Improving Exclusively Through Technological Development: Open Burns/Detonations at the Radford Army Ammunition Plant

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Jake Bales

Spring 2024

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

MC Forelle, Department of Engineering and Society

Introduction

Located in Radford, Virginia, the Radford Army Ammunition Plant has been an integral part of the United States war machine since it was commissioned at the start of the Second World War. After construction finished, nearly half of the American munitions used in the war were powered by powder manufactured in Radford. Since then its importance has only grown, as following decades of Base Realignment and Closure, the plant stands as the sole manufacturing facility in the United States capable of producing military-grade nitrocellulose for use in modern propellants (Lustgarten, 2017). Thus, nearly every bullet, missile, or explosive currently in use by the United States military can be traced back to Radford (Mohamed, 2017).

The strategic importance of the facility has granted it special privileges from the United States government, and regulatory apathy, military lobbying, and the lackadaisical enforcement of modern standards have allowed the facility to continue its archaic ways despite many technological advancements. Many elements of the Radford Arsenal's operation cycle require long overdue scrutiny and attention, including their dumping of toxic materials and the practice of burning their hazardous waste out in the open, as these dated practices expose the surrounding community and environment to excessive amounts of hazardous materials and toxic pollutants (Mohamed, 2017). The town of Radford and the New River have been subjected to this system for 75 years. It is time to expect—to demand—change within the system that has allowed the Radford Army Ammunition Plant to continue its manufacturing and decommissioning protocols.

The classified nature of the facility limits the amount of information that citizens can receive about the processes which occur inside the plant; however, less classified, and easily noticeable, are the processes which occur outside the plant's footprint. Nearly every day, massive plumes of poisonous smoke rise from the banks of the New River as the military destroys

hazardous material in a way that has been banned for decades. And a few times each year, thousands of gallons of sewage and chemical-ridden wastewater are released into the New River, threatening groundwater reserves and polluting the source of irrigation for farms nearby (Fuhrmann & Minovi, 2022).

The Radford Army Ammunition Plant, using the framework provided by the U.S. Army's Organic Industrial Base Strategy: 2025, has treated the improvement of environmental policy compliance as a byproduct of modernization, rather than a separate process, leading to a slow and incomplete response to local environmental concerns. My literature review covers a brief history of nitrocellulose and the surface-level impacts of open burning/detonation to provide context for the situation. Then, my methods section outlines the two mediums for research that I utilize in my thesis, case study and policy analysis. Next, my analysis discusses the medium for advancement at the Radford Army Ammunition Plant, and how and why differing beliefs have created a schism between the community of Radford and plant management. Finally, my conclusion seeks to review the argument, provide developments, and include possibilities for future research at the RAAP.

Literature review

Manufacturing propellant in any form is a dangerous task. In 2021, a facility in Minden, Louisiana which manufactured black powder caught fire, resulting in the complete annihilation of the facility (Lubold, 2023). In 2022, a propellant manufacturing facility in Bergerac, France exploded during production (Roscoe, 2022). In 2015, a series of explosions rocked the Port of Tianjin following the spontaneous ignition of powder which had dried out in the heat. 170 people perished in the incident (Tremblay, 2016). The culprit of the second and third disasters was the same: nitrocellulose.

The name may sound familiar, as you have likely heard of nitroglycerin, a chemical with similarly explosive properties used as dynamite. Developed and 'perfected' in the mid-nineteenth century, nitrocellulose is a highly unstable material and is subject to runaway decomposition reactions (i.e., explosions) triggered by its decomposition, the cause of the tragedy in Tianjin (Li et al., 2021; Tikkanen, 2024). The explosive properties of nitrocellulose make it perfect for military applications, and thus, in the latter half of the nineteenth century, it began widespread use under the name of smokeless powder.

The process by which modern nitrocellulose is produced has been semi-consistent since the late nineteenth century and involves mixing one part nitric acid, two parts sulfuric acid, and cellulose (in the form of cotton) together, and then repeated washing and drying to increase stability (Bergman, 2007). After production, it is often wetted with alcohol or water, or mixed with plasticizers, to reduce the risk of explosions from spontaneous combustion (Li et al., 2021). When in a wetted state, nitrocellulose is significantly more difficult to ignite, as the energy must first evaporate any liquid present. Thus, explosions that occur in stockpiled nitrocellulose can often be traced back to the mismanagement of the volatile chemical.

For the same reason it is used as a propellant, waste/excess/senescent nitrocellulose-based material is too dangerous to let sit around and decay—there is a ton of energy stored in its chemical bonds. The military understands this, and legislation has made it illegal to store these hazardous materials for more than 90 days, as they could react on their own and result in waste that is even more toxic (Smith, 2021). Thus, we have arrived at the crux of the issue at the Radford Army Ammunition Plant: how do you safely decommission explosive material?

