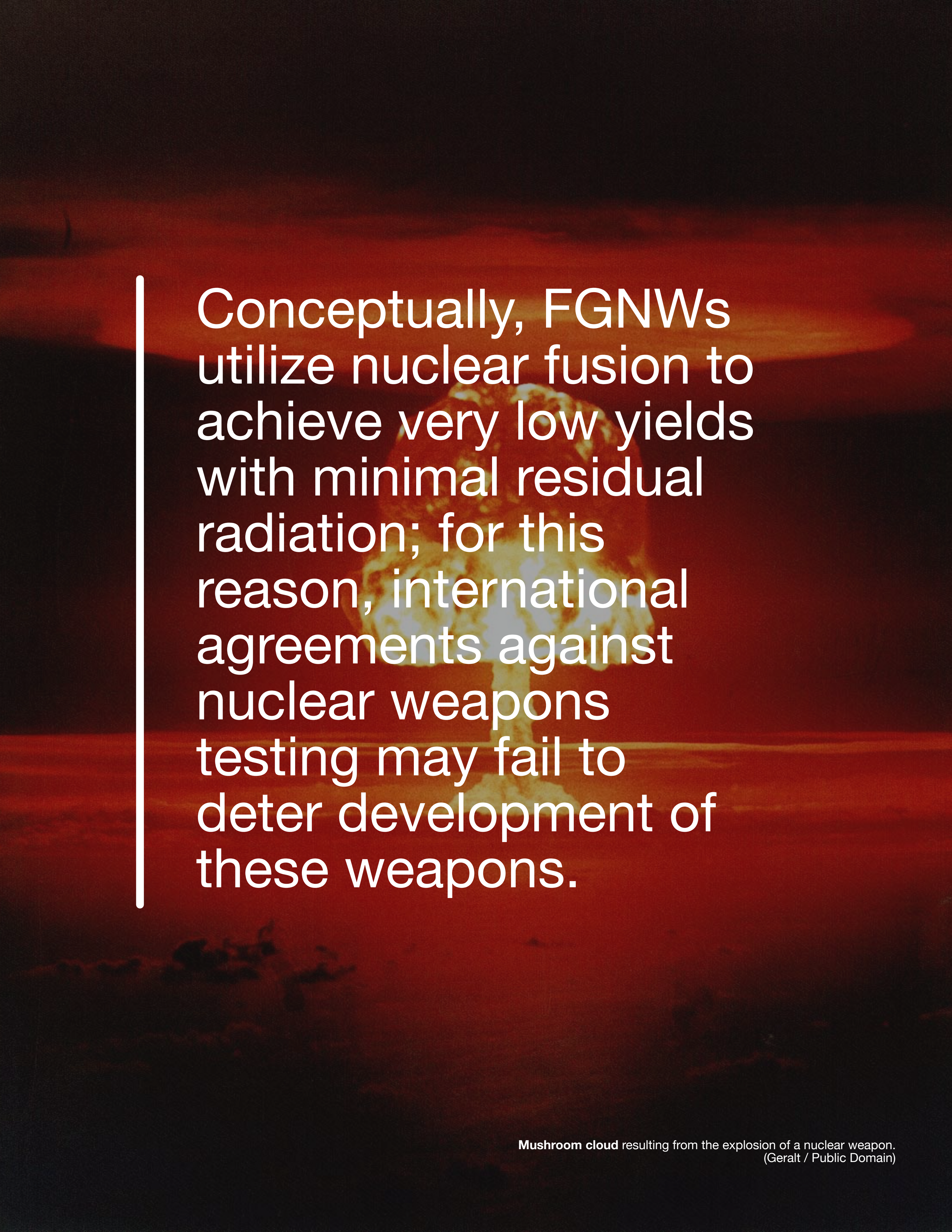

Conceptually, FGNWs utilize nuclear fusion to achieve very low yields with minimal residual radiation; for this reason, international agreements against nuclear weapons testing may fail to deter development of these weapons.

