focus and priority when compared to other government and civilian educational institutions. These include the fields of applied physics, cyber security, operations research, aerospace engineering, and nuclear engineering, among others. Similarly, the Army's FA 52 community has relied on AFIT's nuclear engineering program to provide graduate level STEM education to its officers for over two decades. Several civilian institutions also offer high quality STEM graduate programs focused in areas of interest to DoD and the Countering WMD community. These programs provide a diversity of educational options, and the FA 52 officer corps builds upon the strengths of all relevant educational programs. Yet, there is a unique and special nature in the AFIT experience that enhances the careers of FA 52 officers more than any other graduate STEM institute. You may have seen AFIT's promotional bumper sticker, "Why AFIT? … Because sometimes it does take a rocket scientist.", but in this article, I wish to address "Why is AFIT a good fit for FA 52 officers? … Because

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Figure 1. Why AFIT

sometimes you really do need to focus on Nuclear Weapons." AFIT's unique DoD focus, faculty experiences, multi-service faculty and student body provides a total immersion experience focused on the needs of military students, and has a proven track record of student success.

Unique Program DoD focus

AFIT, and specifically the Graduate School, of Engineering and Management) is in a unique position as one of only two graduate schools operated by the DoD that grants accredited masters and doctoral degrees in engineering. This allows AFIT to include the fundamentals of nuclear engineering in the curriculum with a focus to the specific needs of the Department of Defense. For example, the AFIT nuclear engineering program provides courses in all major topics typically found at a civilian nuclear engineering program, but presented in the context of nuclear weapons, weapon effects, and other aspects of the countering WMD mission. One example is nuclear reactor physics. Civilian schools teach reactor physics in the context of the design and operation of commercial nuclear reactors. AFIT teaches the topic in the context of the nuclear reactions occurring during a weapon's implosion and detonation, while also discussing the use of reactors to produce nuclear materials. The former focuses on the control and efficiency of a steady state system for power production. The latter focuses on some of the same materials and similar physical interactions, but in a system with unique and changing geometries and a dynamic response. Much of the core physics required to understand these systems is the same, but the key takeaways from each course are flavored by the intended application. Another example is the study of radiation health effects. AFIT and civilian universities both offer courses in this area. However, civilian universities often focus on low level doses over extended time periods that are often encountered in civilian laboratories and work sites, while at AFIT the same phenomena are covered with more emphasis on modeling and simulation and responses to elevated radiation exposures warfighters might encounter when operating in a nuclear environment. Figure 2 gives an example educational plan, providing nuclear engineering courses typically taken by nuclear engineering master's degree students at AFIT.

Not surprisingly, AFIT's nuclear engineering research is more focused on the needs of the Department of Defense than any other comparable program. The recent ABET accreditation visit report stated, "The faculty and students have an exceptionally homogeneous sense of purpose, which allows the institution to meet the unique needs of its constituents. Moreover, the dedicated and focused educational

AFIT MS in Nuclear Engineering

Sample Curriculum

Example 18-month program. Mandatory courses indicated with an *

Short Term Review Session (4 weeks), September:

- Calculus and Differential Equations (40 hours)
- Nuclear Engineering (40 hours)
- Computation (40 hours)
- Chemistry (40 hours)

1st Quarter, Fall

- NENG 651 Nuclear Physics
- *NENG 685 Computational Methods for Neutron Transport
- *NENG 681 The Nuclear Fuel Cycles
- PHYS 798 Department Seminar

2nd Quarter, Winter

- *NENG 605 Physics of Nuclear Explosives
- *NENG 650 Nuclear Instrumentation
- PHYS 798 Department Seminar

ONE math course normally chosen from the following:

- MATH 504 Differential Equations of Mathematical Physics
- MATH 506 Fourier Series and Boundary Value Problems
- MATH 511 Methods of Applied Mathematics
- SAT 526 Applied Statistics I

3rd Quarter, Spring

- *NENG 361 Prompt Effects of Nuclear Weapons
- PHYS 798 Department Seminar
- PHYS 598 Engineering Physics Seminar

Plus TWO courses, typically from the following:

- NENG 660 Radiation Effects of Electronics
- NENG 680 Nuclear Forensics
- NENG 705 Methods of Radiation Transport

4th Quarter, Summer

- *NENG 635 Residual Effects of Nuclear Weapons
- NENG 799 Independent Study
- PHYS 798 Department Seminar

Plus ONE of the following courses:

- NENG 664 Radiation Effects Laboratory
- NENG 625 EMP Effects
- NENG 612 Nuclear Engineering Laboratory

5th Quarter, Fall

- NENG 799 Independent Study
- PHYS 798 Department Seminar

6th Quarter, Winter

- *NENG 791 Proliferation of Weapons of Mass Destruction
- NENG 799 Independent Study
- PHYS 798 Department Seminar

Figure 2. Typical Curriculum for the AFIT MS Nuclear Engineering program.

experience provided to student enables them to make significant contributions to the technological capabilities of the Air Force and other branches of the Department of Defense." A majority of AFIT's nuclear engineering research is funded by DoD organizations, with some funding from national security focused organizations in the National Nuclear Security Administration and Department of Homeland Security. These organizations are already vested partners in the nuclear modernization and non-proliferation effort, and likewise act as partners in the graduate research; providing guidance and context to the scientific process to ensure the results are applicable to the DoD's nuclear warfighting and counter WMD missions. This investment ensures AFIT's nuclear engineering program provides awareness, access, and networking with key research organizations directly influencing the DoD. These research areas include nuclear weapons effects (blast, shock, Electromagnetic Pulse (EMP), fallout modelling, radiation effects on materials and electronics), nuclear weapon physics (radiation transport, fusion, explosives engineering), and nuclear forensics (post detonation prompt and residual techniques, pre-detonation techniques). Other research areas such as radiation detection, fundamental nuclear physics, and nuclear materials science are found at both AFIT and civilian schools as they have wide applications. AFIT's focus on DoD needs in both the unique and more general research areas is enabled by its cadre of cleared students and faculty. Cleared cadre allows both research and coursework to be conducted in classified settings when appropriate.

Focus on Military Student Success

Arguably, the AFIT faculty understand the needs of Army FA 52 graduate students better than any other graduate nuclear engineering program. This is not surprising given that 50% of AFIT's nuclear engineering professors are

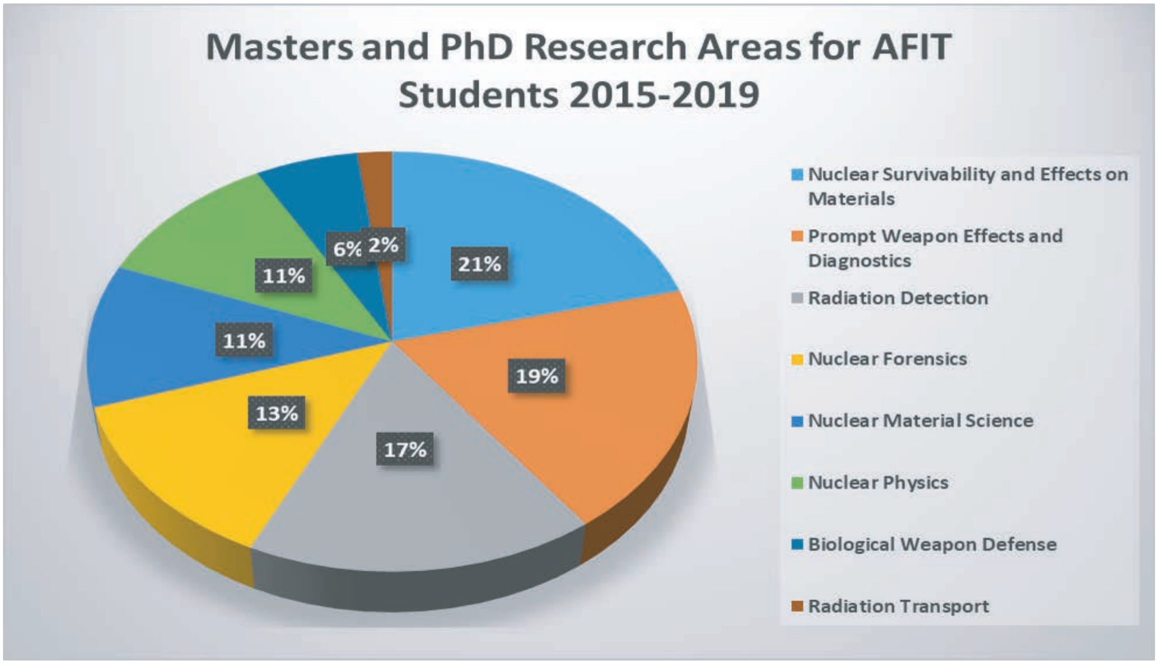

Figure 3. AFIT NENG masters and PhD research areas.

either active duty or retired FA 52s, now Air Force civilians. The other faculty are either Air Force civilians (often retired Air Force officers) or active duty Air Force officers, providing insight into the jointness of nuclear operations. Thus, all of AFIT's faculty are highly sensitized to the unique nature of Army graduate students; such as their tendency to start graduate school after many years away from academics, and a fixed timeline for program completion. To help insure the success of these military students, AFIT has instituted two major programmatic differences compared to typical civilian universities. Incoming FA 52 officers who have had a substantial time from their last experience as university students, or those with a relatively weak background in the material covered in the graduate nuclear engineering curriculum can be offered the opportunity to take refresher classes at Wright State University (WSU) for up to two semesters before beginning the Master of Science in Nuclear Engineering (NENG) at AFIT. WSU is approximately a five minute drive from the AFIT campus, which allows students to take advantage of this option easily without incurring an additional move or resorting to online classes. Historically, students enrolled in the WSU option have been as successful in completing the AFIT MS NENG program as those coming through direct accession. Additionally, AFIT operates on a 10 week quarter system as opposed to a 16 week semester system. The semester system works well for civilian universities which can take advantage of long summer breaks to set up student internships, or release students home to seek summer employment. Since military students have no need for internships or summer jobs to earn college money, the class time can be better organized to allow military students to complete the program more efficiently in the quarter system. The quarter system as implemented at AFIT enables military students to complete their master degree program in 18 months, as opposed to civilian MS programs that typically take a full two years. Given that Army Advanced Civilian Schooling students incur an active duty service obligation (ADSO) of three days for every one day spent in graduate school that time difference can be significant. Additionally, the 18-month program can allow a quicker return to the force thereby enabling greater utilization of the educated officers by the Army while potentially mitigating promotion risks that can be associated with extended attendance at advanced civil schooling, since the time spent in school is considered non-rated time in the Army's evaluation system.

Perhaps more important than the programmatic focus on military students is the culture of personal commitment to military student success at AFIT. Professors at major research universities are judged primarily on their ability to publish research and win research grants. Student success and teaching are also important, but harder to quantify and often relegated to a lower tier of importance. Certainly, AFIT faculty are also required to publish research and compete for research grants; however, the high level of pressure to focus on these activities at the detriment of teaching and student development is lessened. Most faculty are either Air Force civilians, who rely on research dollars for only a small portion of their salary, or active duty military who are not dependent on research awards for any portion of their salary. Additionally, organizations such as the Defense Threat Reduction Agency, the Air Force Technical Applications Center, and the Air Force Office of Sponsored Research are very supportive of AFIT's nuclear engineering program and provide sponsored research funding routinely. These advantages help enhance an institutional military culture of taking care of Soldiers and Airman by enabling the faculty to put the needs of their students first. Thus, courses at AFIT tend to be well taught by actual faculty and all student research receives quality attention.

Dispelling Common AFIT Myths

Despite the advantages described above, there are still some perceptions about AFIT that seem to endure in a part of the DoD's nuclear community and should be addressed. It is common to hear critiques of the AFIT program including that it is a backup school for less capable officers that can't "hack it" at a regular civilian school, that the program does not conduct cutting edge research, or that the faculty are insular (i.e. drawing only from AFIT graduates which lessens originality in thought and ideas). It is easy to understand how someone with only a cursory knowledge of the AFIT program could have these perceptions. However, each myth can be easily dispelled.

While it is true that AFIT has a proven track record of successfully educating students from a variety of educational backgrounds, AFIT has adjusted the curriculum to ensure it is attainable and yet challenging, for those with little nuclear engineering educational preparation to recent graduates of nuclear engineering undergraduate programs. AFIT's nuclear graduates have well documented professional portfolios. AFIT nuclear engineering students have published multiple research articles in prestigious journals including but not limited to: *Nature, Physical Review, Applied Physics Letters, the Journal of Applied Physics, the IEEE Transactions on Nuclear Science,* and *Nuclear Science and Engineering*. In fact, nearly all AFIT MS NENG and all AFIT PhD NENG students graduate with at least a conference publication, if not one or more journal paper authorships. This quality indicator is directly in-line with the statistics of FA 52 students attending civilian schools despite AFIT's willingness to accept students with a somewhat wider variation in academic preparation. Yet, not every student who applies to AFIT's program is accepted. All students must meet a rigorous set of criteria including a minimum 3.0 GPA on a 4.0 scale from an accredited undergraduate program, appropriate undergraduate coursework focused on math, science and engineering, and GRE scores high enough to demonstrate the student's ability to perform at the graduate level, 153 verbal and 148 quantitative. Prospective students who do not meet these minimum criteria must receive a waiver and often are required to attend some undergraduate courses at Wright State University. These waivers and classes are decided on an individual basis based on a holistic evaluation of the student officer. The goal is to give every student the best chance at success as a graduate student.

More important than academic success is military professional success. According to statistics provided by USANCA, as of July 2019, 75% of all FA 52 LTCs and COLs held at least one technical graduate degree. AFIT graduates account for one third of that 75%, by far the largest percentage of any single school. Thus, it is clear that the ability to think critically about technical aspects of the countering-WMD mission is an important skill requirement to a FA 52 officer's professional success. AFIT has educated more senior FA 52 officers with this necessary skill set than any other graduate institution.

Finally, while degrees from AFIT are common among AFIT faculty, half of the AFIT faculty do not hold any degrees from AFIT and only 13% of the faculty attended AFIT for both their master's and PhD. Having faculty with a pre-existing familiarity with the AFIT program does make sense. Many of the research focus areas of the AFIT program are so unique it would be difficult for graduate students to do meaningful research in those areas at other universities. Thus, often the most qualified candidates for faculty to lead those research areas come from AFIT graduates. However, collaboration and diversity of thought are important in all research endeavors. Therefore, over half of all nuclear graduate students conduct research involving collaboration with partners outside of AFIT. Common research collaborators include the Department of Energy (DOE) National Laboratories, Air Force Technical Applications Center (AFTAC), Air Force Research Library (AFRL), Ohio State University, UC Berkeley, and the University of Tennessee, as well as many other government laboratories, universities, and government funded contractors.

Tying it All Together

After a thorough look at AFIT's nuclear engineering program, it is clear to see why it has been so successful in preparing Army FA 52 officers for professional success. The program has unique advantages including a focus on DoD-related nuclear research and coursework, as well as a cadre of faculty sensitized to working with the unique nature of military graduate students. The program is ABET accredited, publishes cutting edge research, and holds its students to rigorous standards for both program acceptance and graduation. The program's success in preparing FA 52 officers is evident in the success of its graduates both during their activity duty service and after serving in leadership positions in the national nuclear and countering WMD enterprise. The career field benefits significantly from the diversity of academic backgrounds provided by our officers attending these other schools. However, AFIT remains the leading institution for FA 52 nuclear engineering graduate education, a distinction the program is proud of and strives to maintain.

Flash Blindness on the Battlefield

LTC Jeff Kendellen

United States Army Nuclear and Countering WMD Agency

Nuclear weapon effects analysts at the United States Army Nuclear and Countering WMD Agency (USANCA) encounter a wide range of questions from customers within the Army, the other services, and throughout the Department of Defense. These questions are sometimes a mere curiosity, for example how is fallout from a nuclear weapon different from the 1986 reactor accident in Chornobyl, Ukraine? While others are connected to potential real world operations, such as, how long until sensitive site exploitation can be performed after a ground burst? In many cases, these real world questions are complex, don't have a simple answer, and require extensive research in order to arrive at an answer.

This paper will address a frequent question asked to the USANCA subject matter experts: what is the risk of retinal burns or flash blindness to friendly troops following nuclear weapon use?

The fact that luminous things can impact the eye has been understood for many years. There are scientific reports from the 1800s detailing eye damage resulting from viewing solar eclipses without protection.[1] While eye safety or damage wasn't studied as part U.S. nuclear weapons tests until the 1950s,[2] personnel involved in the Trinity test in July 1945 did use eye protection to witness the detonation.[3]

When a nuclear weapon is detonated, approximately 35% of the energy produced is in the form of thermal energy (i.e., heat and light). Consequently, even many kilometers away, the fireball will appear many times brighter than the Sun. The luminosity, therefore, has the potential to cause temporary blindness or permanent damage to the human eye even when well outside of the range of other effects (i.e., blast and radiation).

At lower altitudes, the thermal energy is given off in two thermal energy peaks or maximums as seen in Figure 1. The first peak is generated as x-rays interact with the weapon materials and casing. This peak lasts only ~0.1 seconds as a result of the short mean free path of the x-rays and

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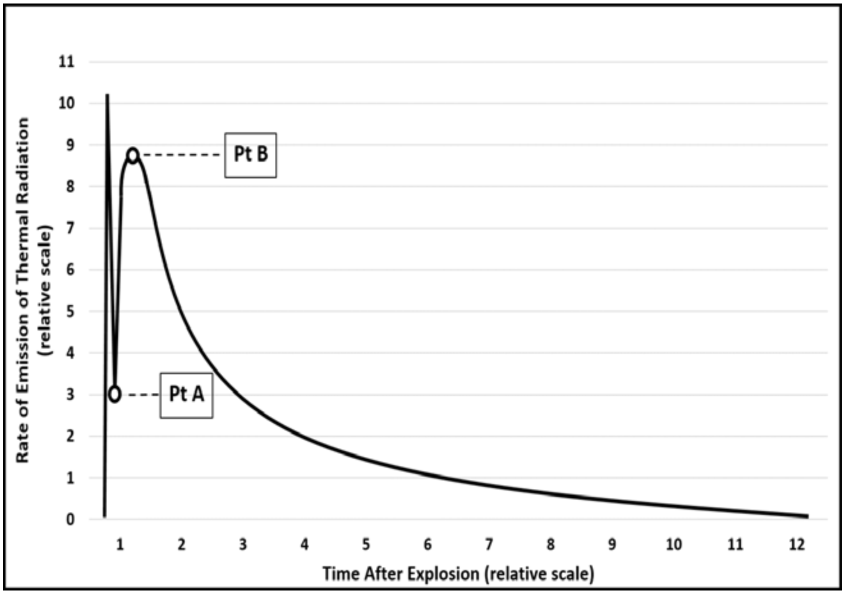

Figure 1. Thermal radiation vs time using a relative scale. Glasstone and Dolan., 1977, pg 41.

only accounts for a few percent of the thermal energy produced by the weapon. A second thermal peak is generated, again from the x-rays, which interact with the air surrounding the weapon. At this later time, the x-rays' mean free path is longer because of the hot (millions of degrees Celsius) and dense (hundreds of gigapascals) conditions of the rapidly expanding fireball. The second thermal peak lasts on the order of seconds for tens of kiloton weapons to over 10 seconds for megaton weapons. This latter peak accounts for 99% of the thermal energy produced by the nuclear weapon. While dependent on yield, the first peak and sometimes portions of the second pulse contribute to the potential for eye injury.