To reiterate: the production process of military-grade nitrocellulose is dangerous—the facility is creating a material whose purpose is to be super volatile. There are obvious risks

associated with manufacturing the explosive compounds: mainly, explosions; but arguably the more dangerous effects associated with the lifecycle of nitrocellulose come after the lifetime of the propellant has passed. The process of destroying or detonating excess, waste, or expired explosive materials releases a laundry list of harmful chemicals, including, but not limited to: carbon monoxide, nitrous oxides, nitrous dioxides, heavy metals (lead, mercury, etc.), volatile and semi-volatile organics (benzene, phthalates, etc.), particulate matter, and per- and polyfluoroalkyl substances (PFAS) (Committee on Alternatives for the Demilitarization of Conventional Munitions et al., 2019, p. 30; Hoskinson, 2022; Kean, 2021; Ludwig, 2016). Suffice it to say, the process is harmful and releases toxic and hazardous contaminants into the atmosphere surrounding the facility at which it takes place.

Moreover, the byproducts released from open burning/open detonation (OB/OD) do not just disappear. They contaminate the soil, water, and air in the area surrounding the facility and pose major health concerns for those in the surrounding community. Whether direct (e.g., smoke inhalation) or indirect (e.g., soil deposition and subsequent bioaccumulation), exposure in some facet is near certainty for those in the areas around the facility. And although limited exposure to these chemicals may not pose health effects, repeated interaction does. The accumulation of heavy metals leads to a diversity of toxic effects on a variety of body tissues and organs (Balali-Mood et al., 2021). Prolonged exposure to perchlorates damages the human thyroid system, which manages the release of hormones in the body (Ludwig, 2016). Exposure to particulate matter leads to a variety of problems in humans including asthma and nonfatal heart attacks, while also causing acidification and nutrient depletion in bodies of water (US EPA & OAR, 2023). The list of toxic interactions goes on.

Facilities already exist across the world to deal with these issues; in fact, one already exists at the Radford Plant. A closed incineration plant should solve all the issues with OB/OD; after all, the chemicals cannot pollute the environment if they are isolated indoors.

If only it were that simple.

Enclosed incinerators do solve a lot of the issues associated with open burning and detonation, but they introduce problems of their own related to cost and size. Open burning is essentially free. Incineration is not—a study of alternative practices found that a contained detonation chamber costs between two and three million dollars per operation. Thus, there is little motivation for the Army or DOD to change their ways, as OB/OD is the cheapest method for them (Lustgarten, 2017). The size of the propellant grains is the second limiting factor. Certain propellant grains are simply too big or expensive for some incinerators to handle, and the process of crushing/grinding them down to size introduces the threat of detonation (Adams, 2019; Smith, 2021). These two factors limit the lengths that some facilities are willing to go for the environmentally conscious route, especially if the government has already sanctioned OB/OD to take place at the facility.

Methods

The framework that I used to analyze the situation was the social construct of technology (SCOT), developed by Trevor Pinch and Wiebe Bijker. The theory behind SCOT is that technology does not determine human action, but rather human action shapes technology. Furthermore, the theory thinks that social groups influence how technologies are designed, used, and redeveloped. A few useful terms to know for SCOT are relevant social groups, interpretive flexibility, and closure. 'Relevant social groups' denote institutions and organizations that fit the key requirement of all members sharing the same set of meanings attached to a specific artifact

(Pinch & Bijker, 1984, p. 414). To demonstrate 'interpretive flexibility,' one must show that differing interpretations of an issue are present and that nature does not force the issue of the existence or non-existence of a phenomenon (Pinch & Bijker, 1984, p. 420). Lastly, 'closure' can mean one of two things: either an experimental result that has the effect of closing the debate on some controversial issue or the stabilization of an artifact and the disappearance of problems (Pinch & Bijker, 1984, pp. 425–427). Utilizing SCOT I attempted to isolate and analyze relevant social groups' positions on the Radford Army Ammunition Plant to determine if a closure mechanism could be reached.

Through the lens of a case study, I gathered information about the Radford Army Ammunition Plant from scholarly websites/journals, local newspapers, and military/government documents dating back to the early 2000s. Moreover, I gathered information about the public perception of the plant through any interviews that have taken place. In addition to case study analysis, I utilized policy analysis to gather information about the laws and requirements for the open burning/detonation of explosive materials throughout the plant's existence. This method allowed me to identify the policies that have allowed the RAAP to act as it has, and through its utilization, I gained knowledge that allowed me to better understand the residents' frustration with how the facility has been managed. These methods allowed me to get a firm grasp on the facts behind the situation, while not ignoring the voices within the community of Radford.