Mushroom cloud resulting from the explosion of a nuclear weapon.
(Geralt / Public Domain)

Fourth Generation Nuclear Weapons

Russia, Arms Control, and Challenges to the Deterrence Paradigm

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INTRODUCTION

In a reversed dynamic from the early Cold War years in which the United States emphasized its nuclear stockpile against a superior Soviet threat, Russia now seeks to counter NATO superiority by bolstering its nuclear capability and adjusting its nuclear use doctrine. The 2018 Nuclear Posture Review states as much by highlighting the challenging strategic operating environment the United States is now placed in, noting that while the United States has worked for several decades to reduce the role of nuclear weapons in foreign policy, other nations, including Russia, have done the opposite.[1] One emerging but realistic technology that Russia may be inclined to develop, which could offer significant military advantages and disrupt existing deterrence and arms control paradigms, is low-yield, pure fusion fourth generation nuclear weapons (FGNWs). This new class of weapons could be designed with a highly-tailorable range of yields and would produce significantly less residual radiation and collateral damage, making them well-suited for close integration with maneuver forces in regional conflicts.

A 2017 Defense Intelligence Agency report assesses that Moscow's perception of modern conventional weapons achieving strategic effects on par with nuclear weapons is one of the primary reasons that Russia revised its doctrine in 2014 to highlight the right to use nuclear weapons in response to a non-nuclear attack.[2] In pursuit of this policy, recently declassified intelligence estimates indicate that Russia could develop a new generation of high-precision, clean, low-yield, non-strategic nuclear weapons, tailor-made for limited nuclear warfighting in regional conflicts like the Russo-Georgian War in 2008 and the ongoing conflict in Ukraine.

Evidence of this trend in Russian nuclear weapons development is contained in a CIA Intelligence Memorandum, declassified in 2005. It states that "[i]n the post-Soviet era, the need for sub-kiloton nuclear weapons with minimal long-term contamination has been argued in the media by senior Ministry of Atomic Energy (Minatom) officials, nuclear weapons scientists, and military academics since the mid-1990s [. . .] they also cite clean, very-low-yield weapons as an 'asymmetric response' to U.S. superiority in conventional weapons."[3] The memorandum goes on to cite public statements by Russian scientists and officials since 1993 which indicate that the last nuclear warhead designed during the Soviet era was tailored for enhanced output of high-energy x-rays with a total yield of only 300 tons.[4] The weapon's characteristics identified in the CIA report—specifically, low yield, high-energy x-ray output devices with minimal residual radiation—describe FGNWs.

Conceptually, FGNWs utilize nuclear fusion to achieve very low yields with minimal residual radiation; for this reason, international agreements against nuclear weapons testing may fail to deter development of these weapons. For instance, the Comprehensive Test Ban Treaty (CTBT) contains no provisions for limiting any testing involving nuclear energy release from pure fusion reactions; as such, it is possible that the development and testing of FGNWs could be done entirely without violating the CTBT.[5] If Russia, or another capable state actor, were able to refine existing technology and fully develop FGNWs, it may be able to do so without violating international agreements.

FGNWs could equip Russia with nuclear weapons that offer significant military advantages without the collateral damage or environmental concerns of current nuclear weapons. Without these drawbacks, there may be less international condemnation of their use which, in turn, would significantly lower the nuclear weapons use threshold. This erosion of the collective impression that nuclear use would be unfathomable is something deterrence theorist Herman Kahn calls "our sense of nuclear incredulity."[6] By eroding nuclear incredulity, FGNWs could disrupt the deterrence paradigm that has prevented nuclear weapons use for the last seven decades.

Before examining the implications of FGNWs on the CTBT and the deterrence paradigm, this article will explain the conceptual development of FGNWs. This is followed by an examination of their military utility, particularly in regional conflicts. Finally, this work will outline the limitations of the CTBT and make recommendations about ways the international community might strengthen existing arms control treaties in the context of emerging technology.