The human eye is an intricate and delicate instrument containing lenses, fluid, light receptors, nerves and connections to the brain that interprets light received from the environment. In order to understand eye damage, one must identify major eye components and how they function in order to understand how they are impacted by very luminous objects. As the light reaches the eye, it travels through the cornea and then the pupil, which is the area formed at the center of the iris. The iris adjusts based on light conditions altering the size of the pupil; that is, it is narrower in the day time (2-3 mm in diameter) and wider at night (7-8 mm in diameter) to allow more light into the internals of the eye. The light that enters the pupil is then focused by the lens and imposed on the retina. The retina contains photoreceptor cells

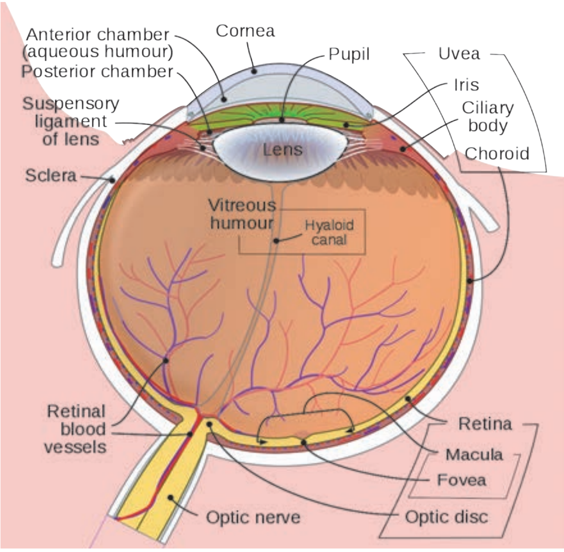

Figure 2. Diagram of the human eye. Credit: Wikipedia; Creative Commons License

called rods and cones which convert the light into nerve pulses and an image for the brain.

The photoreceptors on the retina are arranged in a very specific manner to maximize visual acuity at the visual center while still providing awareness in the periphery. The retina has an area that is comprised of only cones known as the fovea. "When one looks at an object the eye always rotates so that the image falls upon the fovea and the optical system focuses the image upon the retina at this point."[4] Cones are specially adapted to discern color and provide visual acuity when ample light is available. Elsewhere in the retina, rods and cones together create the rest of the image of the environment where the rods provide low light vision in black and white. As previously stated, under low light conditions, the iris opens further and the pupil is enlarged. This occurs on a short time frame of a few seconds. Additionally, the rods and cones regenerate rhodopsin which is a photo pigment that enhances they eye's adaptation to night vision. This process is gradual and occurs over 20 to 30 minutes.

After presenting a general understanding of the functional aspects of the eye, the discussion will turn to how the eye responds to a suddenly luminous object such as a fireball from a nuclear weapon. During the day, the pupil is smaller and when the bright flash of the weapon is sensed, the eye will automatically work to protect itself by closing in approximately 0.1 seconds. However, given that the thermal energy created by the fireball is traveling at the speed of light, a tremendous amount of direct and reflected light can enter the eye within that ~0.1 seconds. At night, the pupil is 16 times larger than during the day and allows significantly more light to reach the retina in the same 0.1 second timeframe.[5]

Referring back to Figure 1, assume Pt A represents a point on the thermal radiation curve at time tA for a 1 megaton weapon. Assume Pt B represents a point on the thermal radiation

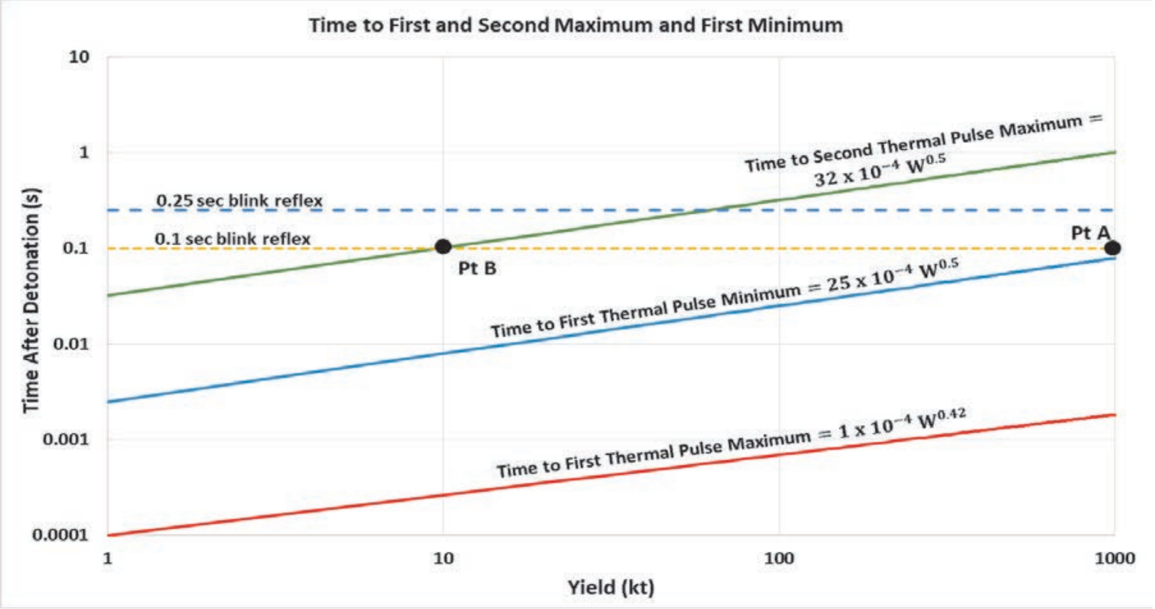

Figure 3. Times and equations associated with the first and second thermal energy maximum and the first thermal minimum. (Taub, et al., 1965, pg. 16 and 17)

curve at time tB for a 10 kiloton weapon. The time frame at which a weapon delivers thermal energy is closely tied to the yield. As such, it may be the case that for some weapon yield pairs, the times between detonation and Pts A and B are equal (i.e., tA = tB). Figure 3 shows Pt A(tA) and Pt B(tB) along with the times to the first and second thermal peak or maximum and first minimum according to yield. When considering the blink reflex, one must consider that weapons smaller than 100 kilotons complete both peaks and deliver thermal radiation by the time the observer executes an eyelid closure at approximately 0.1 seconds.[7] Likewise, for larger weapons, the build up to the first and second thermal pulses occur more slowly allowing time for the blink reflex to execute. Therefore, it is the case that lower yield nuclear weapons are more of a risk to personnel on the ground because they deliver thermal radiation at a faster rate.

Flash blindness describes the temporary blindness induced by the photochemical bleaching of the rod and cone photoreceptors in the retina by extremely bright light. Flash blindness is experienced via two phenomena. The first is dazzle which is the bleaching of the rods and cones throughout the retina due to the intensity of the luminous fireball and/or the reflections throughout the environment: clouds, ground, and buildings. Dazzle can occur when the fireball is not in the field of view due to these reflections. One might relate to or have experienced dazzle after taking a picture at night with the assistance of a flash. The generalized loss of vision throughout the field of view is the dazzle effect. The second phenomena is the after image which occurs when the fireball is in the field of view. The after image is a visual representation of the fireball that exists even after the eye lid is shut or the person looks away. Referring back to the example of taking a picture at night, the after image appears as a distinct spot in the field of view exactly where the flash bulb actuated. During the day, when the eyes are adjusted, flash blindness can last seconds to minutes after the light source is removed as the rods and cones have time to chemically recover. At night, flash blindness can last minutes to hours as the rods and cones recover and the eye readapts to night vision.

A retinal burn on the other hand is a permanent eye injury that occurs whenever the retinal tissue is heated excessively when the radiant fireball is in the field of view. The thermal energy from the fireball is deposited on the retina thereby raising the surface temperature and burning the retina. Due to both the focusing of the lens[8] and the sensitive nature of the retina, the amount of energy required for a retinal burn is magnitudes less than that which is required to burn the skin.[9]

It can be safely assumed that a majority of unwarned Soldiers will not be looking directly at the fireball and will not experience retinal burns. These assumptions are supported by analysis of survivors of nuclear weapon use in Hiroshima and Nagasaki which found a "scarcity of severe eye injuries in Japan."[10] Therefore, the rest of this paper will address the militarily significant aspects of flash blindness and safe separation distances (SSD).

A majority of technical reports on retinal burns and flash blindness are primarily concerned with flight crews and specifically pilots. The safe separation distance is the slant range from the fireball to the observer where the threshold for ocular damage or flash blindness is not exceeded. The threshold is based on pilots experiencing flash blindness for no more than 10 seconds. However, the task for the pilot, in this case, is reading dials in the cockpit. Reading dials is a task reserved for the fovea, the visual center, and difficulty reading dials, even with a significant after image, can be overcome by adding sufficient light to see through the after image.[11]

Today, subject matter experts typically refer to the work done by Allen, et al., (1968) when providing SSDs to planners.[12] Within this technical document are charts and calculations for flash blindness and retinal burns for a number of different circumstances, all of which are focused on the tasks described in the previous paragraph. At first glance, the SSD figures presented in Allen, et al., (1968) don't appear to be suitable to inform Army planners or USANCA subject matter experts because Soldiers engaged in combat operations are just as reliant on the fovea, to aim a weapon, as the other areas of the retina, to monitor for enemy movement or other threats in the periphery. However, after examining the data and the assumptions that went into Allen, et al.,'s (1968) SSDs, the author believes it is appropriate to use them when considering a Soldier performing Soldierly tasks.

For the SSDs, Allen, et al., (1968) assumes the following when performing calculations for flash blindness: 1) blink time of 0.25 second; 2) visibility of 100 kilometers; and 3) 1,000 feet (0.304 km) height of burst.[13] These factors and others contribute to the SSDs being suitable to Soldiers because they are so conservative and because a 10 second recovery does extend to other parts of the visual experience. First, a standard reflexive blink time is about 0.1 second. Adding 0.15 seconds allows significantly more light into the eye. Likewise, visibility of 100 km is a tremendously clear day meaning direct line of sight to the Soldier with very minimal attenuation by the atmosphere. Also, a 1,000 feet height of burst provides a good balance between the slant range and the maximum possible distance (based on curvature of the earth) between the observer and the weapon.[14] Allen, et al., (1968) also included safety factors in the SSD equations associated with variations in weapon output[15] and individuals.[16, 17]

During the literature review, a number of technical papers were examined. In general, they all agreed with the Allen, et al., (1968) data.

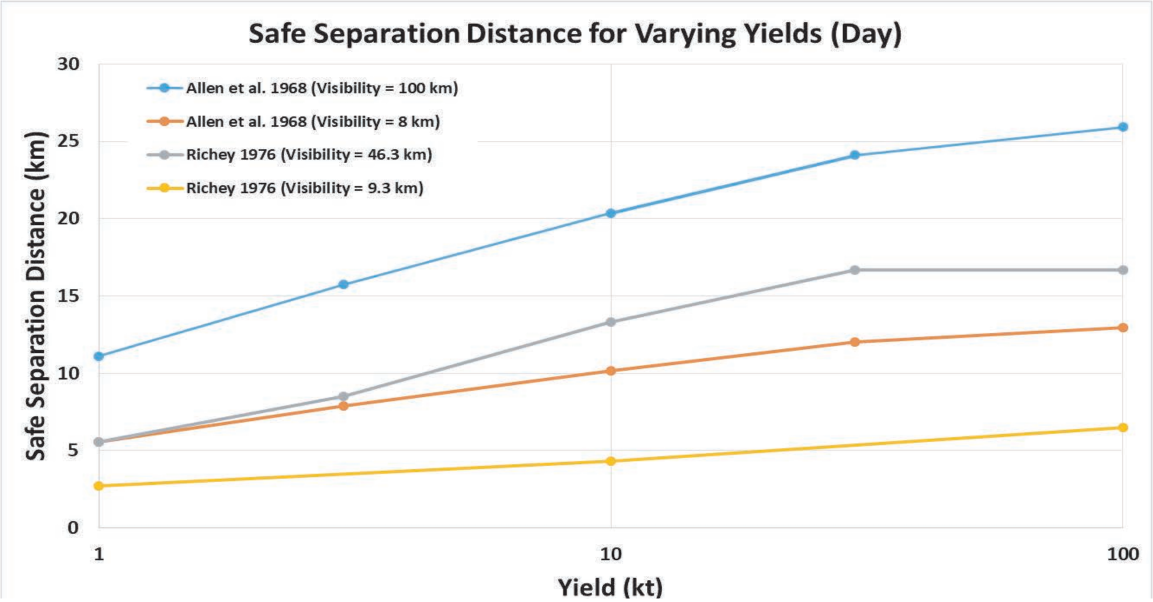

Figure 4. Safe separation distance for varying yields during the day.

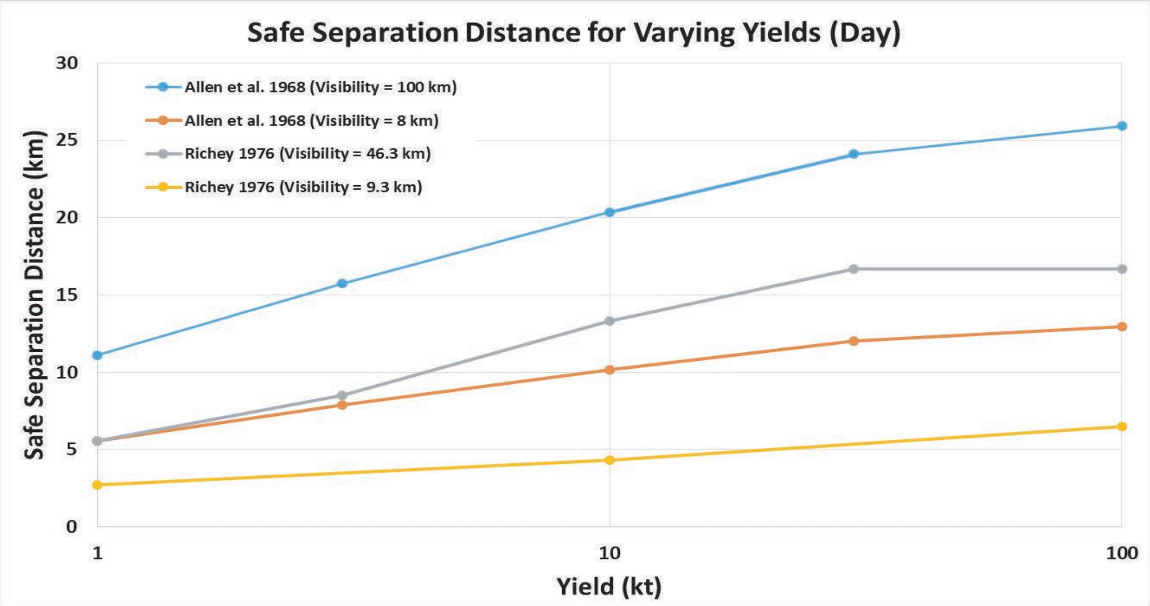

Figure 5. Safe separation distance for varying yields at night.

However, it is important to note that many sources were focused on pilots at cruising altitude and few dealt directly with personnel on the ground. Figures 4 and 5 present data from two technical sources for night and day conditions. Allen, et al., (1968) is presented for visibilities of 100 km and 8 km.[18] The second technical resource was Richey (1976) which used identical yields and height of burst, but the visibility was 46.3 km (converted from 25 Nmi) and 9.3 km (converted from 5 Nmi).[19]

The literature demonstrates that for a nuclear detonation during the day, personnel within the SSD who are otherwise not impacted by a nuclear weapon detonation may experience flash blindness. The effect may be minimal or profound, but a Soldier will be able to return to their duties within seconds to minutes after the event. This differs significantly for personnel within the SSD at night in that when the flash occurs, Soldiers will not only be flash blinded, but they will lose or reset their night vision. Additionally, because the pupil is larger, more light has entered the eye in order to saturate the rods and cones worsening the dazzle effect. As the eye recovers, it must also then re-adapt the night vision characteristics. In short, flash blindness at night could require many minutes to hours to recover.

An additional consideration at night is the use of night vision goggles (NVG). When a Soldier utilizes NVGs, the eye does not truly adjust to night vision. In this case, the flash from the nuclear weapon is obscured physically by the NVG and entering an eye via a restricted pupil. Additionally, when the NVGs "see" the flash from the nuclear weapon, the Auto Gain Control or Automatic Brightness Control circuitry cuts off the amplification of the light. Meaning, where the NVG circuitry enhances a star in the night sky by 100,000 times, the circuitry is designed not to enhance an extremely luminous object by that same amount. Consequently, Soldiers wearing NVGs will most likely fare better and have shorter recovery times than those that are not.[20]

The purpose of this article was to answer the question: what is the risk of retinal burns or flash blindness to friendly troops following nuclear weapon use? Flash blindness is a larger concern than retinal burns when considering troops that are outside of the effects of blast and radiation. Specifically, 1) during the day, there may be some minor impact to personnel within the SSD that require a few minutes to recover their vision; and 2) at night, the impact to personnel is more severe and those within the SSD may require minutes to hours in order to recover. Additionally, the SSDs reviewed during the historical literature review generally agree with Allen, et al., (1968) and therefore, when planners or subject matter experts are considering the effects of flash blindness on the nuclear battlefield, these figures should be considered a conservative, but vetted resource for SSDs.