Analysis

For nearly a half-century, the Resource Conservation and Recovery Act (RCRA) has protected one of the many processes that it initially intended to ban, shifting from opposition to a path of appeasement and inaction, an approach likely attributable to Congress's fear of backlash from the United States military. In 1976, Congress passed the RCRA, a new set of laws to

govern the disposal of waste in the United States. Amongst many regulations, this document banned the open burning and/or detonation of hazardous wastes due to the potential hazards to human health and the environment—with one notable exception. Following intense lobbying by the military, a caveat for the ban was put in place which stated that waste explosives that could not be safely disposed of through other methods could still undergo the process. The logic behind the decision was that it was not feasible to require the retirement of the process without raising serious safety concerns over the handling and transportation of highly reactive materials; however, the exception was only intended to grant temporary relief, stating the EPA would only permit open burning/detonation until a more suitable mode of disposal was developed (US EPA & OLEM, 2023, 2024). Since the bill was signed into law, scientific advancement has provided alternative methods of disposal, but continued pushback by the armed forces has granted protection to the practice of open burning/detonation for the foreseeable future.

Due to its relationship with the United States Army, the Radford Army Ammunition Plant is granted special privilege to continue the open burning/detonation of explosive material, despite the practice having been banned since the 80s. Furthermore, continued governmental oversight in the years following the RCRA emboldened the Radford Arsenal, leading to the facility misrepresenting or ignoring emissions for decades. For 25 years after the Resource Conservation and Recovery Act was enacted, the Radford Army Ammunition Plant (the "RAAP" or "Radford Arsenal") was not issued a permit to perform the open burns/detonations that took place on the bank of the New River (Gangloff, 2015). The facility viewed the lack of a governmental permit as a pass to ignore the regulations set in place by the RCRA and performed unregulated open burns until the year 2005. Moreover, from when the facility opened in 1941 to 2001, neither the Army, nor the EPA (established in 1970), nor the state of Virginia measured

the pollution coming from the burn pads at the RAAP (Lein, 2023). The lack of measurement led to a massive discrepancy in reported and actual releases—the year accurate measurement began, the Radford Arsenal leapfrogged nine other facilities to become the largest producer of toxic release inventory (TRI) chemicals statewide after on-site production increased nearly 10-fold. Since then, it has been a race for second place, as the RAAP has averaged over 11 million pounds of TRIs released per year while only a single other facility in Virginia has ever eclipsed 5 million pounds in one year, doing so just twice since 2001 (Thirunagari & Rynders, 2024)

The Radford Army Ammunition Plant's disregard for environmental regulations and its excessive release of toxic chemicals pose significant risks to the surrounding community of Radford. While most of the TRI production at Radford consists of aerosolized nitrate compounds, the decommissioning process of explosive materials also releases significant quantities of more hazardous chemicals like perchlorates, ammonia, and heavy metals. The substantial release of these chemicals has had a devastating impact on the community of Radford, with air quality monitoring from 2014 to 2018 indicating the area surrounding the facility ranked among the top 1000 most toxic hot spots in the nation (Shaw et al., 2021). Moreover, from 2012 to 2022, the Radford Arsenal faced fines totaling nearly a million dollars for seven instances of non-compliance with environmental safety regulations. And over this period, the facility received over one thousand citations for various other violations, ranging from excessive chromium and lead emissions to the unauthorized release of tens of thousands of gallons of toxic wastewater and sewage into the New River (Bustamante & Duggan, 2014; Fuhrmann & Minovi, 2022).

The brokenness of the system governing permits for open burning and open detonation is evident beyond the semantics of what a suitable replacement implies, as it relies solely on

computer simulations that disregard key factors, a flaw highlighted by recent testing at the Radford Army Ammunition Plant. The current permit granting system relies on computer simulations to estimate the impact of pollution on human health and the environment but fails to consider crucial factors like the weather, the burn time, and the type of fuel being burned (Lustgarten, 2017). Moreover, the simulations have never been rigorously tested, causing discourse over their accuracy. The Department of Defense has argued that this system of approximation works, as field tests at OB/OD facilities have shown that most of the toxic chemicals are consumed by the fires and the pollution released is relatively light. However, following state-of-the-art pollution testing performed by drones at the Radford Arsenal in 2018, it was found that there were significantly higher levels of arsenic, cadmium, silver, and chloromethane in the smoke released by the plant than initial testing had suggested—casting further doubt on the accuracy of these simulations (Fuhrmann & Minovi, 2022; Mastrangelo, 2017, 2018b).

