Deep Cuts Commission Issue Brief

Hypersonic Glide Vehicles: Evaluating inadvertent escalation risks

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In the coming years, the United States is expected to join Russia and other states in deploying a new generation of hypersonic weapons – weapons that travel through the atmosphere at speeds greater than five times the speed of sound (Mach 5). Although alarmism is misplaced, hypersonic ballistic glide vehicles (BGVs) could create new pathways for inadvertent escalation and present additional challenges for arms control. This Deep Cuts Issue Brief looks at how hypersonic weapons affect delivery times, maneuver capability, attack warning and performance against missile defense. Focusing on the Euro-Atlantic region, it proposes risk reduction and arms control measures that could address escalation risks specific to hypersonic weapons.

Key Findings

Much of the alarm around BGVs is unwarranted. The deployment of BGVs should not negatively affect the survivability of nuclear forces.

- The delivery time is not be significantly reduced for BGVs compared to already existing ballistic missiles flying on a depressed trajectory.
- The improved penetration abilities of national missile defense systems increases confidence in second strike survivability.
- BGVs do not provide improved accuracy against mobile of fixed targets compared to existing systems with maneuvering reentry vehicles .

BGVs however increase inadvertent escalation risks due to their target ambiguity during flight and by limiting the dual confirmation of a detected launch through radar and heat signatures.

Policy recommendations

Risk-reduction measures should therefore aim at decreasing declaratory ambiguity and diffusing worst-case assumptions.

- States should clarify internally the mission sets of their BGVs and brief each other on their doctrinal position similar to their nuclear strategy.
- States should keep a hotline open between military commanders with the authority to launch BGVs.
- NATO allies should prepare for future arms control opportunities and prioritize among possible measures and try to form a consensus around the itemsthey deem most important and feasible.

Introduction

The United States, Russia, and China are developing a new generation of hypersonic weapons. The systems under development include both cruise missiles and glide vehicles that are launched by ballistic missiles.[*] Here we focus on hypersonic boost-glide vehicles (BGVs), which are launched by missiles into space but return to the atmosphere shortly after the end of the boost phase and use lift forces to sustain flight at high velocities and altitudes.

The United States has had several hypersonic systems under development: the Air-launched Rapid Response Weapon (ARRW), the ground-launched Long-Range Hypersonic Weapon ("Dark Eagle"), and the sea-launched Intermediate-Range Conventional Prompt Strike (IRCPS) system. In addition, the Defense Advanced Research Projects Agency (DARPA) is developing the ground-launched Operational Fires and the air-launched Tactical Boost Glide systems. Despite the Pentagon's stated goal to "catch up and overtake" Russia and China in the deployment of offensive hypersonic weapons and the intention of the Department of Defense to purchase at least 24 such systems,[1] they are still absent in the U.S. operative arsenal. Flight tests of the U.S. Navy's IRCPS system are scheduled for 2024, with deployment planned the following year.[2] Tests of the U.S. Army's Long-Range Hypersonic Weapon have been postponed,[3] and the U.S. Air Force's ARRW was cancelled in 2023 after multiple unsuccessful tests.

Whereas U.S. efforts focus on the delivery of conventional weapons over short to medium ranges, Russia and China are developing dual-capable systems that can deliver nuclear weapons, including over intercontinental ranges. Russia began deploying its nuclear-capable Avangard BGV in 2019 on SS-19 intercontinental ballistic missiles (ICBMs), and plans to place them on the new RS-28 Sarmat ICBMs after their entry into combat duty. Although technically an aero-ballistic missile rather than a boost-glide vehicle, the Russian Kinzhal system features certain similar characteristics. Deployed on modified MiG-31K interceptor aircraft, the variant of the ground-based Iskander-M SRBM is dual-capable and has a range of up to 2,000 km. While China has deployed its dual-capable DF-17 BGV since 2019 and tested various intercontinental-range variants, several other countries, including North Korea, France, Japan and South Korea, currently seek to develop their own BGVs as well.

Many observers have reacted to the development of hypersonic weapons with alarm. In testimony before the U.S. Senate Armed Services Committee, Gen. Robert Ashley, Director of the Defense Intelligence Agency, stated, "Developments in hypersonic propulsion will revolutionize warfare by providing the ability to strike targets more quickly, at greater distances, and with greater firepower."[4] Gen. Mark Milley, Chairman of the U.S. Joint Chiefs of Staff, referred to a Chinese test of a hypersonic weapon as "very concerning" and said, "I don't know if it's quite a Sputnik moment, but I think it's very close to that."[5] Vice Chairman Gen. John Hyten raised the prospect that such weapons could provide the basis for a surprise nuclear first strike on the United States.[6]

Concerns about hypersonic weapons relate to speed of delivery, maneuver and inability to predict the target of an attack, attack warning, and ability to penetrate ballistic missile defenses. We consider each of these concerns below.