Notes:

1. Barrett, James., "Damage to Vision Caused by Watching an Eclipse of the Sun", Ophthalmic Review, 1895, pg 80.
2. Allen, Ralph., Jungbauer, David., Isgitt, Donald., Arment, Brian., Russell, John., "Nuclear Flash Eye Effects Technical Report for Military Planners", February 1967, pg 1.
3. Richey, Everett., "Predicting Eye Safe Separation Distances from Nuclear Detonations", January 1976, pg 3.
4. Verheul, R., Lowrey, A., Browning, L., "Operation HARDTACK – Project 4.3 Effect of Light from Very-Low-Yield Nuclear Detonations on Vision (Dazzle) of Combat Personnel", April 1960, pg 14.
5. Daytime pupil radius is ~1 mm and night is ~4 mm. Area=πr^2 for a circle. Daytime area = 3.14 mm^2; Night is 50.2 mm^2.
6. Taub, Arthur., Levy, Charles., Wargo, Michael., Hodgson, David., Cummings, Thomas., Goff, Jennifer., Chamberlin, Henry., Moody, John., "Review of Research on Flash Blindness, Chorioretinal Burns, Countermeasures, and Related Topics", 1965, pg 16.
7. Glasstone, Samuel., Dolan, Philip., The Effects of Nuclear Weapons, 1977, pg 572.
8. Even though the fireball's thermal energy dissipates as $1/(r^2)$, the eye's lens counteracts this effects such that the "irradiance at the retina in the image of the fireball is independent of the distance from the fireball." Allen, Ralph., White, T., Isgitt, D., Jungbauer, D., Tips, J., Richey, E., "The Calculation of Retinal Burns and Flash Blindness Safe Separation Distances", September 1968, pg 4.
9. Ibid.
10. Glasstone and Dolan., 1977, pg 570.
11. Allen, et al., 1968, pg 9.
12. Allen, et al., 1968.
13. Ibid, Appendix B.
14. Assuming: 1) 1000 ft (0.304 km) height of burst; 2) direct visual line of sight to the weapon; 3) a person of average height; then the maximum distance to view the fireball is ~ 60 km.
15. As an example, Glasstone and Dolan., (1977, pg 71) states that the well-known fallout safe equation ($HOB(ft)=180*W^{0.4}$) has an error of ±30%.
16. Taub, et al., 1965, pg 56.
17. Allen, et al., 1968.
18. Richey, 1976.
19. Allen, et al., 1968, pg 20.
20. Dyer, Jean., Young, Keith., "Night Vision Goggle Research and Training Issues for Ground Forces: A Literature Review," US Army Research Institute for Behavioral and Social Sciences, May 1998, pg. 7.

Radiological and Nuclear Threat Detection Using Small Unmanned Aerial Systems for DoD Mission Areas

LTC(P) Keith McManus
United States Military Academy

The means to remotely and autonomously sense the location and distribution of radiological and nuclear sources across a range of operational environments is a capability that could benefit nearly every field application of radiation detection. The applications for remote radiation detection are not new. For many years, instrumentation has often been accomplished remotely for activities in the nuclear field such as reactor control, weapons testing, spent fuel monitoring, and dosimetry. The aspect of remote radiation sensing that is novel and exciting is the vast improvement in the technology to access dangerous, harsh, denied, extensive, and otherwise complex environments. Unmanned systems, colloquially known as drones and robots, have rapidly matured in both capability and ubiquity over the past twenty years.

Most ionizing radiation detection methods, particularly for gamma and neutron sources, meet the basic definition for remote sensing; physical contact with the source is not required. However, the term remote sensing generally refers to the use of satellite- or aircraft-based sensor technologies at standoff distances. While large standoff distances are certainly desired, most operationally relevant scenarios involving radiation sources require source-to-detector distances of no greater than several to perhaps tens of meters. In this context, the term remote radiation detection is used to indicate one or more of the following conditions concerning a radiation source or distribution of sources with regards to the location of a sensor: (1) an operationally significant standoff distance between the source and sensor, (2) the presence of structures or other barriers between the source and sensor, or (3) a significant dissimilarity in the source environment and the environment at the location of the human operator or controller. Remote radiation detection generally assumes far-field application, with possible intervening material such as buildings, walls, or vehicles, and does not require an operator to be co-located with the system.

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Unmanned systems are being developed at a rapid pace for military, commercial, industrial, and recreational uses. Improved radiation detection systems and associated imaging and mapping modalities are being mounted on unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs), and even unmanned underwater vehicles (UUVs) to produce novel and innovative radiation detection capabilities. These unmanned systems are often equipped with auxiliary sensors that capture contextual information from a scene and measure the position, velocity, orientation, heading, and altitude to a high degree of precision many times per second. The advancement in these two fields presents a unique opportunity to provide significant improvement in source detection, localization, identification, and mapping, thereby delivering real operational value to the radiation detection community of users. While traditional incremental improvements to detector performance characteristics—better energy resolution, improved efficiency, faster timing—play a role in enhancing capability, it is access to the full range of contextual information and the ability to maneuver within a scene that truly advances the state of what is possible for remote radiation detection.

Remote access, coupled with radiation detection, is desirable for several reasons. First, a human being does not have to enter or remain in a potentially dangerous, harsh, or otherwise difficult to reach environment. Remotely accessing a radiation area precludes unnecessary exposure and possible contamination of personnel. Beyond avoiding potential radiological hazards, remote access also protects personnel from exposure to the elements, heat, cold, sun, and rain, as well as potential threats in a hostile or otherwise uncertain situation.

Second, remote access often denotes access to locations that are inaccessible or inhospitable to a human operator. For radiation detection, this can result in significant increases in the signal collection by (1) positioning the sensors closer to locations of interest to increase the detector solid angle, (2) approaching a location of interest from a different vantage point, including from above, to reduce the attenuation by intervening material, and (3) dwelling in a location for much longer than a human operator could remain safely or comfortably to improve statistical confidence. While there are certain locations and situations where a human operator will have better access or operational insight, many radiation detection operations could be performed just as well or better by remote means.

Third, unmanned platforms can reduce the variation in radiation measurements caused by changes in a human operator's speed and path, position and orientation of the detector, and attenuation and scattering generated by the operator's body and equipment. Integrated sensors on UAVs enable finer control of speed, path, height, and orientation. Additional sensors may also be employed to capture 3-D scene data.

Finally, the cost of remote access has dropped considerably, and access has skyrocketed. Just two decades ago, remote access was primarily limited to specialized robotic platforms designed for scientific investigation, explosive ordnance disposal, or avid hobbyists. Now, children are using smartphones to fly sophisticated UAVs in parks and neighborhoods around the world, which speaks directly to the cost, ease of control, and ubiquity.

However, one does not achieve operational capability by simply mounting a radiation detector to a commercially-available UAV, though that

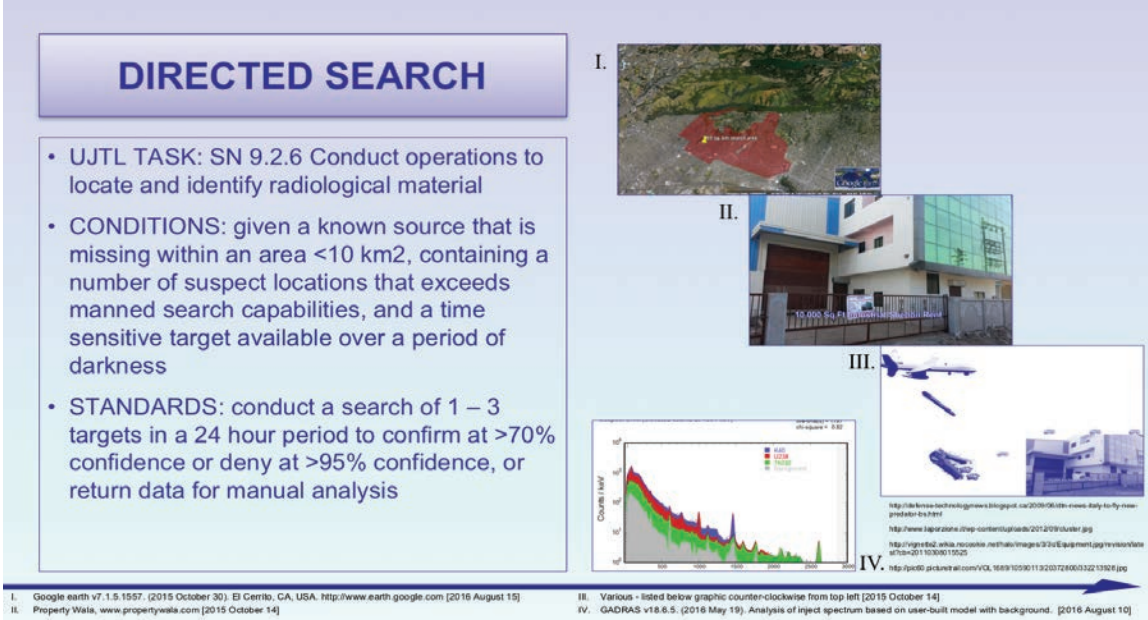

Figure 1: Directed Search UJTL Task, Conditions, and Standards.[1]

avenue has indeed been pursued. While that approach may provide some limited capability and undoubtedly helps identify the shortcomings of a given system, a detailed analysis of requirements and development of key performance parameters often shortens the spiral development cycle and leads to a better capability. The capability to detect, locate, identify, and characterize radiological and nuclear materials using remote sensing platforms is a shared requirement across the many stakeholders in the radiation detection community. This technology has relevance to applications in homeland security and law enforcement, customs and border protection, nuclear power plant activities, nuclear waste monitoring, environmental remediation, and military operations. Military applications present the most diverse, challenging, and likely use-cases for this technology. Of interest are the following military mission areas: *directed search, battle damage assessment, consequence management, accident response, nuclear contamination avoidance, nuclear forensics, nuclear disablement,* and *active interrogation.*

The following sections describe each military mission area and provide further details that include: historical vignettes where unmanned radiation detection assets would have provided considerable value, a summary of the general operational conditions, an assessment of the impact that remote detection might have on the speed, accuracy, fidelity, safety, or feasibility of a given mission, and/or a brief consideration of the unique challenges that might arise in developing a materiel solution.

Directed Search

Radiological and nuclear search is the main effort when it comes to nuclear detection research and development efforts for the DoD, and arguably across other government agencies as well. Nevertheless, what "search" means and what that term implies to different user groups is exceedingly diverse. Therefore, the term "directed search" is defined and used here. Directed search assumes that law enforcement, security forces, or intelligence functions have confirmed the loss, theft, or possession of radiological or nuclear material of concern by a state or non-state actors, such as individuals, extremist organizations, and non-governmental entities. The type, quantity, total mass, chemical form, and geometric configuration of the material are likely known or can be approximated. The suspected location of the material has been narrowed to a reasonable-sized search area through intelligence collection and assessment. For directed search, a reasonable-sized search area is defined here as less than ten square kilometers, as in a small town, a large neighborhood or section of a city, or several small villages. Furthermore, intelligence assets may have identified light industrial or commercial structures within the search area as possible device fabrication, assembly, or material storage sites.

A real threat to the United States would be state or non-state actors smuggling nuclear weapons or radioactive materials into the country. Fortunately, there have not been any publicly confirmed attempts to locate an improvised nuclear device (IND) or radioactive dispersal device (RDD). That is not to say that search teams have not been employed to find lost or stolen material. In 2003, DoD radiological search assets were used to locate two radioactive capsules stolen by looters from a nuclear testing site located at Saddam Hussein's main battlefield testing center in the desert west of Baghdad.[2,3,4]

The site, built in the early-1980s, was used to test equipment, and possibly human subjects, in a simulated battlefield radiation environment by raising large-activity radioactive sources on towers arranged in an arc around a test pad. Small metal capsules, each initially containing approximately 370 giga-becquerels (GBq)—10 curies (Ci)—of the 60Co isotope, had been stored in concrete containers at the bases of each of the eight 23m (75 ft.) testing poles.[2] By 2003, the sources had decayed to approximately 10% of their original activity but remained a significant health hazard and possible RDD threat at ~37 GBq (1 Ci) each.

Finding sources of that strength is "the slow pitch softball" of search operations.[3,4] It was quickly accomplished by mounting a large detector system containing thallium-doped sodium iodide (NaI[Tl]) scintillation gamma-ray detectors and 3He-filled proportional tube neutron detectors into a military helicopter and scanning the nearby area at low altitude and airspeed.[2,3] The two sources were found along with remnants of the tower poles, which were the target of the looting, in two adjacent villages approximately 16 kilometers (10 mi) north of the testing site.[2]

Though this search and recovery operation was swift and successful, changes in the conditions could have made the mission far more difficult. For example, the source strength and primary gamma-ray energies associated with the decay of the 60Co isotope allowed search forces to locate the material from an altitude of more than 100 meters. Suppose instead it was special nuclear material (SNM), secretly hidden from inspectors, that went missing from the Baghdad Nuclear Research Facility. Depending on the material properties—including fissile isotope(s), enrichment levels, impurities, and other factors—the gamma and neutron flux produced by the material would have a wide range and be much more difficult to detect from the air.

For this exemplification, assume that the material consisted of 25 kg of weapons-grade (WG) highly enriched uranium (HEU). An amount classified as a significant quantity (SQ) by the International Atomic Energy Agency (IAEA), denoting the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded.[5] Prior to its removal by the IAEA after the 1991 Gulf War, Iraq possessed more than 12 kg of slightly irradiated 93%-enriched uranium fuel purchased from France as part of the Tammuz-2 reactor. They also possessed more than an SQ of both fresh and irradiated 80%-enriched uranium fuel from the Russian-supplied IRT-5000 research reactor.[6]

Unlike the 60Co sources, which were found lying in the yard of a house and partially buried in a field near another, assume that the value and hazards associated with the stolen SNM were known to the thieves and kept in a secure location, such as a non-descript building in Fallujah. The concept of operations calling for a helicopter to fly low and slow to locate the material fails quickly. First, the expected radioactive signature from the material would be undetectable above background, even at the lowest operating altitude and speed of a helicopter, except for perhaps hovering directly above or landing on the roof. Second, the geographic area that the cobalt sources were recovered from was semi-permissive during the operation; that is, the villagers, while not completely forthcoming with details regarding the missing material, were not actively hostile towards U.S. forces at the time. Had operations taken place later in the conflict, those villages at the southern end of the so-called Sunni triangle may have been much more hostile, thereby precluding the low and slow flight of a manned helicopter or necessitating a much larger security presence. Third, the presence of a helicopter flying a search pattern over buildings would certainly trigger apprehension in the minds of those possessing the material, prompting them to flee the area or to shield the material if they were working with it at the time.

Given these realities, the conditions for high-consequence directed search operations involving SNM require pushing detectors as close to the source location as possible while not tipping off the adversary to one's actions and reducing the risk to personnel and equipment where possible. To that end, a remote sensing platform that can be flown, dropped, or launched to a location is an attractive solution. As such, a modest collection of small unmanned aerial systems (SUAS) outfitted with radiation detectors coupled to contextual sensors could meet those requirements for under $2 million.

SUAS can fly much closer to buildings and could perhaps land on them undetected. Furthermore, reducing the distance between potential sources and the sensors allows one to use smaller and more sophisticated detectors to achieve equal or better sensitivity but with much higher specificity. Moreover, the reduction in risk across-the-board is unparalleled. Not only are several warfighters and tens of millions of dollars of equipment removed from a potentially high-risk situation, but the risk to mission compromise via adversary tip-off is also significantly reduced.

Of course, there are engineering challenges that we must overcome and trade-offs that we need to weigh when designing such a system of systems for this application. Considerations for this mission area are the primary focus of the research conducted and presented in this work. The two chief concerns are the optimization of the sensor package and the development of the search method. The choice of detector materials, the quantity and arrangement of detector elements, and the choice of auxiliary sensors are paramount in developing a system that can detect a sufficient number of threat materials under a given set of conditions. Beyond that, the effective employment of a group of systems requires detailed analysis of individual search patterns, collective coverage schemes, and cooperative detection algorithms.

The other mission areas illustrate various conditions that might dictate a different approach than that of directed search. However, there are likely to be overlaps and synergies that exist between several missions that would permit adaptable or modular multipurpose design approaches that employ the same or similar unmanned platforms, sensors, search schemes, or algorithms.

Battle Damage Assessment

Battle damage assessment (BDA) encompasses the estimate of the damage resulting from the application of lethal or nonlethal military force. Traditionally, it is associated with assessing the damage inflicted on a target from a stand-off weapon, such as a bomb or guided missile. Assessment of the physical damage, functional damage, and effect on the targeted systems are made to inform further actions.[7] As an example, physical damage to an underground hangar complex or airfield that prevents an enemy from launching fighter jets for some number of hours might be the commander's desired effect of a given strike. Verification of craters of a certain depth and placement informs the commander of a functional kill; the strike has not destroyed any of the fighter jets yet has delayed their employment long enough to make their threat moot. Alternatively, if the strike did not achieve the desired effect on-target, it may drive a commander to authorize another sortie or to adjust plans to account for the possible employment of the enemy fighter jets.

While BDA to some extent is unique to military operations, there are corollaries with civil applications that involve the spread of radiological or nuclear sources, especially in an urban area. This spread might be from a "dirty bomb" scenario or an improvised nuclear device that fails to achieve a significant nuclear yield, known as a fizzle. The radiation detection requirements for the offensive military BDA scenario are likely to be quite similar to that of a civil response to an incident where radiological or nuclear material is explosively spread over an urban or industrial area.

The bombings of the Al-Kibar reactor site in the Deir ez-Zor region of Syria in 2007, as well as the bombings of the Osirak reactor at the Al Tuwaitha Research Nuclear Center in Iraq in 1981, both conducted by the Israeli Defense Forces (IDF), are prime examples of where BDA enhanced with radiation detection capabilities could have proved useful.