Spending fatigue after the Gulf War led to a rapid decline in the United States Army's perceived capabilities, as domestic Army plants began to show their age. Following a surge of investment before and during the Gulf War in the early 90s, the funding allotted to modernization efforts of domestic organic industrial bases (OIBs) dropped significantly—up to 80% from its peak during the following years. After over a decade of limited investment into the upkeep and modernization of domestic Army Ammunition Plants, the Army realized that the equipment at these facilities was reaching the end of its useful life (Zimmerman, 2005). This realization placed widespread doubt on the Army's ability to function in a prolonged war, as these facilities were the backbone of the ammunition supply chain in the United States (Lopez, 2019). A few years later in 2009, after years of planning, the Army implemented the SMCA

Industrial Base Strategic Plan with the goal of modernizing industrial base capabilities and, in turn, increasing manufacturing readiness to meet current and future requirements (Zimmerman, 2010). Over the next decade, the focus of the Army remained the same—improving output and safety of Army Ammunition Plants; however, the modernization brought a wave of new technology to the facilities, and with it, environmentally friendlier processes.

The modernization initiatives undertaken by the Army at the Radford Army Ammunition Plant have led to massive reductions in pollution emissions since the early 2000s, inadvertently benefitting the community of Radford. An updated plan, the Army Organic Industrial Base Strategy: 2025, was established in 2016—its details remain classified, but its impacts are widespread and evident at Radford. Substantial investments since then have transformed the Radford Army Ammunition Plant—construction of a new power station, modernization and addition of production lines, and the construction of waste reduction/recycling facilities. These upgrades come as the Army has begun to emphasize the importance of funding facilities designed to embrace modern technology, citing benefits such as improved workforce safety, energy efficiency, and production capacity, resulting in a greater return on investment (Tressel, 2020). Key among these improvements was the construction of a new natural gas-fired steam plant to replace the crumbling and dangerous coal-fired boilers, which virtually eliminated the emission of large quantities of particulate matter, hydrochloric acid, and carbon monoxide into the atmosphere (Mastrangelo, 2018a; O'Meara, 2017). Additionally, newly constructed production lines have reduced nitrates produced per pound of production, complementing the construction of a new nitric/sulfuric acid concentrator to enhance operating efficiency in the previous round of modernization (JMC Public Affairs Office & Joint Munitions Command, 2023; Zimmerman, 2010). However, the pièce de resistance of modernization efforts is the new

incinerator, the "Energetic Waste Incinerator" or EWI, scheduled to begin operation in 2026. Featuring a contained burn chamber that can handle larger propellants without having to grind them, the EWI will reduce the amount of energetic waste that must be treated via open burning and/or open detonation by 95%. Moreover and more importantly to the Army, the new incinerator will work to limit human exposure to hazardous materials by introducing an automated system to move energetic material safely around the complex (Gangloff, 2023; Wall, 2019). The modernization efforts at the facility have drastically reduced the Radford Arsenal's environmental impact, with emissions experiencing an especially significant reduction, but it is difficult to say the role environmental sustainability played in the decision-making process.

Recent statements delivered by Army officials seem to indicate that the improvements are not mere circumstance but rather are a byproduct of the branch's newest foe—climate change. In the past few years, the Army's commitment to combat readiness has become directly linked to its stance on climate change. In 2022, the Army solidified its stance with the release of two documents—the 2022 Army Climate Strategy and the Organic Industrial Base Modernization Implementation Plan (OIB MIP). The OIB MIP is, according to Lt. Gen. Gamble, a forward-looking and thinking solution to keep domestic OIB facilities and infrastructure postured and programmed to sustain Army readiness (Lopez, 2019). The 15-year plan builds upon the precedents set in the Army OIB Strategy: 2025 and is focused on improving the output and safety of ammunition plants with future technologies and manufacturing methods (Tressel, 2020; U.S. Army Materiel Command, 2022). The Army's climate strategy acknowledges the growing risk of armed conflict in regions impacted by climate change and states that it will promote environmentally focused practices worldwide as a mitigation method. However, it maintains that its climate efforts are directed towards increasing the effectiveness of its boots on the ground and

its core mission: “to fight and win the nation’s wars” (Birnbaum & Root, 2022; Department of the Army & Office of the Assistant Secretary of the Army for Installations, Energy and Environment, 2022). In line with these objectives, the U.S. Army has made a concerted effort to minimize the use of open burning and adopt new contained technologies (Smith, 2021)

Despite these improvements, persistent discord continues between the relevant groups involved in the RAAP situation, reflecting the contrasting viewpoints between them. On one side stands the surrounding communities, while on the other stands a collective composed of the government, the Army, and BAE systems—each holding different perspectives on how the Radford Arsenal should function. Facility authorities seem content with their practices; after all, they have been given direct confirmation by the EPA that OB/OD may continue for at least the next decade (Fuhrmann & Minovi, 2022). Moreover, they argue the facility never even approaches the currently permitted OB weight limit only 5% was used in 2020 (Paullin, 2022; Smith, 2021). And the available data appears to further validate the facility’s practices, as in response to claims about elevated rates of thyroid disease and other illnesses near the Radford Arsenal, the DEQ conducted a risk assessment of various sensitive populations (e.g., schools, day-care centers, long-term care facilities) and concluded there was not a statistically significant increase in cancer risk. Furthermore, a 2019 report by the VDEQ indicated a steady reduction in groundwater contamination, suggesting a positive trend in environmental impact mitigation.