FGNWs AND THEIR MILITARY UTILITY

Unlike the nuclear weapons used on Hiroshima and Nagasaki, the theoretical concept of FGNWs entails a new class of nuclear weapon that would produce all, or nearly all, of their yield from fusion alone. This differs from the vast majority of nuclear weapons in the current stockpiles of nuclear weapons states, which produce explosive yield through a combination of fission and fusion. This is significant: it means that FGNWs could theoretically be designed to produce a range of yields, anywhere from very small to very large, and would be free of the fallout-producing residual radiation that make contemporary nuclear weapons use so unacceptable. Combining a fourth-generation nuclear warhead with any of a number of modern, high-precision delivery systems—like cruise missiles or guided bombs—could result in a class of weapons

Bikini Atoll, Micronesia. The “Baker” explosion resulting from a nuclear weapon test. (United States Department of Defense / Public Domain)

that are devastatingly effective and more usable than contemporary nuclear weapons.

Nuclear fission is a process in which a neutron splits the nucleus of plutonium or highly enriched uranium atoms, releasing neutrons and energy in the form of heat, light, and highly-penetrating radiation.[7] The neutrons produced by fission collide with other nuclei and produce successive fission events in a chain reaction. When a nucleus splits, it produces radioactive fission fragments which can contaminate soil and other materials that are sucked into the mushroom cloud of a nuclear explosion. When these radioactive particles settle to the ground, it is known as fallout.[8] Fallout clouds can drift with atmospheric winds, covering hundreds of square miles, dramatically increasing casualties. The indiscriminate and excruciating nature of casualties from fallout is one of the most reprehensible aspects of nuclear weapons use. If a nuclear weapon could be created that would significantly limit the potential for fallout, it may be seen as a much more acceptable option both by decision makers and the international community. By producing explosive yield without an initial fallout-producing fission reaction, FGNWs could provide exactly this capability.

Nuclear fusion, by contrast, is a process in which two nuclei of a lighter material are fused together under intense heat and pressure to form a heavier atom which then breaks apart, releasing energy and high energy neutrons.[9] To date, the only proven means of driving a fusion reaction in a nuclear weapon has been to utilize an initial stage fission reaction. This means that all nuclear weapons built thus far have the potential to create dangerous and persistent fallout.

First, Second, and Third Generation Nuclear Weapons

Conceptually, FGNWs follow a progression in weapons design that extends from the first three generations of nuclear weapons developed since the 1940s. First generation nuclear weapons are pure fission weapons like the bombs dropped on Hiroshima and Nagasaki. This design requires bringing together a critical mass of either plutonium or highly enriched uranium and bombarding it with neutrons to trigger a chain reaction.[10] The minimum explosive yield of first-generation weapons is governed, in part, by the minimum critical mass required to sustain a chain reaction. A technique known as boosting involves injecting deuterium and tritium (DT) gas into the hollow shell of fissile material which increases a weapon’s efficiency.[11] While boosting allows for a reduced quantity of fissile material in the fission primary, first generation nuclear weapons are still limited by the physics of critical mass and thus have a lower limit on the yield they produce. The fission reaction also means that all first-generation weapons produce radioactive fission fragments capable of causing fallout.

Second generation nuclear weapons have a primary stage fission device, and a secondary stage of fusion fuel. Both the primary and secondary are enclosed in a radiation case designed to contain x-rays, produced by the fission reaction.[12] Second generation nuclear weapons are referred to as thermonuclear weapons because the thermal energy released from the primary provides the heat and pressure necessary to drive fusion in the secondary. The x-rays produced in the detonation of the primary fill the radiation case, ablating the surface of the secondary which creates inward pressure to compress the fusion fuel.[13] Second-generation weapons made the production of nearly limitless yields possible.

Third generation nuclear weapons are generally thought of as special purpose weapons that were designed and built between the late 1950s and 1980s. Some weapons were designed but never built, while others were built and retired from the stockpiles of nuclear weapons states.[14] This generation of weapons still utilizes a fission primary and fusion secondary, but the secondary is constructed of materials designed to produce tailored effects including enhanced radiation production. Third generation devices also include specialized nuclear devices designed for peaceful nuclear explosions. These devices were developed to have a high fusion fraction and to produce less residual radiation, making them more suitable for civilian applications such as mining and digging canals.