Though Syria signed and ratified the Treaty on the Non-proliferation of Nuclear Weapons (NPT), they failed to declare Al-Kibar to the IAEA. Intelligence collected by Israeli- operatives over some time determined that they were building a clandestine reactor at Al- Kibar in the remote desert of eastern Syria, near the Euphrates River. The facility was built in cooperation with North Korea and modeled after the Yongbyon facility.[8] Shortly after conclusive intelligence was gathered that proved the existence and purpose of the facility, a decision was made to execute a strike on the suspected plutonium production reactor. The IDF anticipated that the Syrians had not yet fueled the reactor, but that construction was complete and the facility was nearing operational capability. Recently released cockpit footage and photographs suggest that standard BDA means were sufficient for the circumstances encountered. However, had the Syrian's fueled the reactor or stored fissile material onsite, a method to confirm

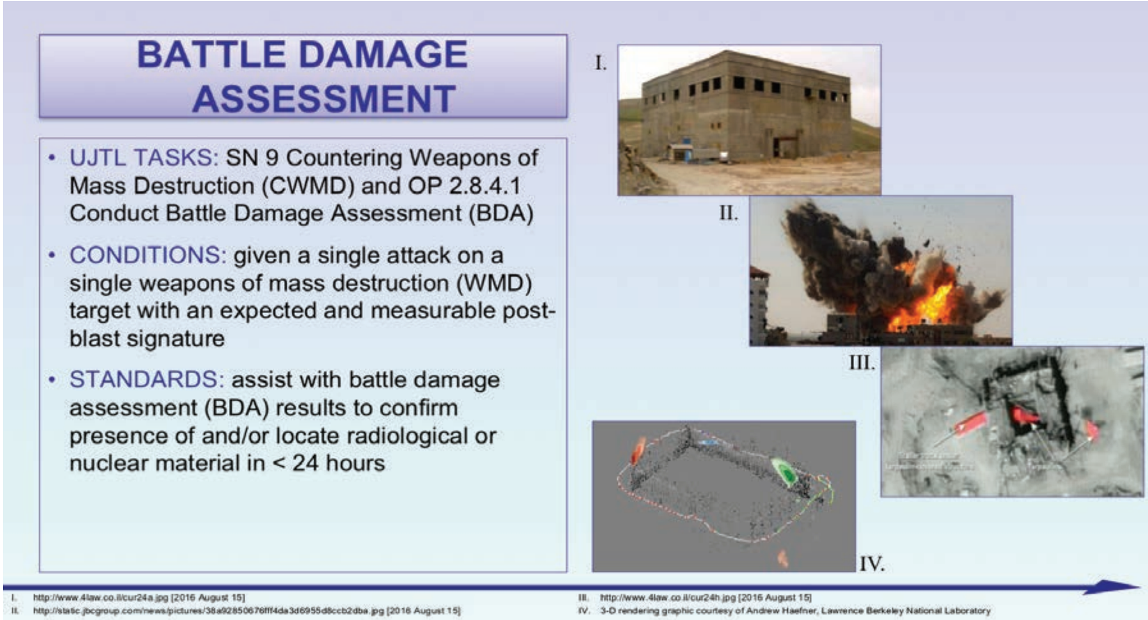

Figure 2: Battle Damage Assessment UJTL Task, Conditions, and Standards.[1]

or deny such a condition would be highly desirable.

The bombing of Osirak was conducted under similar auspices, though it is interesting to note that Iran attacked and initially damaged the site first in 1980, shortly after the outbreak of the Iran-Iraq war. However, due to concerns about spreading radioactive material, they did not attack the actual reactor building dome. Instead, they targeted the control room, research facilities, and adjacent centrifuge buildings. While both sides disputed the efficacy of the attack, Iran dropped nearly a dozen 500-pound bombs on the site resulting in severe damage to several buildings along with the plant cooling mechanisms. However, based on the reactor building remaining intact, suspected rebuilding efforts of the ancillary infrastructure, and the desire to send a message to Arab nations regarding the pursuit of nuclear weapons, Israel completed the mission and destroyed the reactor complex with an overwhelming strike in June of 1981.

While other remote sensing modalities may have informed targeteers that the bombing achieved the desired effect, it is unlikely that they were able to sense whether nuclear material was present at the site or if such material had been dispersed or otherwise released in conjunction with the bombing. The advantages of a remote sensing radiation detection platform that conducts BDA following a strike on a suspected nuclear or radiological target are numerous. First, the ability of a team of people to rapidly access the target area is likely to be far more limited. Second, the synchronization required to deploy remote platforms on target is far more flexible than that required to put BDA teams on the ground. Third, several remote platforms could easily be deployed to achieve redundant coverage, corroborate findings between systems, or investigate multiple targets.

The employment of remote sensing radiation detection platforms allows the commander to preserve limited critical resources, such as a force designated to recover weapons-usable material, until measurement confirms the presence of the material at a specific target. Furthermore, timely and accurate information gathered by a remote platform may have strategic

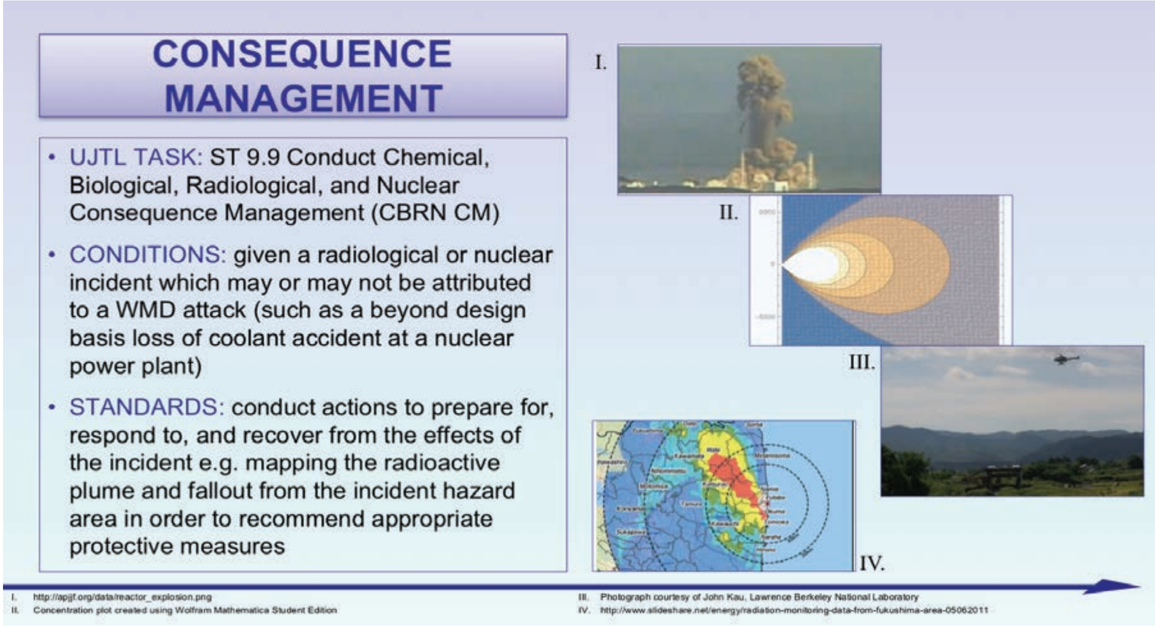

Figure 3: Consequence Management UJTL Task, Conditions, and Standards.[1]

messaging implications concerning the spread of radioactive contamination or the presence of materials which violate international treaties or agreements.

Consequence Management

The term consequence management comprises those measures taken to protect public health and safety, restore essential government services, and provide emergency relief to governments, businesses, and individuals affected by the consequences of a chemical, biological, radiological, nuclear, or high-yield explosive incident.[7] From a DoD perspective, there are several reasons to maintain the capability to conduct nuclear consequence management operations. First and foremost, the DoD possesses, operates, and maintains nuclear reactors and weapons that could be the source of the situation. Second, DoD forces could be part of those affected by the consequences of a nuclear situation. Third, the DoD could be called to assist civil authorities with executing the measures taken to protect the public, restore services, and provide emergency relief.

One only needs to look to the relatively recent past to find an example where autonomous, remote radiation detection could have proved invaluable to a consequence management situation; specifically, the significant release of radioactive cesium and iodine triggered by the massive earthquake and follow-on tsunami that occurred in Japan on March 11, 2011. While the reactors automatically shut down as designed immediately after the earthquake, the six external power sources to operate the cooling systems were lost and the tsunami that followed within an hour wiped out the emergency backup generators. Insufficient cooling to three of the reactors caused partial melting of the fuel and led to hydrogen gas buildup from high-temperature reactions with the zirconium cladding, which eventually triggered explosions in the containment buildings and an above-grade fuel cooling storage pond.

The release of an estimated 570 petabecquerel's (15.4 MCi) resulted in the government-directed evacuations of the area within 30 kilometers of the Fukushima Daiichi

Nuclear Power Plants. In support of the Japanese government, the U.S. Department of Energy aided in producing a survey of the initial contamination. Members of the combined team completed the survey with a combination of fixed and rotary-wing aircraft as well as various ground stations to provide calibration reference data. The first measurements flown near the Fukushima Daiichi Nuclear Power Plant took place six days after the earthquake and tsunami. The delay was caused by the time it took to deploy assets and obtain the clearance to begin work. While this was undoubtedly beneficial and the efforts of those who conducted the surveys should be commended, a small fleet of instrumented fixed-winged UAVs could have provided a more rapid response along with higher fidelity knowledge of the extent and deposition of contamination.

There are several aspects of the response that could have benefited from SUAS technology: plume/fallout characterization would have drove evacuation recommendations, full motion video would have provided a more complete view of the reactor site, and unmanned systems would have deployed much faster and flown closer to the source, limiting exposure to flight crews. "A significant problem in tracking radioactive release was that 23 out of the 24 radiation monitoring stations on the plant site were disabled by the tsunami."[9] With regards to ground stations, a handful of multi-rotor detection platforms would have provided a better representation of the average contamination for a given monitoring site rather than relying on measurements from a single position, owing to the inhomogeneous spatial distribution of the deposited radioactive material.

Remediation and recovery efforts represent an even broader application space. The government is allowing people to move back into areas that they have "cleared," often through hand-collected and recorded monitoring data. The alternative drone-based detection system could cover the same area in a shorter amount of time with sub-meter position resolution, and provide a detailed radiation "heat map" survey to residents to assure them that the area is safe as well as providing a baseline measurement record to monitor for change over time.

Accident Response

The priorities for the DoD response to U.S. nuclear weapon accidents are the location, security, and recovery of the weapon; the protection of lives and property; and remediation of the site.[10] Even though accidents involving nuclear weapons are particularly low occurrence events—just 32 documented U.S. "broken arrow" events since 1950—they remain a low-probability high-consequence event, even when taking modern safety design features into account.[11] While the high-alert nature of Cold War–era strategies, particularly Operation Chrome Dome, increased the probability of such events, the estimated 1,550 U.S. strategic nuclear weapons that could potentially be deployed under the New START agreement is a sobering fact that must be taken into consideration when planning a response to mishaps involving special nuclear materials.[12] Some of the tasks where an unmanned capability could prove useful are assessing the extent of the accident site, confirming or denying the release of radioactive material, mapping the radioactive contamination, locating aircraft or missile parts, locating nuclear material or weapons components, and verifying site remediation.

Two events that exemplify the need for a robust capability to remotely detect, locate, identify, characterize, and map radiological and

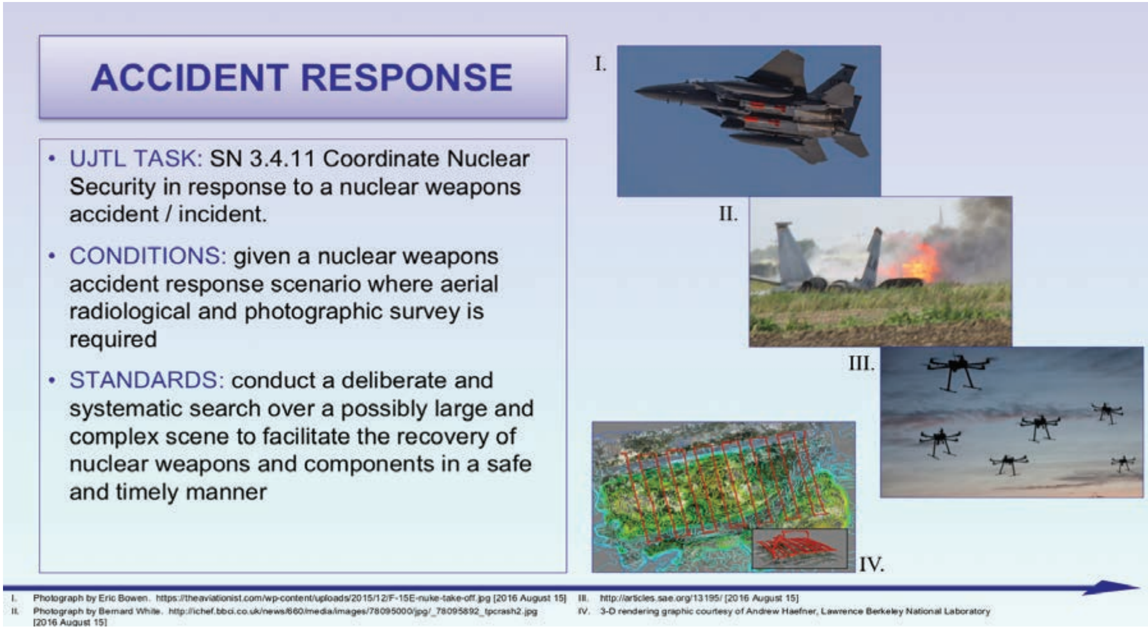

Figure 4: Accident Response UJTL Task, Conditions, and Standards.[1]

nuclear material and contamination involve U.S. Air Force bombers that crashed with nuclear weapons onboard during Operation Chrome Dome. The first was the crash of a B-52 during airborne refueling operations taking place near Palomares, a small fishing village on Spain's Mediterranean coast. The second involved the abandonment of a B-52 due to a fire in the cockpit. The crew was attempting to make an emergency landing at Thule Airbase in Greenland but became overwhelmed by the smoke.

Each accident required significant recovery efforts and involved personnel looking for bomb material in austere environments. In the Thule accident, four thermonuclear weapons were on-board, and radioactive material was released from the bombs upon impact and detonation of the high explosives, though a nuclear detonation did not occur. The recovery effort took months; sub-zero conditions and lack of daylight made the effort that much more difficult. The blackened snow from the burning of the aircraft fuel delineated the general search area. Officials estimated recovery of 94% of the plutonium and 85% of the uranium, as well as 2,100 m^3 of contaminated liquid which was shipped to Savannah River, SC for storage and processing. Nevertheless, if at the time they could remotely map the spread of the contamination as well as indicate potential hot spots, the recovery of the special nuclear material and contaminated snow and ice could have been more efficient and thorough. Large-scale human involvement would still have been integral to the recovery and cleanup effort. However, a remotely acquired map of the contaminated area with hot spots identified would have given those planning and supervising the operation valuable situational awareness and allow them to focus initial efforts in key locations. It would also give them better fidelity on the effectiveness of their removal efforts. Alas, these two events occurred before the advent and widespread use of global navigation satellite systems, though drones and remote sensing capabilities were on the rise at the time.

Current response procedures entail the use of fixed-wing aircraft for aerial photography and imagery collection for multispectral, hyperspectral,

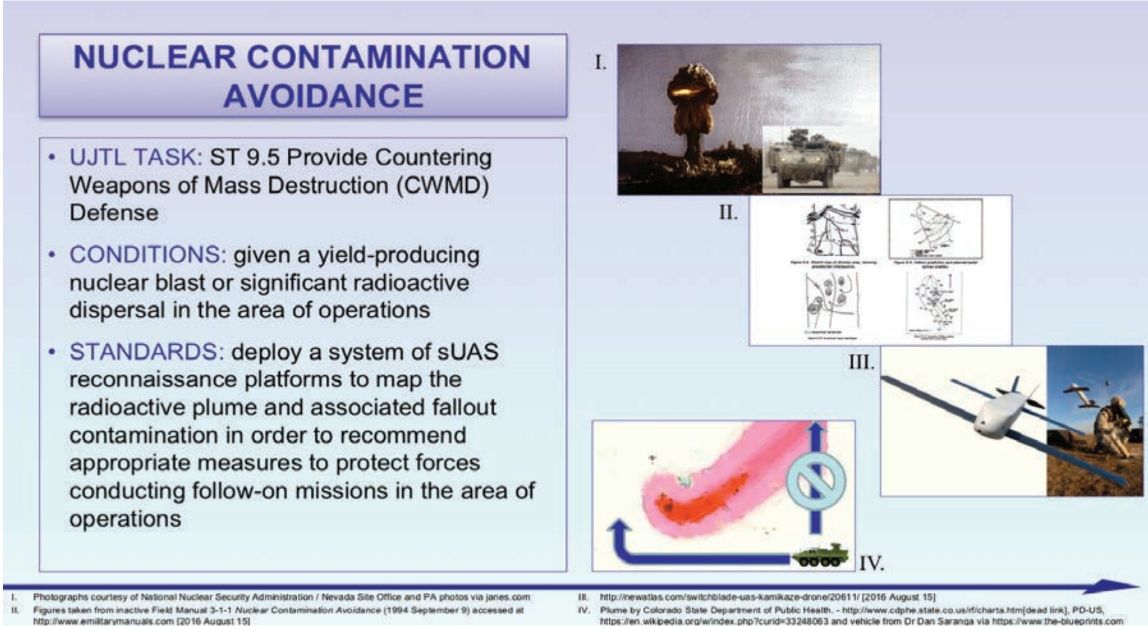

Figure 5: Nuclear Contamination Avoidance UJTL Task, Conditions, and Standards.[1]

and thermal images and previously discussed rotary-wing assets for aerial search and radiological mapping. There is also mention of a four-wheel drive vehicle with detectors capable of high-spatial-resolution mapping of contamination.[13] While we should not discount these capabilities and agree they still have relevance to the mission, they all require putting human operators into the debris field and do not provide the speed, fidelity, specificity, and coverage that a swarm of SUAS-based detectors flying close to the ground could. The essential take away is that the risk of accidents involving nuclear weapons still exists, yet the organizations responsible for the assessment, consolidation, recovery, disposition, and site remediation phases currently possess little or no capability to locate nuclear material and assess the spread of contamination by remote means.

Nuclear Contamination Avoidance

Limited nuclear warfare requires forces to be prepared to operate in and cross through a nuclear-contaminated area. A required supporting task is to conduct a terrain-oriented zone or route reconnaissance to plan a route that minimizes the radiation exposure to forces, subject to the constraints of other competing military factors.[14] Current doctrine employs either Chemical, Biological, Nuclear, and Radiological (CBRN) reconnaissance platoons or rotary-wing aircraft outfitted with dosimeters and survey meters. Current generation M1135 Stryker Nuclear, Chemical, Biological Reconnaissance Vehicles (NBCRV) are medium armored vehicles which use readings from a vehicle-mounted beta and gamma probe—the Army-Navy Vehicle or Dismounted Radiac-meter (AN/VDR- 2)—that measures dose rate and records accumulated dose.[15] There are efforts to integrate the data from the AN/VDR-2 with automated collection and mapping software, known as nuclear, biological, and chemical sensor processing group (NBCSPG), however, it is not currently fielded to CBRN units.

Although the threat of limited nuclear warfare may not be at the top of the list of the most likely conflict scenarios, it remains possible and is a driver of validated materiel requirements within the DoD. The potential benefits of developing an unmanned reconnaissance system for contamination avoidance are numerous: (1) reduce dose to personnel, (2) increase coverage area, (3) avoid terrain limitations, (4) allow CBRN personnel to conduct other missions, (5) lower cost, and others. A UAV could even be launched from an M1135 Stryker NBCRV.