Local activists, however, expect more. The Citizens for Arsenal Accountability (CAA), founded in 2017, has been vocal in advocating for more community engagement and environmental transparency from RAAP. They argue that the facility’s reliance on outdated disposal methods is unacceptable and urge for stricter protocols in measuring, modeling, and reducing pollution emissions (Connor, 2017; Paullin, 2022). The group is not alone in these

beliefs, as shown by the EPA's proposal of regulatory revisions for open burning and open detonation of hazardous waste in March 2024, citing a paper from the National Academic of Science, Engineering, and Medicine which highlights advancements in waste munition disposal technology.

A main point of contention between the two groups is related to heavy metal exposure within the community and the significant health risks that exposure poses to children. Heavy metals (e.g., lead, mercury, arsenic, etc.) are toxic to life and cause a multitude of issues in humans, but exposure is especially impactful in young children as the effects of heavy metal poisoning are very strongly correlated with body mass. Lead specifically is a potent neurotoxin that greatly hinders brain development causing decreased intelligence, behavior disorders, and learning problems (Rees & Fuller, 2020). The five schools located closest to the RAAP burn site all fell within the 99th percentile in the United States for toxic hazard exposure from lead compounds in 2021(Fuhrmann & Minovi, 2022; Weinstein & Ash, 2024). This is despite a reported 73% decrease in lead emissions by the Radford Arsenal since 2017, meaning previous exposure was likely significantly higher (Wall, 2019). This fact—along with findings published in 2008 by the Lead-Safe Virginia Program which stated that the number of children aged 0-15 in Radford with elevated levels of lead in their blood was nearly 2.5 times the general population—has prompted public outcry demanding safer methods for destroying waste munitions, arguing that the health and wellbeing of children should come first. In 2017, the DEQ assured the public that exposure to lead from the RAAP was unlikely to pose significant health risks, citing newly installed air monitors and third-party research conducted by students at Virginia Tech (Harris, 2017). According to the student's assessment, heavy metals and volatile

organic compounds were not migrating off-site in quantities that threatened human health (Hammack, 2021; Wall, 2019).

The conflicting assessments of lead exposure levels near the RAAP by the DEQ and third-party data sources reveal an ongoing issue regarding palatable public health risks in Radford, particularly for children. The exposure of children to lead compounds at Belview, Riverlawn, and Belle Heth Elementary—which were 722, 141, and 98 times the median national exposure respectively in 2021—is unacceptable. The ongoing nature of the situation leaves room for further developments, but it is rather nonsensical to accept that these concentrations pose no threat to the children attending these schools.

The Radford Arsenal must treat reducing toxic exposure as more than a byproduct of modernization. While the adoption of new technologies undeniably contributes to pollution reduction, it should not be the exclusive or primary approach to progress. Historically, environmentally beneficial developments at the Radford Army Ammunition Plant have stemmed from technological advancements rather than a deliberate focus on reducing emissions. Army-mandated modernization efforts aimed at increasing production inadvertently led to a reduction in nitrate emissions per pound of propellant. Similarly, the unreliability of coal-fired boilers led to a new natural gas steam plant, reducing particulate matter, hydrochloric acid, and carbon monoxide emissions (Barati, 2016). Furthermore, the significant reduction in waste treated by open burning/detonation since 2017 was primarily facilitated by a new disposal method for large-grained propellants, allowing a significant portion of previously OB/OD propellants to be diverted to the closed explosive waste incinerator (Kirchner, 2020). And while these developments are great, and the facility has reduced its pollution, an approach that also utilizes

environmental stewardship as a central focus is required to address the complex challenges facing the Radford Arsenal.

Conclusion

The story of the Radford Arsenal's environmental impact is shaped by legislative semantics, technological development, and community advocacy. Through military privilege, the Radford Army Ammunition Plant was able to neglect environmental regulations and poison southwestern Virginia for decades. While recent updates made by the United States Army have shown a percentage reduction in toxic release chemicals by the RAAP, these improvements have stemmed from technological development rather than a focus on improving environmental conditions around the facility. Addressing the issues facing the Radford Arsenal requires an effort from all stakeholders involved—one that places emphasis not exclusively on adopting modern technologies, but also on recognizing and focusing on environmental stewardship and community well-being.