It was design innovations that emerged from peaceful nuclear explosions by the United States and the Soviet Union that would set the stage for the concept of FGNWs. Both the United States and the Soviet Union pursued programs for peaceful nuclear explosions in the late 1950s and 1960s. In 1957, the Nuclear Energy Commission established the Plowshare Program to investigate the use of nuclear explosions for civilian applications, including excavation of canals, or roadway cuts, as well as underground mining.[15] Throughout the program, emphasis was placed on designing special very low fission explosives.[16] Twenty-seven peaceful nuclear explosions were conducted in total, some with yields ranging as low as 0.1 kt.[17] Nine of these tests were conducted with the purpose of evaluating the design of an ultra-low fission thermonuclear device. The test resulted in a validated design with a fission yield that released as little as 20 tons of fission products into the atmosphere.[18] This emphasis on low-fission devices with less residual radiation laid the conceptual groundwork for the future concept of FGNWs that could be completely free of hazardous fallout.

The Soviet government also pursued a peaceful nuclear explosions program that produced developments which contributed to the conceptualization of FGNWs. "Program No. 7 – Nuclear Explosions for the National Economy," was established in 1965.[19] From the program's inception, Soviet nuclear weapons laboratories played major roles in the design of devices.[20] These labs placed a premium on reducing the radioactive tritium produced.[21] Some of the most startling Soviet tests were a series of six detonations conducted in 1977 and 1978 that produced yields between 0.01 and 0.08 kt.[22] These extremely low yields indicate that Soviet device designs had progressed to an advanced level where they could drive a fusion reaction with a very minimal fission primary. The design innovation and testing during this era paved the way for future scientists and weapons designers to conceptualize FGNWs for military application. Without the Soviet Government's peaceful nuclear weapons program, development of FGNWs would likely be several decades into the future.

Developing Technology of Fourth Generation Nuclear Weapons

Fourth generation nuclear weapons differ from previous generations in that the majority of the yield comes from a fusion reaction that is not driven by a fission primary. Multiple developing but realistic technologies in a field known as high energy density technologies have the potential to make such an independent fusion reaction possible. The first is the use of powerful, petawatt-class lasers. If directed at small pellets of fusion fuel, these lasers can deliver sufficient energy to ablate the surface of the pellets, generating heat and pressure sufficient to induce fusion. The use of lasers to drive fusion is a proven technology in use at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL). Similar research with high energy lasers is also ongoing in Japan, France, the UK, and Germany.[23] At the NIF, this laser-based fusion research helps the U.S. nuclear enterprise certify the reliability of the nuclear weapons stockpile without underground or atmospheric testing. Currently, such high-powered lasers are far too large and require far too much energy to be used in a weapon. However, as technology advances, lasers could become a viable technology in the design of fourth generation nuclear weapons.

The second technique involves harnessing the energy released by nuclear isomers, as they transition from an excited energy state to a lower energy state. Nuclear isomers are stable, excited states of either one or more of an atom's protons or neutrons in its nucleus.[24] If that energy could be released on demand, it would be a viable means of driving a nuclear fusion reaction in an FGNW. As with high-powered lasers, nuclear isomers are the subject of ongoing experimentation that could enable the development of fourth generation nuclear weapons in the near future.

The third and most promising technique for triggering a fusion reaction in FGNWs involves antimatter. Produced only in small quantities in advanced laboratories, antimatter is composed of atoms made up of inversely charged particles (positively charged electrons, or negatively charged protons). When antimatter particles come into contact with matter, they annihilate in a burst of energy sufficient to drive a fusion reaction. Antimatter is most promising because there is no fundamental scientific problem with the technology or its potential applications.[25] There are, however, challenges. Beyond the cost to generate, there are engineering considerations such as designing a reliable containment device that would meet the reliability requirements of components in nuclear weapons.