While accurate meteorological data and dose rate level of specificity may be enough to plan a route, the requirement to use manned armored vehicles or aircraft to probe the contours of a high radiation area is nonsensical. One could easily outfit NBCRV with one or more small, tube-launched, fixed-wing unmanned aerial systems with onboard sensors optimized for aerial monitoring of radioactive plumes and fallout. Moreover, the sensor for chemical, biological, and meteorological information requirements could potentially be integrated into the same platform, thereby streamlining and modernizing the reconnaissance and collection capabilities of CBRN units.

The potential benefits of such a system are numerous. First, the idea of sending a $5M-vehicle with a crew of four highly trained, low-density personnel to gather dose rate information to help protect the rest of the force is archaic. The DoD can, and certainly should, have a capability beyond this 1930's chemical warfare-based approach. In fact, during the nuclear weapons testing conducted as part of Operation Crossroads in 1946, drone aircraft and boats were used to assess the radiation intensities before anyone was permitted to enter the area following a detonation.

Second, aerial collection, while not immune to becoming contaminated, offers a far better option in terms of reducing contamination to the vehicle and sensing instruments and is much easier to decontaminate. That is, the 21-ton vehicle kicking up dust and debris while traveling through the contaminated area is far more likely to become inundated with contamination and therefore systematically over-estimate dose rates because of the near field effects of radioactive particles stuck to the vehicle. It is also much easier to decontaminate or abandon equipment costing ~$100k with a surface area < 0.5 m^2 than it is to do the same with a $5M vehicle with a surface area greater than 75 m^2.

Third, a small, unmanned aerial system is a much lower priority target for enemy engagement than an armored reconnaissance vehicle. While an unmanned aerial system is still susceptible to enemy fire and countermeasures, a peculiar-looking group of armored vehicles traveling in and around the vicinity where a nuclear weapon was employed is much more likely to attract a lethal enemy response. The loss of one M1135 Stryker NBCRV, not including the personnel, specialized equipment, armament, and ammunition, represents at least 50 SUAS.

Even so, this integration effort is not quite as simple as mounting a dosimeter on a UAV and calling it a capability. Some excellent work in pursuing an initial capability, including autonomous search, was carried out by investigators at the Johns Hopkins Applied Physics Laboratory (APL). Unfortunately, the work was not pursued further by the sponsor and a true capability never made it through the research and development "valley of death" into the hands of a user.

Further tasks in designing such a system would include (1) developing the radiation detection element so that it provided an adequate

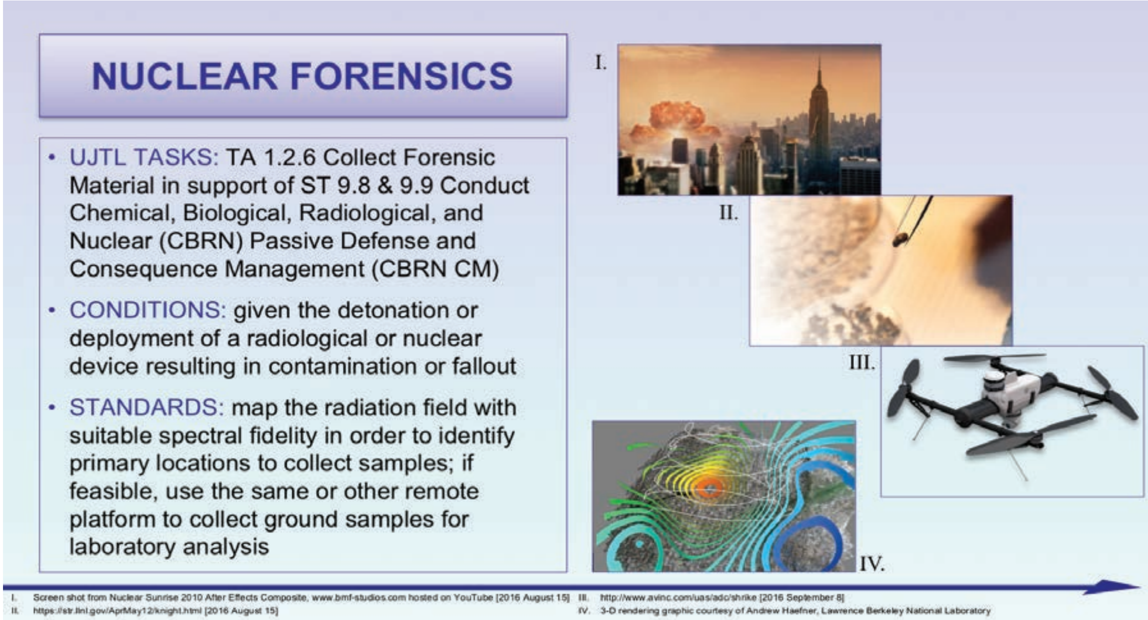

Figure 6: Nuclear Forensics UJTL Task, Conditions, and Standards.[1]

response across the entire range of possible radiation environments while optimizing it for the most likely, (2) engineering the system from radiation hardened electronic components, and (3) ensuring the range, duration, and recovery of the system meets or exceeds threshold user requirements, and (4) integrate the data from the multiple radiation sensors into a situational awareness tool.

Nuclear Forensics

Nuclear forensics is the examination of nuclear and other radioactive materials, either pre- or post-detonation, using various collection methods and analytical techniques to determine the composition, origin, age, and history of a material.[16,17] Arguably the most advanced capabilities in remote sensing of radiation reside within the field of nuclear forensics. Most government research on pre-detonation capabilities focus primarily on nonproliferation and monitoring efforts. In monitoring for nuclear testing, the source term is generally located deep underground and very little of the fission products make it out into the atmosphere unless there is a major malfunction during the test; or a nation could decide that it is necessary and prudent to conduct atmospheric testing of their nuclear weapons, which makes forensic collection easier. Such a capability has been demonstrated as a bolt-on pod with the collection and measuring systems integrated onto a UAV.[18]

However, we do not possess an advanced capability to collect materials for post- detonation nuclear forensics. Should a nation-state or violent extremist organization detonate a nuclear device in the U.S. or one of our partner-nations, our response policies dictate the collection and measurement of forensic materials from the nearby fallout area to attribute the device or fissile material to a source, especially when it is not readily evident or needs to be confirmed. An unmanned system would be very beneficial but would likely have the most demanding environmental and design constraints of all the mission areas. Not only would it need to operate in a complex and high radiation setting, like that of a contamination avoidance mission, it would

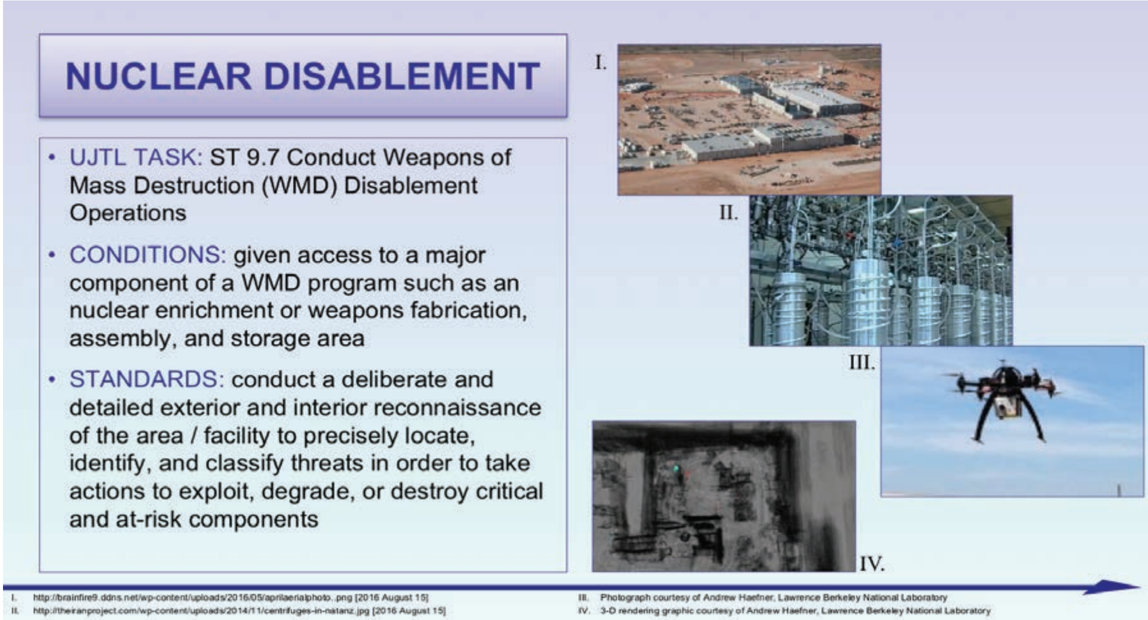

Figure 7: Nuclear Disablement UJTL Task, Conditions, and Standards.[1]

also need to be capable of excellent specificity and localization in a highly inhomogeneous environment. Current efforts are focused on using swarms of UAVs to characterize a debris field to direct follow-on forces to auspicious collection areas with lower dose rates.[19]

These requirements point to a very sophisticated radiation sensor package, likely using cutting edge detection materials such as GaGG, which has excellent timing characteristics for high count rate environments, medium energy resolution for isotope identification and characterization, and it can be finely pixelated for imaging applications. Other potential detection materials include LaBr3. Current semiconductor materials would likely incur significant dead time as well as crippling radiation damage.

Nuclear Disablement

This mission area is a bit nebulous but is somewhat aligned with consequence management and environmental monitoring. Nuclear disablement includes those operations associated with the assessment and handling of supporting nuclear infrastructure that might be encountered or targeted as part of military actions in a given area of operations. Most likely this involves the safe shutdown of enrichment or reactor facilities, securing materials not yet assembled as a weapon, and any other tasks that fall into the category of nuclear-related, excluding weaponized or deployed systems.[12]

Current capabilities reside in small teams of military personnel (~15 personnel) with specialized training in the operation of such facilities, and a limited amount of hand-operated or vehicle-mounted detection equipment. Due to the uncertain nature of the mission, location, and conditions, most tasks are completed by hand. However, teams usually conduct an initial survey of a facility using either a small, all-terrain vehicle, a vehicle-towed trailer system, or a helicopter, outfitted with a set of large directional gamma and thermal neutron detectors.

The scale of facilities like a centrifuge plant is on the order of a square kilometer or more. This

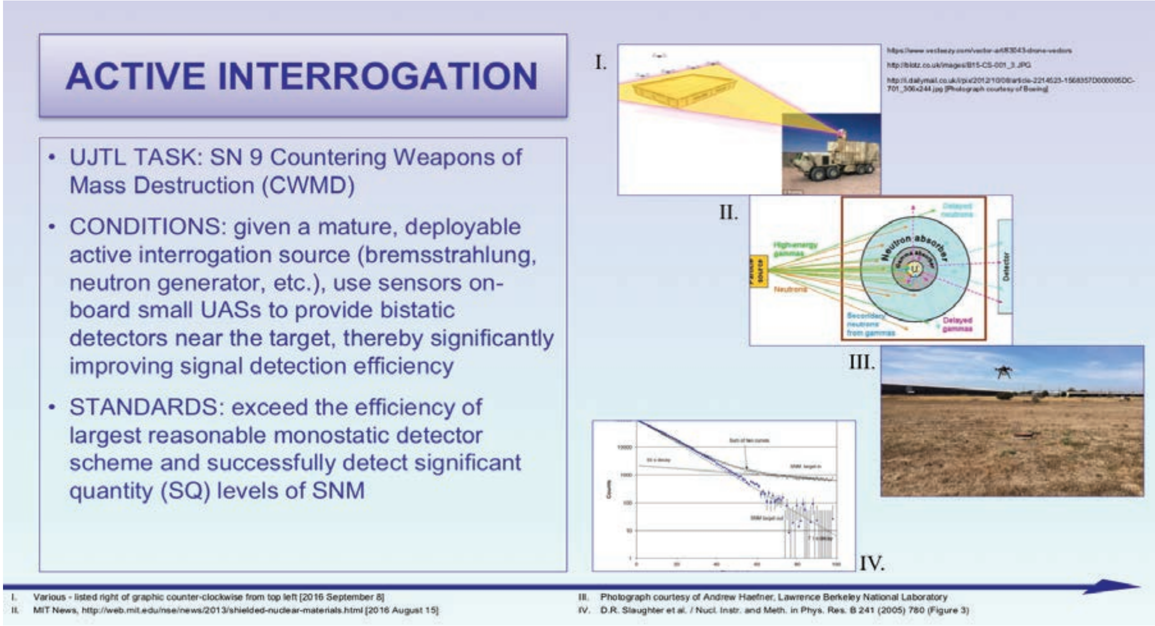

Figure 8: Active Interrogation UJTL Task, Conditions, and Standards.[1]

vast area presents a challenge to small nuclear disablement teams that are quickly triaging a vast site to identify and classify threats in order to take actions to exploit, degrade, or destroy critical and at-risk components. While these operations are likely to take place in a semi- permissive environment, an area protected by a security force or with a negligible threat, nuclear disablement forces could also be high-value targets for snipers or insurgents in the area. A small number of autonomous radiation sensors could prove invaluable for deliberately conducting exterior and interior reconnaissance of the facility. These sensors would relieve a good portion of the NDT members from swinging a meter and free them to use their human sensors—primarily their eyes and ears coupled with their intellect and training. Anyone who has operated a radiation detector in the field recognizes the tunnel vision that goes along with it and how difficult it is to conduct other tasks simultaneously. Moreover, an autonomous capability does not rule out the need to maintain a certain level of human-operated equipment or other specialized detectors. It merely acts as a combat multiplier by alleviating a monotonous task that drains personnel resources for a good portion of the initial phase of an operation.

Active Interrogation

Active interrogation involves directing neutrons or high-energy photons toward a target and measuring the secondary radiation to gather information about the target. Government agencies have expended tens of millions of dollars or more on active interrogation projects since 2001. Whether the method includes a sizeable bremsstrahlung source, a pulsed neutron source, or some other novel source, such as cosmic muons or a photon beam driven by laser- wake field electron acceleration, they all suffer from one common limitation: the signal they induce, while unique and identifiable, obeys the same inverse square law as the passive signal and is therefore difficult to detect at any operationally significant range.[16]

While several schemes also have issues with delivering potentially harmful doses to humans, both to the operator as well as persons within the screening area, the biggest hurdle is the need for large detectors often located away from the interrogation source; known as a bi-static or bicentric arrangement. So, not only is a trailer-sized source required, but one or more trailer-sized detectors must be arranged around the target but away from the source as to not be washed out by the source signal. This *sine qua non* is insupportable for most military applications, aside from using the source as a directed energy weapon.

However, continuing research could provide more compact sources that deliver an acceptably-low dose to operators and potential bystanders within the target area. Couple that to a detection platform that is small, autonomous, remote, and has a sensor with high energy resolution and imaging capabilities, and a tractable concept of operations begins to emerge. That is, a suite of remote detectors could be flown, dropped, or launched to locations on or around the target of interest, thereby significantly decreasing the detector size required to achieve the same sensitivity. With this reduction in detector size, employment of high-resolution detection materials becomes feasible, thereby improving specificity and reducing the minimum detectable amount of material. Moreover, the use of a position- sensitive arrangement of detectors, from simple occlusion up to a pixelated Compton imaging array, is conceivable and could provide additional information regarding the quantity, location, and arrangement of material being interrogated.

Summary

The identification of capability gaps and the prospect of filling one or more of them is the primary motivation for this article. It appears that the technology is available and the tools to engineer a solution exist. There are several mission areas that could benefit from an unmanned approach to radiation detection. The intent is to get detectors out of the hands and off of the backs of warfighters and move them closer to the sources of interest. It is a matter of systematically analyzing the threat-space and developing a solution to overmatch it. The mission areas introduced in this article illustrate various conditions that might dictate different approaches. However, there are likely to be overlaps and synergies that exist between several missions that would permit adaptable or modular multipurpose design approaches that employ the same or similar unmanned platforms, sensors, search schemes, or algorithms.

Of course, there are engineering challenges that must be overcome and trade-offs that need to be weighed when designing such a system of systems for these applications. The two chief concerns are the optimization of the sensor package and the development of the search method. The choice of detector materials, the quantity and arrangement of detector elements, and the selection of auxiliary sensors are paramount in developing a system that can detect relevant threats under a given set of conditions. Beyond that, the effective employment of a group of systems requires detailed analysis of individual search patterns, collective coverage schemes, and cooperative detection algorithms.

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CBRN Survivability: Defining a CBRN Mission Critical System

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Designating a chemical, biological, radiological, and nuclear (CBRN) Mission Critical System (MCS) is a simple task with the correct information. Army and Marine land-based systems face the threat of CBRN attack or operating in contaminated environments where compliance with CBRN survivability requirements is important. CBRN MCS designation is common for major land-based systems but even non-major systems providing mission critical operations support need CBRN survivability protections. This article addresses the importance of the designation, definition, and CBRN survivability requirements for CBRN MCS.

The Importance of CBRN MCS Designation

Ever Growing Threat. Advances in manufacturing, computer processing, and speedy electronic data transfer increases force vulnerability as the threat of weapons of mass destruction (WMD) use grows. Nuclear and chemical survivability requirements began after World War II and continues to today. Following the demise of the Soviet Union in 1991, nuclear and chemical survivability priorities waned. Subsequently, by the early 2000s, preparing to fight dirty (in a contaminated environment) was merely a holdover requirement from the Cold War. Pressure for fielding newer warfighting capabilities was a higher priority than ensuring that the new warfighting capabilities be tested and evaluated for CBRN survivability. Program Managers (PM) commonly used CBRN survivability requirements as quick trade space for recovering program cost and schedule delays. Times have changed as the WMD threat from great power adversaries and new nuclear capable rogue states is rising.

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North Korea became nuclear capable in October 2006[1] and Iran is still pursuing nuclear options following the failed Joint Comprehensive Plan of Action meant to delay Iran's nuclear capabilities.[2,3] The U.S. believes China will double its nuclear stockpile over the next decade.[4] Additionally, China is challenging international trade lanes in the South China Sea, exploiting resources of other nations, and modernizing its nuclear capabilities.[5] Russian aggression is growing as demonstrated in part by their annexation of Crimea. Pundits purport that even deterrence toward peace is drawn into question considering Russia's doctrine to escalate to de-escalate.[6] Russia's doctrine makes the unthinkable possible when one considers regional limited nuclear engagements versus the old deterrence paradigm of mutually assured destruction. The heady days of post-Cold War WMD defense peace-dividends are over. Evidence of growing WMD threats include advances in WMD technology, adversary nuclear stockpile modernization, spread of global industrialization with on-demand chemical and biological manufacturing capabilities, eroding taboos on the use of WMD, the dissolution of strategic arms treaties,[7] additions to nuclear capable rogue states, and increasingly lethal violent extremist organizations. All these factors combine for unprecedented levels of increasing CBRN threat in the 2020s and beyond.