That is not to say that there is no end in sight to this situation. Since the appointment of Lt. Col. James Scott as plant commander in 2017, there have been noticeable strides towards addressing the concerns raised by the Citizens for Arsenal Accountability. Lt. Col. Scott's approach, characterized by open communication and willingness to engage with community stakeholders, has led to several positive developments. These include facilitating on-site testing, offering guided tours of the facility, and making commitments to reduce pollution—actions that have been implemented as promised (Adams, 2019; Mastrangelo, 2018b). Carrying on Lt. Col. Scott's will, subsequent plant commanders have continued to prioritize transparency, a stark contrast to the RAAP of the past. Moreover, there has been a growing willingness within plant

management to collaborate with the community in addressing their concerns with the facility, leading to a positive relationship forming between the groups.

I believe that my project establishes a strong foundation for future research endeavors concerning the Radford Army Ammunition Plant. In particular, an analysis of my paper following the declassification of the OIB MIP holds promise to give insight into any disparities between anticipated outcomes and actual developments. In the short term, I envision researchers expanding upon my work by examining TRI data once construction of the EWI has finished. This would enable a comparison between the commitments made and the realized environmental impact. Additionally, I hope that future researchers will explore the evolution of the culture of transparency at the plant over time, assessing whether it has persisted into the future.

The classified nature of the Radford Army Ammunition Plant imposes significant restraints on the accessibility of information, thereby restricting the scope of the project—the inherent secrecy surrounding military operations hinders obtaining comprehensive data and insights necessary to fully understand the environmental impact and operational practices at the facility. Furthermore, the infrequent release of data increases limitations, as the information utilized in the project may already be outdated, undermining the accuracy and relevance of the findings. Nonetheless, I hope that the findings of my research elucidate the reality of the situation and that the study can be used as the basis for expanding environmental accountability beyond technological development within the military.

Citations

Adams, M. (2019, March 28). Softer tone emerges in meetings between community, military over munitions plant pollution. *Virginia Mercury*. https://virginiamercury.com/2019/03/28/softer-tone-emerges-in-meetings-between-community-military-over-munitions-plant-pollution/

Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M. R., & Sadeghi, M. (2021). Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. *Frontiers in Pharmacology*, *12*, 643972. https://doi.org/10.3389/fphar.2021.643972

Barati, J. (2016, April 22). *Radford Army Ammunition Plant is Going Green*. U.S. Army. https://www.army.mil/article/166554/radford_army_ammunition_plant_is_going_green

Bergman, Y. (2007). The Moulin-Blanc Nitrocellulose Plant in France: Process and Improvements in the 1880's and Early 1890's. *Icon*, *13*, 19–34.

Birnbaum, M., & Root, T. (2022, August 1). The U.S. Army has released its first-ever climate strategy. Here's what that means. *Washington Post*. https://www.washingtonpost.com/climate-solutions/2022/02/10/army-military-green-climate-strategy/

Bustamante, A., & Duggan, J. (2014). *Multimedia Compliance Investigation Redacted vp1068e02 Rfaap Final Report Redacted*. United States Environmental Protection Agency. https://www.documentcloud.org/documents/3897551-EPA-Multimedia-2014-Compliance-Investigtion.html

Committee on Alternatives for the Demilitarization of Conventional Munitions, Board on Army Science and Technology, Division on Engineering and Physical Sciences, & National Academies of Sciences, Engineering, and Medicine. (2019). *Alternatives for the*

Demilitarization of Conventional Munitions (p. 25140). National Academies Press. https://doi.org/10.17226/25140

Connor, C. (2017, April 20). Citizens for Arsenal Accountability group demands transparency from Radford Arsenal. *Collegiate Times*. https://www.collegiatetimes.com/news/citizens-for-arsenal-accountability-group-demands-transparency-from-radford-arsenal/article_43d4949a-2604-11e7-8cb6-6f44c3f11f61.html

Department of the Army, Office of the Assistant Secretary of the Army for Installations, Energy and Environment. February 2022. United States Army Climate Strategy. Washington, DC.