Military Advantage of FGNWs and Implications

Since fourth generation nuclear weapons use pure fusion to produce explosive yield, they do not produce radioactive fission fragments like other nuclear weapons. As a cleaner weapon with significantly reduced residual radiation, FGNWs could be used close to formations of troops or civilians in tactical scenarios without the risk of contaminating those areas with radioactive fallout.

Additionally, FGNWs could be designed with an unconstrained range of yields which would allow them to fill the capability gap between advanced conventional weapons and existing nuclear weapons. Since FGNWs do not rely on an initial fission reaction to drive fusion, the limitations imposed by a minimum critical mass do not exist. This means that designers could create FGNWs of any yield or an easily adjustable range of yields. Currently, the most powerful non-nuclear weapon ever built is the Russian Father of all Bombs (FOAB) with a total explosive yield of 44 tons.[26] This is still about ten times smaller than the lowest-yield nuclear weapons, which leaves a capability gap. With an unconstrained range of yields, FGNWs could fill that gap. The potential for low nuclear yields combined with reduced residual radiation makes for a weapon with significantly reduced collateral damage to both civilians and one's own troops.

FGNWs could present a fundamental shift in nuclear warfighting by dangerously reducing the nuclear use threshold. Decision makers could find it much easier to authorize the use of weapons that are cleaner and produce less collateral da-

Control panel of the first Russian nuclear reactor. (Борис Приходько / CC BY-SA)

mage, particularly if they are embroiled in a conflict against a conventionally superior adversary. In the case of limited, regional conflicts occurring on the periphery of NATO, FGNWs could significantly influence Russian strategic effects. Examining conflicts such as the Russo-Georgian war in 2008 and the Russian military intervention in Ukraine, the use of FGNWs in such limited, regional conflicts, would likely play out in two ways.

First, Russia could use FGNWs to rapidly gain a military advantage in a conflict, creating a *fait accompli* before NATO could deliberate over a response, mobilize forces, and intervene. The strike at Zelenopillya, Ukraine in July 2014 was a striking example of the effective combination of aerial reconnaissance and precision guided, long-range artillery to achieve this effect. In one engagement, Russian forces destroyed more than two battalions of Ukrainian combat vehicles in the span of a few hours; the Ukrainian government sought a political solution less than two months later.[27] Rather than expending 40 salvos of costly precision-guided munitions, a half dozen FGNWs could produce a comparable effect.

The second motivation for Russia to employ FGNWs would be in an attempt to rapidly de-escalate a conflict with NATO in order to extricate themselves from a conflict that they are not prepared to fight. What has been referred to as Russia's "escalate to de-escalate" strategy is part of an evolution in the Russian perception of modern conflict that can be traced back to at least 1991.[28] The more doctrinal terminology, "escalation control" has origins in the writing of Thomas Schelling and encompasses the idea that an actor can determine the level of violence of a conflict in such a way as to discourage one's adversary from raising it further.[29] Russian military leaders have noted the tendency for crises to "develop impetuously, and to potentially escalate from local wars to global ones."[30] Furthermore, the assessment that the speed, accuracy, and destructiveness of modern precision-guided munitions can achieve comparable strategic effects to nuclear weapons prompted Moscow to reject a no-first-use nuclear policy, thereby opening discussion to using nuclear weapons to de-escalate a conflict.[31]

CHALLENGES TO THE DETERRENCE PARADIGM

Deterrence theorist Herman Kahn refers to escalations in armed conflict as "competitions in risk taking" in which two sides apply a certain amount of resolve and resources.[32] If one side increases their effort in some way and the other side does not respond in kind, it is possible to secure victory. As Kahn contends, the increase in effort that results in victory will be considered low in cost compared to the benefits. Therefore, as the parties in a conflict apply their decision-making calculus, the greater concern is not so much the cost of applying additional resources to escalate the conflict, but rather the fear of how the other side will react. In short, fear of reprisal is the force that is more likely to deter.[33] It follows logically that if there is a reduced fear of reprisal then an actor will be less deterred to escalate. The development of FGNWs would insert a new military capability in the gap that currently exists between advanced conventional munitions and nuclear weapons. Their creation would blur the lines of what is tactical and what is strategic. FGNWs would alter the current deterrence landscape and complicate the decision-making process in response to their use.