CBRN Survivability as a Deterrent. U.S. CBRN survivability protections serve to deter an adversary's use of WMD when credible and well-communicated in both words and actions. U.S. intent to fight in CBRN environments and have survivability protections is clear in published strategies and doctrine. The 2018 Nuclear Posture Review[8] and 2018 National Security Strategy[9] outline the importance of CBRN survivability. Defense strategic studies pundits reason that U.S. preparation and planning to fight against WMD serves to deter less prepared adversaries from engaging with WMD.

Winning the War. Success in nuclear conflicts and chemical, biological, and radiological (CBR) contaminated environments is critical to winning WMD engagements and overall mission accomplishment. When the U.S. force enjoys conventional superiority, near-peer competitors and rogue states may be more inclined to use WMD to "level the playing field." Weapon systems must be nuclear hardened in order for commanders to have confidence in their operability should nuclear weapons be used in a regional conflict. Following the use of a WMD, technical over-match is reduced when U.S. systems aren't protected from high-altitude electromagnetic pulse (HEMP) or shielded from chemical contaminants (chemical agent resistant coating (CARC) paint). Despite the best efforts of the Organisation for the Prohibition of Chemical Weapons (OPCW), conflicts in the Middle East and Ukraine have demonstrated that tactical use of chemical warfare agents is no longer taboo.

Operational tempo declines without materiel contaminant protection, also known as CBR Contamination Survivability (CBRCS). Even though individual protection equipment may be used to avoid lingering lethal agents, clouded optics impede ability to target and navigate, moving parts seize, and system sustainability declines due to accelerated corrosion.

Nuclear survivability is important to equipment crews that may not survive initial nuclear weapon effects long enough to complete a mission. Electronic devices and weapon systems may stop working when an electromagnetic pulse (EMP) power surge destroys advanced electronic circuitry disabling controls, targeting, movement, sensing, and communication systems.

CBRN survivability protection is vital for winning on a contaminated battlefield. In WMD environments, competitive advantage relies on hardened CBRN MCS. CBRN survivability is best addressed early in the materiel development process through well-defined requirements and detailed test and evaluation master plans. If evaluated materiel performance proves inadequate, remedies to meet survivability needs can be developed. USANCA assists materiel developers with survivability requirements to ensure mission success in the field.

DoD and Army Policies Require CBRN Survivability. The Secretary of Defense recognizes the importance of CBRN survivable systems and requires all CBRN MCS be compliant with survivability requirements. CBRN survivability requirements are documented in DoD policies: Department of Defense Instruction (DoDI) 5000.02 "Operation of the Defense Acquisition System" 26 Nov 2013, Joint Capabilities Integrated Development System Manual 31 Aug 2018, DoDI 3150.09 "CBRN Survivability Policy" 31 Aug 2018, Joint Publication 3-11 "Operations in CBRN Environments" 29 Oct 2018, and the electronic Defense Acquisition Guidebook available on the Defense Acquisition University website. CBRN survivability requirements are also documented in Army policies: Army Regulation (AR) 70-75 "Survivability of Army Personnel and Materiel" 29 Apr 2019, AR 15-41 "CBRN Survivability Committee" 8 May 2018, and AR 750-1 "Army Materiel Maintenance Policy" 12 Sep 2013.

Defining a CBRN MCS

Understanding the appropriate definitions and guidance is important in determining when a system needs the CBRN MSC designation.

DoDI 3150.09 defines a **MCS** as "a system whose operational effectiveness and operational suitability are essential to successful mission completion or to aggregate residual combat capability. If this system fails, the mission likely will not be completed. Such a system can be an auxiliary or supporting system, as well as a primary mission system."[10]

DoDI 3150.09 further defines **CBRN MCS** as "a MCS with operational concepts requiring employment and survivability in CBR environments or nuclear environments."[11]

AR 70-75 defines **mission critical** as "a system whose operational effectiveness and operational suitability are essential to the successful completion/outcome of the current or subsequent combat action; a system used by Soldiers on the battlefield to perform their primary or secondary functions. Loss of the system could result in an unfavorable outcome of the combat action."[12]

AR 70-75 goes further to define **critical system functions** as "those functions that the system must perform in order to carry out its intended mission" and **critical system characteristics** are "those design features that determine how well the proposed concept or system will function in its intended environment."[13]

Military Standard (MIL-STD) 3056 "DoD Design Criteria Standard for Chemical, Biological, and Radiological (CBR) System Contamination Survivability" (23 Nov 2016) defines CBR MCS as “a MCS with operational concepts requiring employment and survivability in CBR environments.”[14]

Additionally per DoDI 3150.09, all Acquisition Category (ACAT) 1 programs with a mission critical system expected to operate in CBRN environments must be designated CBRN MCS and must be CBRN survivable in accordance with the applicable key performance parameters (KPPs).[15] KPPs under JCIDS are mandatory for a Milestone Decision Authority’s approval to field a new capability. Note: DoDI 3150.09 ACAT 1 policy does not exclude non- ACAT 1 programs from being designated a CBRN MCS. The Army policy per AR 70-75 does not make a CBRN MCS distinction based on size of the ACAT program. For CBRN MCS determination, analysis includes mission criticality, threat of CBRN environments, and mission profile.

Designating a CBRN MCS

Capability developers (CAPDEVs) answer several questions when determining whether a new capability should be designated CBRN MCS. *Is the system mission critical? Will the system be used in CBRN environments? What is the mission profile? Should the system be designated a CBRN MCS?*

Is the system mission critical? Most major ACAT 1 systems are mission critical or they would not be needed in the field. Support systems to major MCS may also be mission critical. Mission criticality determination for support systems is based on the definition of mission critical but excludes high density, low-value, expendable unit pacing items (e.g., water bottles).

MCS designations are commonly applied to major tactical, operational, combat, and command systems. Examples of MCS weapons systems include: main battle tanks, tactical fighting vehicles, attack helicopters, radar systems, missile systems, and other defense systems. Key MCS logistic support systems (i.e. power generators) essential for major MCS mission effectiveness and sustainment, require the CBRN MCS designation. Major tactical support equipment should also be designated CBRN MCS. An example of major tactical support equipment includes the use of bulldozers in support of the employment of main battle tanks as these bulldozers are critical for protection construction and mobility. Smaller items like a remote-powered concrete saw may not require nuclear survivability or CBRN MCS designation.

The program size does not determine CBRN MCS designation for annual compliance tracking and reporting purposes as requirements must still be met to address CBRCS. CARC paint or use of a chemically hardened tarp may be enough to meet CBRCS requirements. Trailers are commonly used to haul equipment although when that trailer has the option of mounting a machine gun or attack drone control system, the trailer becomes a MCS due to the optional mission profile. Mission profiles determine whether a system requires nuclear survivability.

Examples of systems not requiring CBRN survivability include: training systems for peacetime use, cyber software solutions, and small expendable items and planning tools. A note of caution, when a software solution performing mission critical functions or support functions moves to a dedicated computer system, the software exemption will not apply to the hardware.

Will the system be used in CBRN environments? The first indication that a system

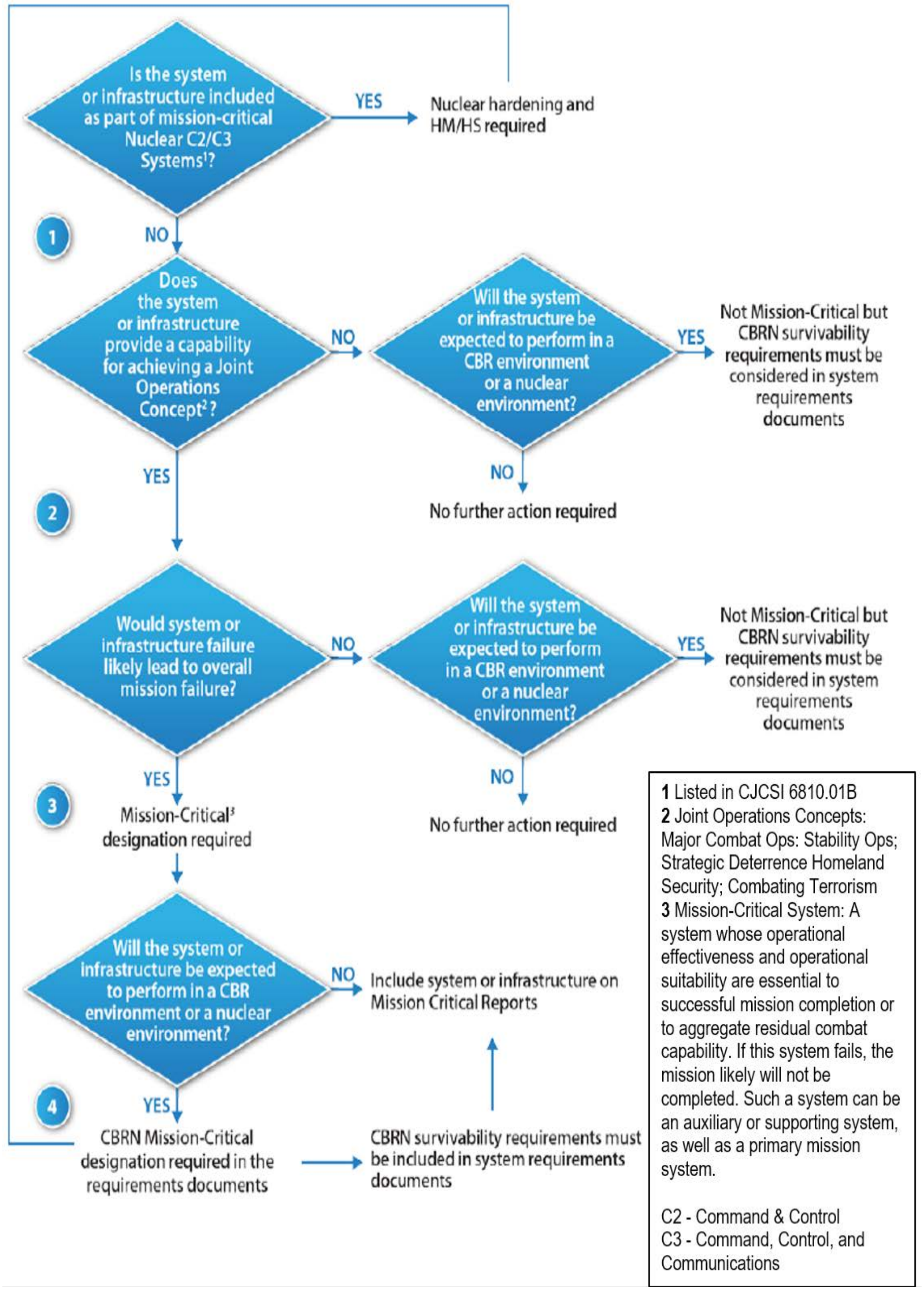

Figure 1: CBRN MCS Decision Tool from DoDI 31050.09[16]

needs CBRN survivability protection is when the threat section in the development requirements documents mention CBRN. In general, land-based Army systems operate under the threat of CBRN environments. Therefore even water storage bladders qualify as a potential CBRN MCS because of the need to protect the potable water supply from contamination.

A common misconception is that CBRN MCS subsystems are sheltered from CBRN environments. In reality, subsystems are not likely to be protected as the larger systems are not required to protect add-on subsystems (e.g. sensors, detectors, computers, and radios). As a result, computer hardware needs CBRN survivability protections. Acceptable computer system protection may be a hardened carrying case and EMP-shielded cabling for some commercial-off-the-shelf equipment.

What is the mission profile? A capability developer (CAPDEV) may designate their system as mission critical, but then be tempted to not designate the system a CBRN MCS. The mission profile describes whether system or subsystem performs mission critical tasks. Most systems that perform mission critical functions and operate under CBRN threat will be designated a CBRN MCS. Mission profiles for systems performing command, control, communications, combat, reconnaissance, or navigation functions require a CBRN MCS designation. Examples of mission critical systems with these mission profiles include: missile defense, radar, weapon systems, reconnaissance, radios, intelligence, defense satellites, and Global Positioning Systems (GPS).

Systems used exclusively for peacetime training, planning, modeling, and analysis are exempt from the CBRN MCS designation. Many commonly used logistic support systems have mission profiles with important mission critical support functions. For example, generators that enable MCS to operate are CBRN MCS because command and control functions fail without power. Soldier survivability can be severely impacted in a water depleted environment. Thus, water storage and distribution systems are critical for mission success and should have CBRN protection but don't necessarily have to be designated as a CBRN MCS as they are not required for the immediate fight and may be readily replaced.

If an aviation platform is an Army weapon system, the platform is mission critical and must have the ability to operate under WMD threat. An attack helicopter's mission profile as a weapon system requires it to be a CBRN MCS whereas a dedicated transport helicopter is not a CBRN MCS. Nuclear survivability requirements for a helicopter are significantly lower than that of a main battle tank, but having an adequate level of CBRN survivability protections to complete an attack mission is important.

Should the system be designated a CBRN MCS? The CAPDEV is tasked with determining the initial CBRN MCS designation. Their decision will be reviewed by the DCS G-3/5/7 for verification and validation. A CAPDEV's decision to dismiss CBRN survivability requires analysis based upon mission profile and CBRN operational threat. CBRN MCS designation disagreements are elevated for informed senior leader involvement and resolution. CAPDEV and PM understanding of CBRN survivability requirements is crucial to determining CBRN MCS designation. Figure 1 presents a determination flow chart to assist with system designatation as a CBRN MCS.

Requirements for CBRN MCS

Army Regulation (AR) 70-75 sets CBRN survivability requirements for Army CBRN MCS. The regulation states that "all CBRN MCS must be CBRCS and that CBRCS is provided in large part by the CARC system".[17] CARC paint is also required in AR 750-1.[18] If the CBRN MCS or component is electronic, the system must be able to survive a HEMP and electronic attack. CBRN MCS weapon systems and included mission critical components must survive initial nuclear weapon effects (INWE). Protections from INWE include blast, thermal radiation, initial nuclear radiation, and source region electromagnetic pulse (SREMP). *Importantly, AR 70-75 states the use of critical commercial-off-the-shelf or Non-Development Item does not grant relief from the need to meet CBRN MCS requirements.*[19]

CBRN MCS that either fail or partially meet contamination or nuclear survivability test requirements, must obtain an approved waiver by DCS G-3/5/7. This must occur prior to a milestone decision authority review transitioning the item from development to fielding. The PM must submit a waiver package to the CBRN survivability committee (CSC) for consideration and recommendation for final DCS G-3/5/7 approval per AR 70-75 and AR 15-41. The package should consider a remedy to address shortcomings by one or more of the following; hardening by redesign or retrofit, sparing by adding protected on-board spares for components likely to fail, redundancy through fielding plans that include multiple back-up units or systems, or operational tactics, techniques, and procedures (TTPs) that could protect the system including storing or sheltering in a shielded area. Other examples include adding a protective tarp, extra shielding, temporary pre-contamination sprays, or stocking of extra back-up systems. Testing and evaluation of survivability performance is important because without testing, a PM's waiver or get-well plan will have little evidence to support DCS G-3/5/7 approval. Conducting initial CBRN survivability testing at the end of a program's development prior to a pending milestone decision to field the item, adds avoidable program cost and schedule risk. A further waiver discussion, in accordance with AR 15-41, will be presented in a future WMD journal article detailing ways to comply with CBRN survivability requirements.

A CBRN MCS must have a maintenance and sustainment program plan for both CBRCS and nuclear survivability when it has been approved for fielding. All CBRN MCS require CBRCS sustainment in accordance with appropriate preventive maintenance checks and service (PMCS) program found in AR 750-1.[20] CBRCS maintenance typically amounts to inspection and CARC paint touch-up, but may also involve replacing gaskets or other less durable materials. For nuclear survivability sustainment of electronic and weapons systems, a system hardness maintenance and hardness surveillance (HMHS) program plan is required per AR 750-1.[21] A good HMHS plan will periodically check nuclear survivability protections to determine the effects of weathered aging and major platform retrofits or add-ons.

DoDI 3150.09 establishes the Army's CBRN Mission Critical Report (MCR) for readiness assessment.[22] The MCR reports the status of CBRN MCS CBRN survivability. Additionally, AR 15-41 requires system managers to annually provide CBRN MCS compliance status to the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA(ALT)). The ASA(ALT) prepares the Army's CBRN MCR which is formally approved by DCS G-3/5/7 prior to submitting to the Secretary of Defense.

The Challenge of CBRN Survivability

Incorporating CBRN protections into a new capability may be challenging and should be addressed early in the acquisition process or mission success can be compromised. If our fighting force is perceived as vulnerable to CBRN effects, conventionally under-matched opponents will see WMD use as an opportunity to equalize forces or gain superiority.

The mid-tier acquisition (MTA) approach used with the Army's latest high-priority capabilities development programs, delivers cutting edge off-the-shelf technologies with the intent to rapidly field in under 5-years.[23] The challenge is ensuring CBRN survivability concerns are addressed. The first step is properly designating systems as CBRN MCS. The next step is assigning the right CBRN survivability requirements; contact USANCA for assistance. CBRN survivability performance should be tested and evaluated early in development. Without adequate testing, there is no way to know the system survivability performance or development options needed to remedy shortcomings.

The initial cost to get CBRN survivability requirements into a system is estimated to be 1% of program cost if included early in the acquisition process. Though costs can be higher for more sophisticated electronic systems such as missile defense and radar, the initial costs are still minimal and estimated to only be 2-3% of program cost.[24] Incorporating CBRN survivability protection requirements into a system after initial fielding can incur significant impacts to the program.[25]

Army CBRN MCS Observations

In general, CBRCS is easily met by using CARC paint. The cost of CARC paint for defense contractors is comparable to similar quality commercial paints. CARC offers dozens of other superior properties (e.g. durability, signature masking, corrosion control, quality control, and pedigree) making it a clear choice over commercial paints.[26] Many smaller electronic devices come with a robust amount of HEMP protection due to commercial electromagnetic spectrum and interference standards.[27] Testing handheld electronics to HEMP per MIL-STD-2169C affords evaluation of off-the-shelf nuclear survivability and adding more protection if needed.

Senior leaders, capability requirements writers, and materiel developers need to be informed about CBRN survivability requirements to ensure that the Army is ready and able to fight and win in CBRN contaminated environments. Lack of awareness or ambiguous requirement writing can discourage capability developers from designating their system as a CBRN MCS. Consideration of system mission profile and possible CBRN threat drives CBRN requirements. Addressing CBRN survivability requirements will not happen without stakeholder familiarity with CBRN survivability compliance. Incorporating CBRN survivability protection requirements early in the development process is the best way to ensure the U.S. Army is able to fight and win future WMD conflicts.