Fuhrmann, L., & Minovi, D. (2022, September 28). *Radford Arsenal: Toxic Contamination from Open Burning and Open Detonation*. Earthjustice. https://earthjustice.org/feature/radford-open-burn-detonation-toxic

Gangloff, M. (2015, June 28). Radford ammunition plant seeks fresh permit for controversial open burning. *The Roanoke Times*. https://roanoke.com/news/local/radford-ammunition-plant-seeks-fresh-permit-for-controversial-open-burning/article_03c7f407-d191-5749-b6ee-d627a2d21116.html

Gangloff, M. (2023, August 5). Radford Army Ammunition Plant breaks ground for long-awaited waste incinerator. *The Roanoke Times*. https://roanoke.com/news/local/government-politics/construction-begins-for-incinerator-to-replace-open-air-burns-at-radford-arsenal/article_9064ecd4-3240-11ee-822e-57cae52cd83f.html

Hammack, L. (2021, August 21). Permit allows outdoor burning of hazardous waste to continue at Radford arsenal. *The Roanoke Times*. https://roanoke.com/news/local/permit-allows-

outdoor-burning-of-hazardous-waste-to-continue-at-radford-arsenal/article_ca206ee6-029d-11ec-9831-23e15aaa5448.html

Harris, R. (Director). (2017, August 22). Burning Question: When Will Radford Army Ammunitions Plant Stop Open Burning Toxic Munitions Waste? In *WVTF*. https://www.wvtf.org/news/2017-08-22/burning-question-when-will-radford-army-ammunitions-plant-stop-open-burning-toxic-munitions-waste

Hoskinson, C. (2022). *Open Burning and Open Detonation (OB/OD) of Waste Explosives Under the Resource Conservation and Recovery Act (RCRA)*. United States Environmental Protection Agency. https://www.epa.gov/system/files/documents/2022-06/OBOD_Policy_Memo_signed_6.7.22_508.pdf

JMC Public Affairs Office & Joint Munitions Command. (2023, March 8). Radford Army Ammunition Plant breaks ground for energetic waste incinerator. *DVIDS*. https://www.dvidshub.net/news/450906/radford-army-ammunition-plant-breaks-ground-energetic-waste-incinerator

Kean, S. (Host), (2021, November 9). *Burn After Watching*. [Audio podcast episode] In *The Disappearing Spoon.* Science History Institute https://sciencehistory.org/stories/disappearing-pod/burn-after-watching/

Kirchner, L. (2020, October 15). A new transparency at the Radford Army Ammunition Plant. *News Messenger*. https://montcova.com/2018/06/26/a-new-transparency-at-the-radford-army-ammunition-plant/

Lein, P. (2023, January 4). Military burn pits: A toxic legacy of war. *Open Access Government*. https://www.openaccessgovernment.org/military-burn-pits-a-toxic-legacy-of-war-verteran-health-conflict/149605/

Li, Z.-P., Jiang, J.-C., Huang, A.-C., Tang, Y., Miao, C.-F., Zhai, J., Huang, C.-F., Xing, Z.-X., & Shu, C.-M. (2021). Thermal hazard evaluation on spontaneous combustion characteristics of nitrocellulose solution under different atmospheric conditions. *Scientific Reports*, *11*(1), 24053. https://doi.org/10.1038/s41598-021-03579-z

Lopez, C. T. (2019, November 21). *Military Services Strengthen, Modernize Industrial Base*. U.S. Department of Defense. https://www.defense.gov/News/Feature-Stories/Story/Article/2023403/military-services-strengthen-modernize-industrial-base/https%3A%2F%2Fwww.defense.gov%2FNews%2FNews-Stories%2FArticle%2FArticle%2F2023403%2Fmilitary-services-strengthen-modernize-industrial-base%2F

Lubold, G. (2023, April 26). The U.S. Military Relies on One Louisiana Factory. It Blew Up. *The Wall Street Journal*. https://www.wsj.com/articles/the-u-s-military-has-an-explosive-problem-6e1a1049

Ludwig, M. (2016, January 20). *Why Is the US Military Still Burning Its Explosive Waste in the Open Air?* Truthout. https://truthout.org/articles/why-is-the-us-military-still-burning-its-explosive-waste-in-the-open-air/

Lustgarten, A. (2017, June 20). Open Burns, Ill Winds. *ProPublica*. https://www.propublica.org/article/military-pollution-open-burns-radford-virginia

Mastrangelo, D. (2017, September 12). Radford Arsenal fined $263,335 by DEQ for permit violations. *The Roanoke Times*. https://roanoke.com/news/local/montgomery_county/radford-arsenal-fined-by-deq-for-permit-violations/article_5712e652-353f-53c1-b2ba-7c6ac20ebcf9.html

Mastrangelo, D. (2018a, March 30). Radford arsenal tops state polluter list again; commander seeking waste reduction. *The Roanoke Times*. https://roanoke.com/news/local/montgomery_county/radford-arsenal-tops-state-polluter-list-again-commander-seeking-waste/article_6961d1a0-b1aa-596b-b280-b6436a2aaa1d.html