Kahn describes an "escalation ladder" to examine one way in which a conflict may escalate.[34] The ladder depicts a linear arrangement of roughly increasing levels of intensity of crisis ranging from political, economic, and diplomatic gestures to insensate war.[35] Writing in 1965, Kahn's contemporary example was the Cold War, a conflict between two superpowers. Both the incomprehensible cost of a massive nuclear exchange and the vast capabilities on both sides made it such that a conflict could theoretically involve all 44 rungs of Kahn's ladder in a deliberate, protracted conflict. The limited, regional conflicts such as the Russo-Georgian war and the Russian military intervention in Ukraine are quite different, but Kahn's depiction of the escalation ladder remains useful. For Russia, the development of FGNWs would essentially add a rung on the ladder that only those with FGNWs can access. By creating an additional rung for themselves, Russia would make it more difficult for the United States or NATO to respond to the use of FGNWs. Knowing that the United States or NATO has no appropriate response, deterrence would be threatened.

Consider, for instance, the U.S. position in a regional conflict in which FGNWs are used. It would be disproportionate to respond to the use of a sub-kiloton FGNW with a strategic system or even a non-strategic nuclear weapon with potential for considerably more collateral damage. Therefore, this response would be seen as politically unacceptable.[36] Further complicating the deterrence calculus is the consideration that the use of FGNWs could result in significantly less collateral damage and fallout. This begs the question; how do you deter the use of weapons that are increasingly "usable"? In order to deter an adversary, the other party must at least have a creditable response available. FGNWs complicate deterrence because they would be weapons that have no precisely equivalent response.

LIMITATIONS AND AMBIGUITY IN THE COMPREHENSIVE TEST BAN TREATY

Because FGNWs could offer significant military advantages, lower the nuclear use threshold, and disrupt the deterrence paradigm, the international community has a vested interest in discouraging their development. Since 1996, the foremost diplomatic apparatus for preventing the development of new nuclear weapons has been the Comprehensive Test Ban Treaty. The intent of the CTBT is to render nuclear weapons testing illegal, thereby ensuring that nuclear weapons states are not able to develop more advanced nuclear weapons technology.[37] Although a non-nuclear weapons state could develop a nuclear weapon without testing, "the CTBT nullifies the possibility of a state gaining confidence in an untested thermonuclear weapon, particularly a sophisticated one."[38]

However, the text of the CTBT contains no definition of "nuclear explosion," leaving this provision to potentially ambiguous interpretation. One of the most contentious issues to emerge in the process of negotiations was the precise interpretation of the phrase zero nuclear yield, which defines the paramount limitation on nuclear weapons testing as outlined in Article I. After some negotiation, the five nuclear-weapon states agreed to not restrict subcritical experiments or inertial confinement fusion.[39] A liability in the decision not to restrict fusion research that increases as technology advances is that the kind of fusion research that is permissible under the CTBT could be leveraged to develop FGNWs. This decision was contentious as the aim of the treaty was to be comprehensive, but nuclear weapons states staunchly advocated to allow experimental testing, including fusion research, necessary to certify their stockpiles. The crux of the negotiation focused on striking a balance between being restrictive enough to be considered "comprehensive" without impinging on the ability of nuclear weapons states to certify the safety and reliability of their stockpiles.