If you have questions regarding CBRN MCS designation or CBRN survivability requirements, please contact USANCA's CBRN Survivability Program Manager.

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Complexity on the Modern CBRN Battlefield
Warfighter 19-4: Protection Warfighting Forum

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"Protection is the preservation of the effectiveness and survivability of mission-related military and nonmilitary personnel, equipment, facilities, information, and infrastructure deployed or located within or outside the boundaries of a given operational area (JP 3-0)." ADP 3-37 Protection, 11 December 2018 page iv.

The 21st Century Battlefield has only grown more complex for Joint Force operations, including US Armed Forces and its Allies. This fact was prevalent during Warfighter Exercise (WFX) 19-4 conducted from 6 – 15 April 2019, led by III Corps Headquarters in multiple locations; including Fort Hood, Fort Riley, and Fort Leavenworth. WFX 19-4, along with other exercises, are designed to facilitate the transition of the US Army's focus from counterinsurgency to large-scale ground combat operations.[1] While the focus of this Warfighter exercise was on ground maneuver forces, the adversary's use of ground forces and technology demonstrated near-peer capabilities. As stated in the 2019 National Defense Strategy, "this increasingly complex security environment is defined by rapid technological change, challenges from adversaries in every operating domain, and the impact on current readiness from the longest continuous stretch of armed conflict in our Nation's history."[2] Advancements in ballistic missile technology, unmanned aerial vehicles (UAV)/drones, artificial intelligence (AI), miniaturization of manufacturing/3D printing, and increased ease of access to biological weapons have brought the threat of Weapons of Mass Destruction (WMD) within range of the United States. With these advancing technologies, adversaries will develop new or revolutionary employment methods that may not follow former Soviet Union CBRN employment. A recent US Army TRADOC publication describes this threat with, "advances in weapons of mass destruction, including the development of a range of nuclear payloads, advanced chemical weapons employing new technologies and understanding of chemistry and chemical engineering, and perhaps most significantly, biological weapons, present a devastatingly lethal and disruptive WMD threat profile."[3]

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Warfighter 19-4

During WFX 19-4, the complexity of CBRN hazards and threats were highlighted, especially for the III Corps Protection Warfighter Forum (WfF). This article will summarize three complex CBRN vignettes the Joint Force encountered on the battlefield and their response in addition to the adversary striking the Joint Force Area of Operations (AO) periodically with both persistent and non-persistent chemical munitions. These vignettes demonstrate that not all answers are in a manual. On the battlefield, when CBRN is added to the fight, there are no easy answers. WFX 19-4 provided a sample of what could be encountered on a future battlefield.

In a near-peer conflict, US forces will fight as a coalition and include longtime allies such as the United Kingdom, Australia, Canada, New Zealand and NATO.[4] To be a successful coalition, these forces must be compatible and integrated from deployment to re-deployment and throughout combat operations. In future conflicts, the Joint Force will not likely have the time to build and train a multi-national coalition prior to combat operations. Coalition forces must already be familiar with each other's capabilities and limitations before entering the AO. Integration was one major objective for WFX 19-4. A Mission Partner Environment (MPE) system integrated all of the exercise units by using Command Post Computing Environment (CPCE) software to communicate and battle track formations. The same system was used across all three III Corps field elements and subordinate units that participated in the WFX. This allowed III Corps to operate as a single element and enabled large-scale ground combat operations during the adversary's use of WMDs.

WFX 19-4 Road to War

An adversarial country (Redland) invades a neighbor (Blueland), a US and UK ally. In response, the three countries' militaries deployed to halt the Redland offensive. III Corps Headquarters, with two divisions (one US and one UK) deployed as part of a coalition to attack into the nation of Redland. III Corps tasks include: 1) conduct a deliberate attack, 2) secure multiple wet-gap (river) crossing sites, 3) deplete a Redland Corps equivalent (four Divisions), and conduct passage of lines with follow-on forces.

CBR Vignette #1 (Radiological)

Early in the scenario, as the Joint Force maneuvered into Redland, a civilian suffering from radiation exposure approached some Soldiers. The civilian was forced to by Redland to manufacture Radiological Exposure Devices (REDs). At the time of this event, the RED manufacturing facility was in Redland's rear area. The Protection WfF assessed the RED threat to the Joint Force and in conjunction with the other III Corps staff elements (Provost Marshal, Corps Surgeon, JAG, and Department of State Liaison), developed a warning for all units.

Later in the scenario, a captured Redland health physicist revealed he was ordered to design and test the RED employment concept. The scientist admitted to building and testing approximately 100 REDs. The Redland concept of employment included scattering them in front of advancing forces as a delaying tactic. Redland leadership planned to use this delay in the coalition offensive to re-organize their forces for a counter attack. Additionally, Redland would strategically message that allied forces employed the REDs themselves, intentionally contaminating the environment.

Once III Corps maneuver forces secured the RED manufacturing facility, technical units conducted Sensitive site exploration (SSE) minimizing the risk to the Joint Force. It was determined that none of the devices were able to be employed against the Joint Force.

The Protection WfF assessed the RED threat to the Joint Force and in conjunction with the other III Corps staff elements (Provost Marshal, Corps Surgeon, JAG, and Department of State Liaison), developed a warning for all units. Once the RED manufacturing facility was secured a sensitive site exploration (SSE) unit minimized the risk to the Joint Force.

CBR Vignette #2 (Biological)

While the ground maneuver forces advanced through a Redland city, they were alerted to the presence of a pharmaceutical plant on the city outskirts. Upon arrival, the Joint Force found the workers were killed prior to withdrawal of Redland combat forces. Luckily, the plant manager survived the massacre and surrendered to Allied forces. He revealed the pharmaceutical plant was also a Redland biological agent production facility.

The Protection WfF determined the pharmaceutical plant required sensitive site exploration (SSE). A chemical platoon was assigned to exploit the site and secure samples.. A sample plan was developed by the Protection WfF and permissions were granted for sample shipment through Blueland to both a national lab and an international certified lab. Unfortunately, due to the ground maneuver forces being delayed at the wet-gap crossing sites, Redland forces had time to sabotage the biological agent production facility. The initial testing by the chemical platoon was inconclusive. Additionally, samples were required to undergo testing in certified laboratories to positively identify biological agents. This in turn delayed the Joint Force from having actionable data to address the potential threat.

CBR Vignette #3 (Chemical)

Despite years of counter-proliferation diplomacy, the adversary had a long history of chemical agent/munitions production. Following the first chemical attack in theater, Redland employment of chemical munitions and the allied response quickly becomes the "new normal." Redland routinely targeted terrain, troops and logistic nodes by launching rockets, penetrating allied air and missile defenses.

The Protection WfF plotted and reported all chemical attacks throughout the WFX. After a sufficient number of attacks, both in theater and the III Corps AO, the Protection WfF conducted an analysis of what the attacks meant in the broader scope of the adversary's overall strategy. The adversary use of non-persistent chemical munitions on maneuver forces was to require personnel to don protective gear and cause casualties. The wider implication of this analysis was the adversary not contaminating their forward units and/or terrain with persistent agent with the expectation to regain the initiative. The use of persistent chemical munitions was in the III Corps rear areas to disturb logistics operations. As the operation progressed, replacement personnel and equipment and resupply became critical to simply maintain the ground that was secured.

There were few traditional chemical attacks in the entire theater and significantly less in the III Corps AO affecting maneuver. This could have been partly due to weather conditions. For several days of the exercise, the weather was so unfavorable it grounded most army aviation and air assets. As on a real battlefield, an adversary's chemical employment plan could be severely affected by the same weather effects. Rain and high winds would reduce the effectiveness and persistence of chemical munitions.

Conclusion

Countering Weapons of Mass Destruction and CBRN Defense, especially at the Division or Corps level, in the next conflict will be more than calculating downwind hazards, planning CBRN recon, and decontamination operations. The future Joint Force will encounter complex situations not in any Army Doctrine Publication, Field Manual, Army Techniques Publication, or taught in Professional Military Education. With access to commercial off the shelf equipment, adversaries have the ability to cheaply simulate Joint Force capabilities or effectively degrade Joint Forces to near peer levels.

The role of the Protection WfF is to preserve the Joint Force's combat capabilities. The Protection WfF's definition of success or failure is its ability to manage the risk from: "known knowns, things we know we know; known unknowns, things we know that we do not know; and unknown unknowns, things we don't know we don't know."[5] WMD sites, the threat of WMD and battlefield employment of WMD, create a significant amount of 'unknown unknowns' as part of creating a more complex battlefield for the rest of the 21st century. III Corps demonstrated its ability to effectively manage CBRN threats during WFX 19-4.

Notes:

1. HQDA EXORD 067-19 (Army Campaign Plan 2019+) Page 2.
2. Summary of the 2019 National Defense Strategy Page 1.
3. The Operational Environment and the Changing Character of Future Warfare V.5. 10/23/2018.
4. Multinational exercises aim to improve coalition data sharing By Amy Walker and Justin Eimers, PEO C3T Public Affairs April 8, 2019 http://www.army.mil/article/219641/multinational_exercises_aim_to_improve_coalition_data_sharing.
5. Secretary of Defense Donald H. Rumsfeld, News Transcript, February 12, 2002 https://archive.defense.gov/Transcripts/Transcript.aspx?TranscriptID=2636.

CBRN Vignette 19-1

"Back to Basics"

LTC Daniel Laurelli
United States Army Nuclear and Countering WMD Agency

This CBRN vignette is part of an ongoing series of scenarios developed as a training tool for decision makers at all levels – tactical to strategic. The goal is to foster thought, discussion and to support training. Readers are encouraged to send possible solutions to the Countering Weapons of Mass Destruction Journal as a means of interaction with the CBRN community. The author's solution, along with selected readers' solutions, will be published in future journal issues.

Situation

You are the CBRN Officer in charge of a Weapons of Mass Destruction Coordination Element (WMD CE) deployed to the threatened nation of Transia, placed under operational control (OPCON) of the 55th Light Armor Division (LAD), Divisional Headquarters. The CJTF-Freedom (US III Corps HQs), see Figure 1, Protection Warfighter Forum (WfF) just completed the assessment of the 55th LAD from Kemalia and commanded by Major General Sosabowski, The CJTF-Freedom Protection WfF determined the unit is completely deficient in CBRN training, and equipment.

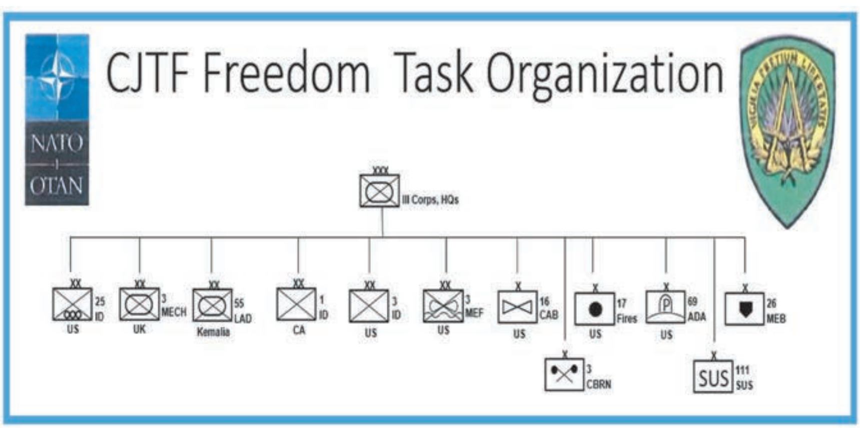

Figure 1: CJTF Freedom Task Organization

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Background

The nation of Kemalia is a former satellite nation to the Soviet Union that was recently granted membership to NATO. Kemalia spent many years rebuilding its nation after the fall of the Soviet Union, which left it in economic ruin. In the last five years Kemalia's economy improved enough to increase its national budget, which included revitalization of it's military forces. In order to demonstrate Kemalia's new alliance and military prowess, the country volunteered to support NATO missions. With the crisis in Transia, Kemalia deployed its premier Combat Element, the 55th Light Armor Division (LAD). The 55th LAD was assigned to CJTF-Freedom. CJTF-Freedom is composed of the US III Corps Headquarters along with US and other NATO units (Figure 1). US European Command (USEUCOM) is CJTF-Freedom's higher headquarters for defending the country of Transia from its neighbor Donovia. The 55th LAD is in Tactical Assemble Area (TAA) Hedgehog scheduled for frontline tour of duty in the next 6-8 weeks. The CJTF-Freedom Protection WfF coordinated with US logistics planned to provide sufficient basic CBRN equipment for the division to include joint service lightweight integrated suit technology (JSLIST), Protective Masks (M24, M40, M42, M45 and M48), M41 Protection Assessment Test System (PATS), Improved Chemical Agent Monitor (ICAMs), M22 Automatic Chemical Agent Detection Alarms (ACADAs), M8 Chemical Agent Detector Paper, M9 Chemical Agent Detector Paper, M265A2 Chemical Agent Detector Kits, M291/295 and M285A1 Decontamination Kits) for the 3,500 Soldiers in the 55th LAD.

55th LAD

The 55th LAD is well lead, highly trained, and motivated, but equipped with refurbished French and United Kingdom hardware (Figure 2). The 3,500 soldier division was composed of a scout company (Scorpion – scout vehicles), one mechanized infantry brigade (Scorpion – Infantry Fighting Vehicle (IFV)), two armored bridges (AMX main battle tanks (MBT)), a self-propelled artillery battalion (105mm), a support battalion, chemical company, engineer company and air defense artillery company. While the 55th LAD does have an organic CBRN Company, it is more a firefighting element equipped with bunker gear and 8 tactical fire trucks.

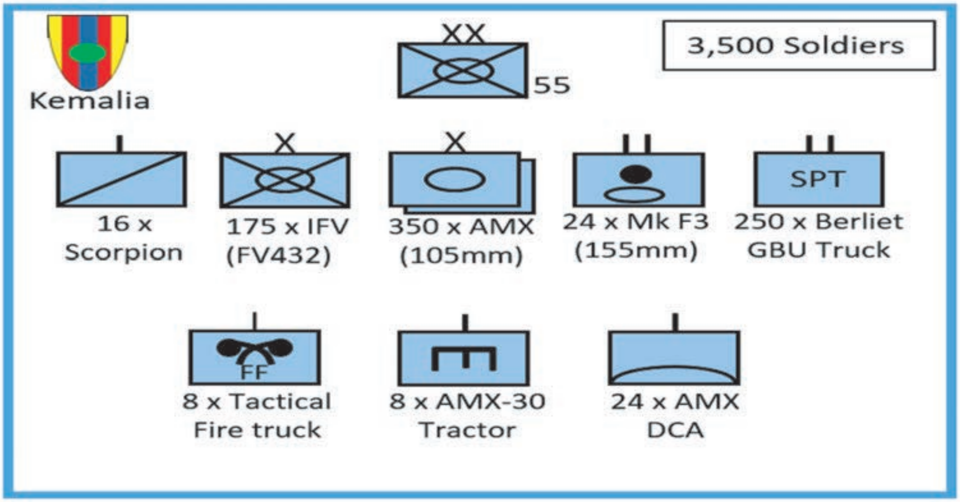

Figure 2: 55th Light Armor Division (LAD)

Leadership

Brigadier General Sosabowski is a 56 year old career soldier just assigned to the 55th LAD prior to ts deployment to Transia, having both academic (Masters in political science – Public Policy from Kamila University) and military degrees (graduate the Kemalia and UK War colleges). He has multiple combat and peacekeeping deployments and several levels of command, including the 32nd Airborne Brigade (Kemalia) with three combat jumps. Brigadier General Sosabowski demands that his officers and NCOs are professional and competent.

Enemy Forces

The nation of Donovia is preparing to invade its neighbor of Tranisa. Donovia military is a credible threat to any modern military force. Donovian Divisions (Figure 3) are in prepared defensive positions just over the Donovia/Transia border. Donovia combat elements are near full strength and operational rate of over 95%. Their units are well trained and equipped with modern battlefield systems. Donovian ground units are well trained in combat and both offensive and defensive operations while in a chemical environment. In addition to organic division artillery battalions (2 Battalions of 122mm per Division), each Corps is supported by an Artillery Group (4 Battalions of 152mm) (Figure 4) and each Artillery Group is supported by an Offensive Chemical Battalion. Each Offensive Chemical Battalion can provide Donovian artillery units with a range of munitions including Tear Gas, Phosphorous, GD, HD and VX. Donovia concept of operations is to conduct both conventional and unconventional (Chemical) artillery attacks prior to initiating offensive operations.

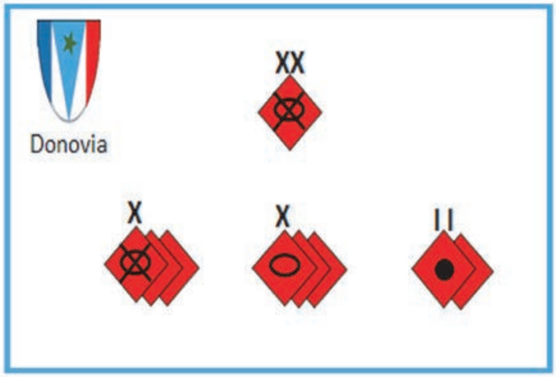

Figure 3: Standard Donovia Division

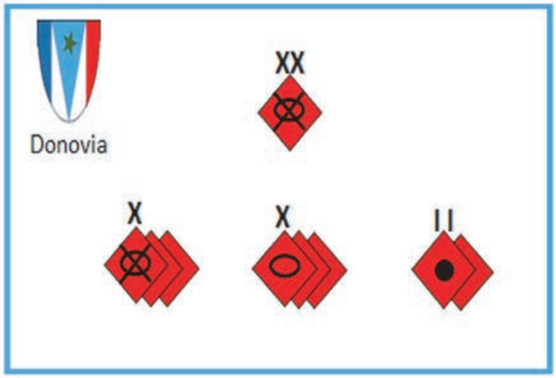

Figure 4: Standard Donovia Artillery Group

Requirement

Your WMD CE was tasked to develop a CBRN training plan for Brigadier General Sosabowski to prepare his division. After reviewing the situation, outline your plan for preparing the 55th LAD to move into the frontline in 6-8 weeks. Readers wanting to submit their solutions to USANCA, should submit in care of daniel.p.laurelli.mil@mail.mil.