Mastrangelo, D. (2018b, June 21). In wake of deadly fire, Radford arsenal invites public to plant. *The Roanoke Times*. https://roanoke.com/news/local/radford/in-wake-of-deadly-fire-radford-arsenal-invites-public-to/article_956c6c53-f23a-54b5-b8d9-cc74e5efaa14.html

Mohamed, I. (2017, April 10). The Radford Arsenal must be designated as a superfund site. *Collegiate Times*. http://www.collegiatetimes.com/opinion/the-radford-arsenal-must-be-designated-as-a-superfund-site/article_f7fc2d1e-1e09-11e7-8a29-874299ce0e45.html

O'Meara, E. (2017, May 2). Radford Army Ammunition Plant modernizing by opening new, more eco-friendly facilities. *WDBJ7*. https://www.wdbj7.com/content/news/Radford-Army-Ammunition-Plant-modernizing-by-opening-new-more-eco-friendly-facilities-421103763.html

Paullin, C. (2022, October 11). Citizen group pushes for halt to open burning at Radford Army Ammunition Plant. *Virginia Mercury*. https://virginiamercury.com/2022/10/11/citizen-group-pushes-for-halt-to-open-burning-at-radford-army-ammunition-plant/

Pinch, T. J., & Bijker, W. E. (1984). The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other. *Social Studies of Science*, *14*(3), 399–441.

Rees, N., & Fuller, R. (2020, July). *The Toxic Truth*. United Nations International Children's Emergency Fund. https://www.unicef.org/reports/toxic-truth-childrens-exposure-to-lead-pollution-2020

Roscoe, M. (2022, August 3). BREAKING: Dangerous explosion at Manuco nitrocellulose factory in Bergerac France. *EuroWeekly*. https://euroweeklynews.com/2022/08/03/explosion-manuco-nitrocellulose-bergerac-france/

Shaw, A., Younes, L., & Kofman, A. (2021, November 2). The Most Detailed Map of Cancer-Causing Industrial Air Pollution in the U.S. *ProPublica*. https://projects.propublica.org/toxmap/

Smith, H. (2021, October 22). RFAAP implements environmental improvements, invites public to tour facility at public meeting. *DVIDS*. https://www.dvidshub.net/news/407800/rfaap-implements-environmental-improvements-invites-public-tour-facility-public-meeting

Thirunagari, S., & Rynders, D. (2024). *2022 Virginia Toxics Release Inventory Report*. Virginia Department of Environmental Quality. https://www.deq.virginia.gov/our-programs/land-waste/superfund-amendments-and-reauthorization-act-sara/toxics-release-inventory

Tikkanen, A. (2024, February 27). *Nitrocellulose*. Britannica. https://www.britannica.com/science/nitrocellulose

Tremblay, J.-F. (2016, February 11). Chinese Investigators Identify Cause Of Tianjin Explosion. *Chemical & Engineering News*. https://cen.acs.org/articles/94/i7/Chinese-Investigators-Identify-Cause-Tianjin.html

Tressel, A. (2020, October 15). Army to draw up new 15-year ammunition modernization plan with $16B price tag. *Inside Defense*. https://insidedefense.com/daily-news/army-draw-new-15-year-ammunition-modernization-plan-16b-price-tag

U.S. Army Materiel Command. (2022, April 12). *Army Organic Industrial Base Modernization Implementation Plan*. U.S. Army. https://www.army.mil/standto/archive/2022/04/12/

US EPA & OAR. (2023, August 23). *Health and Environmental Effects of Particulate Matter (PM)* [Overviews and Factsheets]. https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm

US EPA & OLEM. (2023, May 5). *Requirements for Miscellaneous Hazardous Waste Units*. https://www.epa.gov/hwpermitting/requirements-miscellaneous-hazardous-waste-units

US EPA & OLEM. (2024, March 12). *Energetic Hazardous Wastes*. https://www.epa.gov/hwpermitting/energetic-hazardous-wastes

Wall, S. (2019, April 15). RAAP secures funding for incinerator. *The Roanoke Times*. https://roanoke.com/news/local/montgomery_county/raap-secures-funding-for-incinerator/article_233d5c5e-e7ff-50dd-8023-1719ebe9a6d3.html

Weinstein, K., & Ash, M. (2024). *PERI: Air Toxics at School Index* [dataset]. https://www.grconnect.com/tox100/schoolry2021/index.php?search=yes&school_name=&city=&state=VA&state_sum=&page=1

Zimmerman, M. (2005, June 14). *PEO Ammunition Joint Lethality* [Powerpoint]. https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2005/armaments/zimmerman.pdf

Zimmerman, M. (2010, February). *Ammunition Industrial Base Modernization Brief* [Powerpoint]. NDIA Munitions Executive Summit. https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2010/MES/Zimmerman.pdf