The international community cannot outlaw, *vis-à-vis* the CTBT, fusion research *in toto* because fusion experiments help nuclear weapons states certify their nuclear weapons stockpiles without weapons testing. The NIF at Lawrence Livermore National Lab is an essential component of the National Nuclear Security Administration's stockpile stewardship program, which is charged with certifying the safety and effectiveness of the U.S. nuclear arsenal without conducting nuclear explosive tests.[40] The NIF accomplishes this by allowing scientists to perform experiments at a much higher rate than was possible with underground testing. Russia has a similar facility for inertial confinement fusion which allows for

Poti, Georgia. A ship sunk during the Russo-Georgian War. (Gavin / CC BY-SA)

New York, NY, U.S.A. Minister of Foreign Affairs for Algeria Sabri Boukadoum (left) meets with CTBTO Executive Secretary Lassina Zerbo (right) during the 14th CTBT Conference. (CTBTO / CC BY)

responsible stockpile management of Russian nuclear weapons without nuclear testing. In short, the kind of nuclear fusion research that could facilitate the development of FGNWs is pervasive, it is not prohibited under the CTBT, and it is vital for nuclear weapons states to validate the safety and reliability of existing nuclear weapon stockpiles.

INTERNATIONAL RESPONSE, CONCLUSIONS, AND RECOMMENDATIONS

This work seeks to offer policy considerations pertaining to the development of fourth generation nuclear weapons. The fourth generation of nuclear weapons would leverage emerging technology to offer significant military advantages with fewer collateral or stigmatic concerns. In doing so, these devices could lower the nuclear use threshold, jeopardize the current deterrence paradigm, and call into question the effectiveness or validity of current arms control treaties.

The first conclusion from this analysis is that FGNWs, while conceptual in nature, are based on realistic technology that is being demonstrated now. Second, the potential development of FGNWs could provide an actor with significant military and strategic advantages by delivering greater effects on select targets than advanced conventional munitions with less collateral damage and fallout than current nuclear weapons. By offering significant advantages with fewer drawbacks, FGNWs may be seen as more acceptable and could lower the nuclear use threshold, threatening the paradigm that has helped the world to avoid their use for the last 74 years. Third, while the CTBT has been largely effective at limiting the development of new nuclear capabilities over the last two decades, the treaty does not restrict the kind of nuclear fusion experimentation that could facilitate the development of FGNWs. In short, the CTBT in its current form will not prevent the development of FGNWs.

The first policy recommendation to follow from this analysis is that the international community must begin a dialogue about emerging technologies that could enable the development of FGNWs. As a corollary, this dialogue must address how such weapons could impact deterrence and arms control efforts. Relevant technologies are continuing to mature; if arms control policies are to remain effective, a forum of ideas must be facilitated now so that we may be better prepared for the future. The second policy consideration is that the parties to the CTBT must consider the need for an arms control treaty that addresses the potential development of FGNWs. From this analysis, it is clear that, in its current form, the CTBT cannot be relied upon to achieve this. A revision to the CTBT or enhancements of its verification regime could potentially be sufficient. The substance of such a revision could include limitations on certain types of fusion research or enhancements to the treaty verification regime aimed at detecting fusion testing to develop FGNWs. An appropriate venue for such a dialogue is the Conference Facilitating Entry into Force held every other year.[41] While its advocates hope that the Treaty on the Prohibition of Nuclear weapons could make up for deficiencies in the CTBT, it is unlikely to ever enter into force. The reality is that arms control treaties cannot be expected to maintain effectiveness indefinitely into the future, particularly as technology continues to advance. We must not consider them to be static, enduring documents, but rather as continually evolving efforts that must be revisited as technology develops.

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[31] Ibid.
[32] Kahn, Herman, *On Escalation: Metaphors and Scenarios*, New York: Praeger, 1965, 3.
[33] Ibid.
[34] Ibid., 39.
[35] Ibid., 38.
[36] Here the definition of "strategic nuclear weapon" refers to those nuclear weapons that are limited under the New Strategic Arms Reduction Treaty (New START) which, in the U.S. nuclear weapons stockpile, includes the W78 and W87 thermonuclear warheads delivered by the Minuteman III intercontinental ballistic missiles (ICBM), the W76 and W88 thermonuclear warheads delivered by the MARK V submarine launched ballistic missile (SLBM), and the B83 gravity bomb, the only remaining megaton class weapon remaining in the U.S. inventory.
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