CBRN Vignette 18-1
"NDT Dilemma" - Author's Solution

LTC Daniel Laurelli
United States Army Nuclear and Countering WMD Agency

Vignette 18-1 Requirement: Develop a FRAGO to conduct disablement operations at the Transia Nuclear Power Plant and the National Nuclear Refinement and Research Facility in the Area of Operations (AOR). Consider including the following items: 1) strategic messaging; 2) prioritization of the two sites for exploitation; 3) task organization; 4) unit tasks and purposes; and 5) rationale. Refer to *CWMD Journal* Issue #17 for details.

Situation You are the Chemical Officer for JTF-Elimination. JTF-Freedom is its higher headquarters for stability operations in the failing nation of Transia. JTF-Elimination is composed of 1/4 HBCT, A Co 2/3 GSAB (8xUH-60s), and 55th EOD Co with 1 NDT. The JTF mission is to exploit and disable nuclear and radiological WMD infrastructure and components in Transia, a semi-permissive environment in order to deny near-term capability or reuse by renegade elements of the Transia military and criminal organizations, and facilitate follow-on WMD Elimination operations, as required.

Task Organization
Initial Entry Force: Consists of 1x IN CO, 2 x EOD PLTs [EOD CO (-)], 1 x NDT with 3 x Teams
2nd IN BN: Assigned Initial Entry Force, A/2-3 GSAB
3rd IN BN: Assigned EOD PLT
1st AR BN: No Change

Mission JTF-Elimination seizes Transia Nuclear Power Plant (805159) and the National Nuclear Refinement and Research Facility (210245) NLT D+3 in order to conduct disablement operations of the two nuclear facilities and deny threat use of nuclear material.

Intent The intent of JTF-Elimination is to quickly secure and exploit the two nuclear facilities in the AOR.

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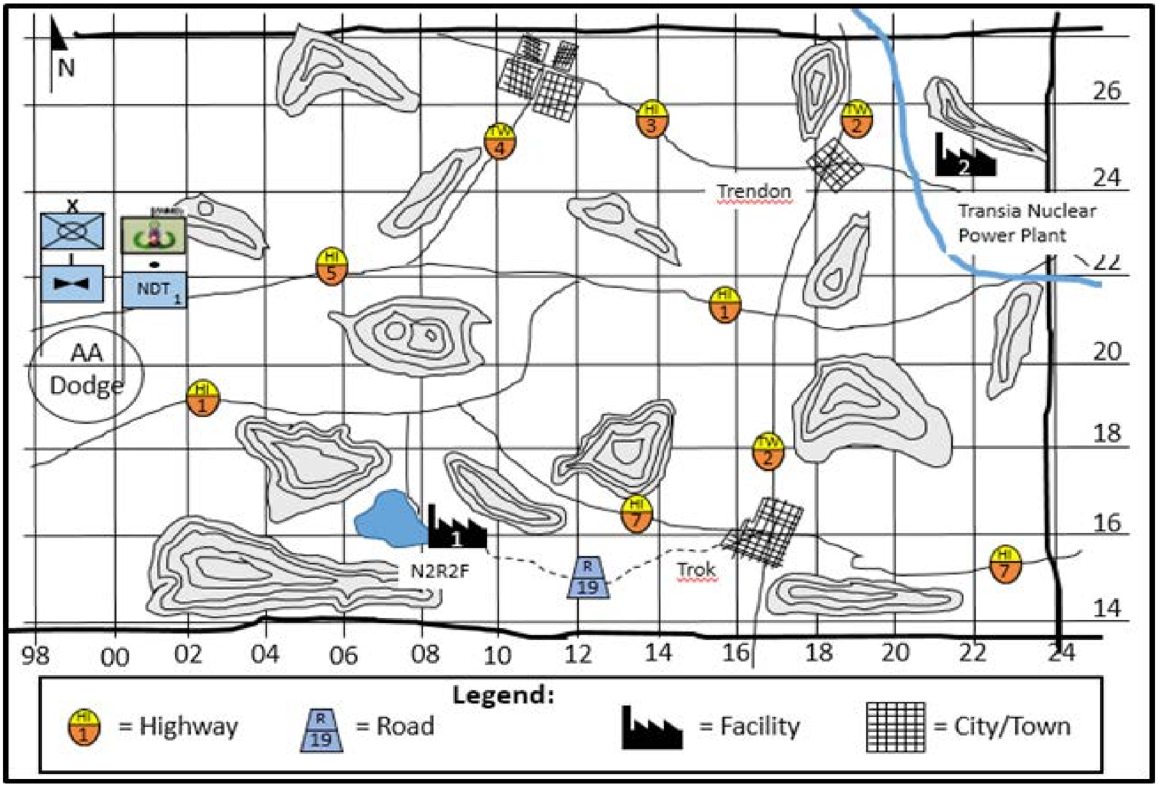

Figure 1: JTF-Elimination Area of Responsibility

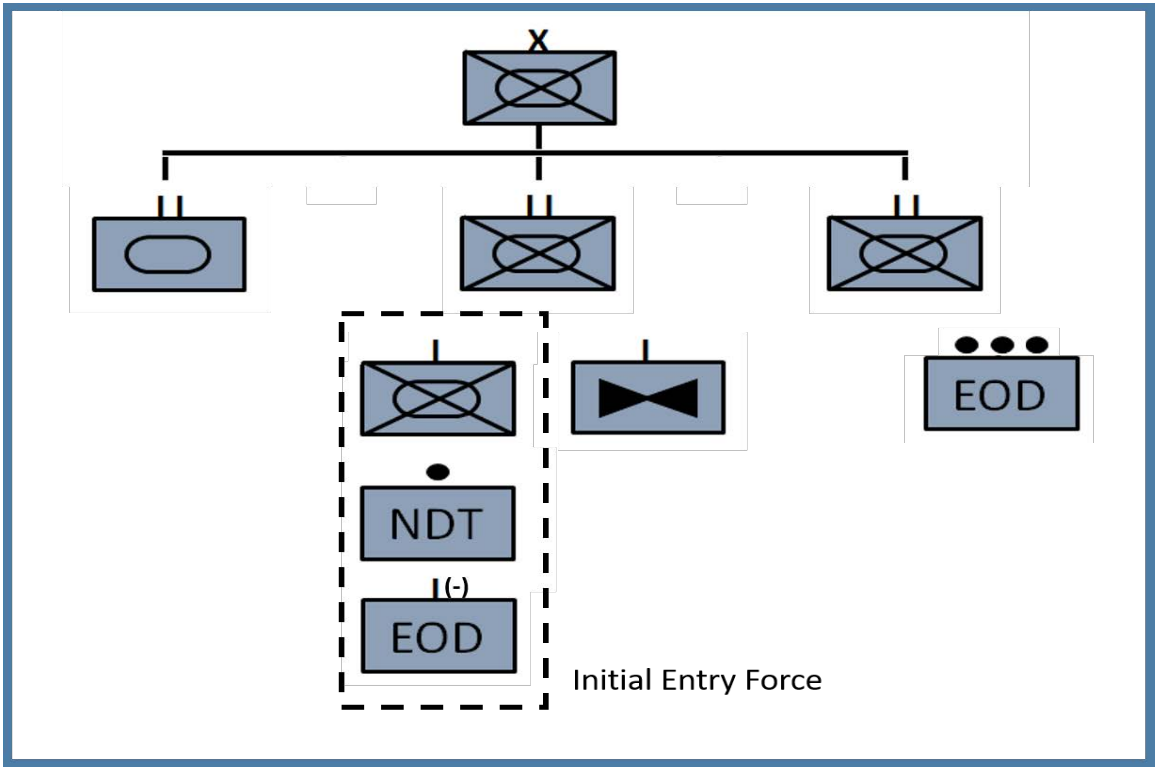

Figure 2: Updated JTF-Elimination Task Organization

Key Tasks

1. Seize National Nuclear Refinement and Research Facility (N2R2F).
2. Seize Transia Nuclear Power Plant TNPP.
3. Conduct Disablement Operations of N2R2F.
4. Conduct Disablement Operations of TNPP.
5. Prevent threat from acquiring nuclear material.

Purpose and Endstate The purpose of this operation is to secure and prevent threat use of nuclear material in the AOR. This operation ends when Transia forces are able to secure the N2R2F and TNPP.

Task to subordinate units

Main Effort (ME): Initial Entry Team conducts Helicopter Assault Force (HAF) with A Co, 2-3 GSAB to effect breach of N2R2F.

NDT Team 1: Locate and mark all hazards. Contains: Health physics and EOD expertise.

Purpose: Conduct assessment operations (initial entry) of N2R2F for follow-on elimination mission/ forces.

Shaping Effort 1 (SE1): 2nd IN BN conducts HAF with A Co, 2-3 GSAB to seize N2R2F.

NDT Team 2: Characterize the site infrastructure and material. Contains: Health physics and nuclear engineering and physics expertise.

NDT Team 3: Disable critical infrastructure and package material as necessary. Contains: Health physics, technical escort, and nuclear related EOD expertise.

Purpose: Immediately secure the N2R2F for ME and Follow on Forces.

(SE2): 3rd IN BN with EOD PLT seizes TNPP.

EOD PLT: conducts sensitive site exploitation operations of TNPP.

Purpose: Secure TNPP and commence initial entry operations.

(SE3): 1st AR BN Isolates TROK City in order to allow freedom of maneuver for ME. BPT support ME.

Priority of Support

1. Initial Entry Force
2. 2nd IN BN, 1/4 HBCT
3. A/2/3 GSAB
4. 3rd IN BN, 1/4 HBCT
5. 1st AR BN, 1/4 HBCT

Strategic Messaging

1) The three work forces at TNPP and N2R2F must be engaged and encouraged to support JTF-Elimination. The local work forces continuing their occupational tasks will increase the stability of the country, assist in securing each facility and reduce materials associated with WMDs.

2) Additionally the local population should be engaged. The Transians must be told they are valued for maintaining the country and the facilities. These people are the first and best defense against insurgence, criminal elements and rogue military units.

Command and Signal

1. 1/4 HBCT TOC remains at AA DODGE.
2. 1/4 HBCT TAC will deploy IVO N2R2F.

Rationale

The N2R2F must take priority for JTF-Elimination as N2R2F has multiple possible points it can be compromised. The contracted security force is unprofessional and will probably not secure the facility against a serious/organized threat. The Support Force is underpaid and treated poorly making them vulnerable to organized criminal activity at the facility. Due to having three missions, the N2R2F has multiple operations that can be interdicted, especially the research labs, and the nuclear weapon storage and maintenance areas.

The uranium processing area is vulnerable to espionage from nations seeking nuclear weapons technology. The Technical Force (especially the research portion of the staff) will be protective of the facility due to the dependency on grants. The refinement of uranium will have to be modified and monitored to prevent the building of further nuclear weapons. The weapons grade uranium and the nuclear weapons will need to be disabled and transported out of country. 1/4 HBCT can provide escort but may need to request additional assets like USAF air support, AH-64s for close air support, as well as a transport company.

The Transia Nuclear Power Plant is in much better shape with treatment of workers, a semi-professional security force, and lack of weapon grade uranium at the facility.

The personnel at N2R2F, especially the Support Staff and Security Force, will need special considerations besides additional screening and the site security plan will need to be evaluated. A support program will need to be established to bolster the Support Staff and Security Force to increase their quality of life. In their current situation both groups are vulnerable to renegade elements of the Transian military and criminal organizations, especially with the facility's uranium enriched program and three nuclear weapons under refurbishment.

Notes:

Transia Nuclear Power Plant based on Entergy's Indian Point Energy Center (IPEC) in Buchanan, NY.

National Nuclear Refinement and Research Facility (N2R2F) based on Oak Ridge National Laboratory in Tennessee.

NBC Report Fall/Winter 2003 "Nuclear Disablement Team Operations in Operation Iraqi Freedom: Part 1" pages 9-12.

ATP 3-37.11, Chemical, Biological, Radiological, Nuclear, and Explosives Command HQDA Aug 2018, Pages F-1 – F7.

Book Review: Chinese Nuclear Proliferation- How Global Politics is Transforming China's Weapons Buildup and Modernization

By Dr. Susan T. Haynes

Review by MAJ Christopher Mihal
Air Force Institute of Technology

Chinese Nuclear Proliferation: How Global Politics is Transforming China's Weapons Buildup and Modernization (2016, ISBN 1612348211) by Dr. Susan Haynes looks at a heretofore neglected subject of nuclear proliferation. Dr. Haynes notes, there are two types of proliferation – horizontal proliferation, the transfer of nuclear technology between states and which receives the bulk of literary analysis, and vertical proliferation describing the evolution of nuclear technology within a state. This book encompasses China's vertical proliferation and seeks to answer several questions regarding China's nuclear weapons: what are China's nuclear capabilities, what are its policies regarding use of nuclear weapons, are those policies changing, and if so, why? Given the opacity of much of China's nuclear apparatus, these are difficult issues to address, especially its capabilities and policies. Thus, Dr. Haynes utilizes a broad spectrum of resources to arrive at her conclusions: official government documents, official military documents, and articles from Chinese academia. It is important to note that these three spheres of Chinese society do not always agree, and some subtle shifts in literature can portend future policy shifts.

In order to evaluate a nation's nuclear weapons policy, one must first determine a nation's nuclear capabilities. Unlike the U.S. and Russia, which have treaties in place that determined precisely how many strategic nuclear weapons they have, China has never signed any such treaty. This leads to much ambiguity in the size of the Chinese arsenal, with estimates in 2012 ranging from 120 to 300 warheads. What is certain, however, is that China does in fact possess a nuclear triad, although the degree of performance in each facet of the triad is currently unknown. Unlike the U.S. and Russia, there has been a distinct upward trend in the size of the Chinese arsenal in recent years. *Chinese Nuclear Proliferation* postulates this increase is in reaction to a rise in tensions with the U.S., as well as signifying a shift in overall Chinese nuclear deterrence policy. To this end the book reviews several Second Artillery Force (SAF) manuals, their military formation in charge of nuclear weapons, then compares and contrasts these documents with academic and government sources to best determine how the SAF views its role in a nuclear confrontation.

MAJ Christopher Mihal is a student at the Air Force Institute of Technology at Wright-Patterson Air Force Base, working on a M.S. in Nuclear Engineering. He has a B.S. in History from the United States Military Academy, a M.S. in Engineering Management from University of Missouri Science and Technology, and is a certified Project Management Professional. This is his first assignment as a FA 52. His email address is christopher.mihal@afit.edu.

Chinese Nuclear Proliferation does a substantial job identifying and defining five types of nuclear deterrence policies a nation might adopt then compares and contrasts policies amongst the major nuclear powers. One aspect of deterrence is communicating your intentions and capabilities. One communication issue that China has had with other states is that until the past decade or so, deterrence had an entirely different meaning in Chinese culture than used by other states. Chinese policy never even mentioned the word deterrence until very recently. To the Chinese, deterrence involved coercion or threats and so was much more active and confrontational than, for instance, in U.S. policy. This has caused confusion and consternation in the past. China's recent embrace of the word deterrence, and agreement on internationally accepted definition, in official policy is promising.

Dr. Haynes' primary thesis is that China is transitioning from a policy of *minimum deterrence* to a policy of *limited deterrence*. In short, this represents a paradigm shift in how China views use of nuclear weapons, and is an indication that China may become more aggressive in its use of nuclear weapons. Whereas previously China proudly proclaimed that it would always maintain a "no first use" (NFU) policy regarding the use of nuclear weapons, Dr. Haynes makes an adequate case that this former bedrock of Chinese policy may be eroding and that there may be circumstances where China would abandon NFU if it was strategically beneficial to do so. This stance also correlates with the buildup of the Chinese nuclear arsenal. A NFU policy makes sense if China has a very limited arsenal and would only use it at a time of existential survival, but a larger arsenal can be used more freely.

For a state to undergo such a drastic shift in policy, there must be a variety of factors for it to do so. These factors are analyzed in the final third of the book. The factors fit into three categories: regional influences, domestic influences, and influences from the United States. China perceives the U.S. as its greatest rival and threat. Many of the drivers of Chinese policy can be traced to reactions to U.S. actions, such as implementing regional missile defense. Regardless of U.S. intentions, China will react to U.S. actions, particularly in Asia. Given the tensions over Taiwan and the South China Sea, a nuclear buildup is one of China's options to dissuade further U.S. action. Given China's extreme hierarchy and single-party system, it is perhaps surprising how much disagreement there can be in official literary sources. Although Dr. Haynes points out that sometimes these very obvious disparities serve to obfuscate China's actual policies as a defense mechanism.

Overall, *Chinese Nuclear Proliferation* is a valuable reference manual for determining a nation's nuclear policy and observing trends in nuclear capabilities over time. Given the deliberate masking of Chinese capabilities and policy, it is probably the best analysis of Chinese intentions available today. *Chinese Nuclear Proliferation* is a worthy addition to the professional library of anyone interested in Chinese nuclear capabilities or in analyzing Chinese deception operations at the strategic level.

Looking Back:

Functional Area 52 In Transition

LTC Gary Pettit

Previously printed in "Surety Information Letter, Spring 1994"

Functional Area 52 "Nuclear Research and Operations Officer" has been and is changing. You may be unaware of these changes, so let me fill you in. President Bush's Nuclear Initiative announced in September of 1991 started the transition. This initiative effectively took all organic nuclear weapons systems out of the US Army. The ripple effect worked its way throughout the "nuclear fabric" of the Army. There has been and continues to be changes in materiel, training, doctrine, personnel and leadership. I cannot talk to all these issues, so let me focus on the functional area changes. At the time of the announcement, FA 52 consisted of two distinct functional areas, 52A and 52B. The 52As were the operators/warfighters. They were the ones who dealt directly with the employment and planning of tactical nuclear weapons. 52As were found at Division and Corps headquarters, TRADOC (CAC, FA/ORD/CHEM schools), nuclear sites, etc. The 52Bs were the "brains" of the Army nuclear world. The majority of them received advanced degrees in nuclear physics, engineering, etc. They worked in the labs, the Defense Nuclear Agency, reactors, etc. The first real personnel change was the elimination of 52A positions. The Army's FA 52 authorization went from 200 positions down to 112 today. To accommodate this reduction, a review (QVC board) of all 52s was conducted in June 1993. Officers were selected for retention based upon their service and academic record. The conclusion of the board designated all retained officers as 52Bs. These officers are a mixture of our best operators and those with advanced degrees. At the same time, the requirements for accession into FA 52 were changed to ensure only officers with "hard science" degrees enter in the future. Currently, we have 330 officers assigned to the functional area and this provides the Army with 84% fill of authorized positions. FA 52 is just one part of the evolving transition the Army nuclear program is taking. As the transition continues, look for more articles on our functional area and the Army's nuclear program.

U.S. ARMY NUCLEAR AND CHEMICAL AGENCY

Fort Belvoir, Virginia

How to Submit an Article to the *Countering WMD Journal*

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