Delivery time

The term "hypersonic" gives the impression that such weapons are much faster than traditional delivery vehicles. While it is true that long-range bombers and cruise missiles have generally been subsonic or low supersonic (less than Mach 1.5), traditional ICBMs and submarine-launched ballistic missiles (SLBMs) achieve speeds up to Mach 20. Although Gen. Hyten asserted that BGVs could reach targets faster than ballistic missiles,[**] the advantage is modest at best. A BGV can reach targets at long ranges 3 to 6 minutes faster than a reentry vehicle (RV) delivered by a ballistic missile on a typical (minimum-energy) trajectory:

* Long-distance hypersonic flight poses extreme challenges for cruise missiles, due to the heating they experience over long flight times at relatively low altitudes. Hypersonic cruise missile development has generally focused on tactical (e.g., anti-ship) weapons with ranges of 1000 km or less, such as the Russian Tsirkon.

** In response to Sen. Shaheen, who asked "how much time we have from the point at which those weapons might be launched until when they might land in the United States," Gen. Hyten replied, "it is a shorter period of time. The ballistic missile is roughly 30 minutes. A hypersonic weapon, depending on the design, could be half of that, depending on where it is launched from, the platform. It could be even less than that." U.S. Senate, Committee on Armed Services, "Hearing to Receive Testimony on United States Strategic Command and United States Northern Command in Review of the Defense Authorization Request for Fiscal Year 2020 and the Future Years Defense Program" (Washington, DC: Alderson Court Reporting, 2019), 36, https://www.stratcom.mil/Media/Speeches/Article/1771903/us-strategic-command-and-us-northern-command-sasc-testimony/

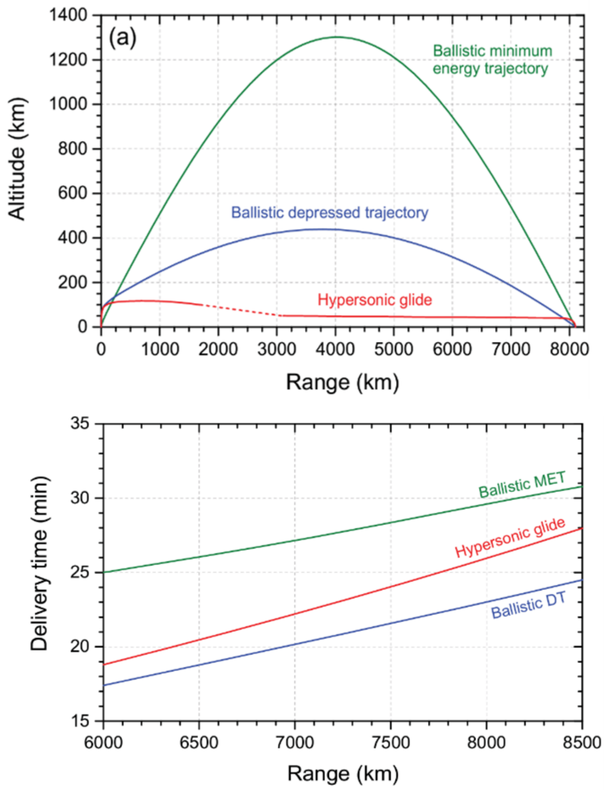

Figure 1. (a) Trajectory of a BGV compared to an RV on ballistic minimum-energy and depressed trajectories; (b) delivery time of a BGV compared to an RV on ballistic minimum-energy and depressed trajectories for ranges of 6000 to 8500 km.[21]

19 v. 25 minutes at 6000 km range; 28 v. 31 minutes at 8500 km range.[7] But nuclear states have long had to consider the possibility that adversaries might launch ballistic missiles on depressed trajectories, with faster arrival times. In fact, an RV delivered on a depressed trajectory would arrive 2 to 4 minutes faster than a BGV.[8] Thus, BGVs provide no new or unique capability for increased speed or decreased delivery time compared to the ballistic missiles that have been widely deployed for over 60 years. Figure 1 compares the trajectory and delivery time of a BGV compared with a traditional RV on minimum-energy and depressed trajectories.

Maneuver capability

Unlike ballistic RVs, which travel on fixed and predictable paths after being released from the final stage of the ballistic missile, BGVs use aerodynamic forces to change direction over the duration of their flight in the atmosphere. The ability to maneuver could be used for four possible purposes: to achieve higher accuracies in attacks against fixed targets; to attack targets that have changed position after the launch of the glide vehicle; to evade air and missile defense interceptors; or to avoid over-flight.

It is important to note that maneuver capability sufficient for the first three of these purposes has long been possible using maneuvering reentry vehicles (MaRVs). MaRVs were originally developed by the United States in the 1970s as a countermeasure to ballistic missile defenses but were not deployed because they were determined to be unnecessary to penetrate Soviet defenses. A MaRV was first deployed in the mid-1980s on the intermediate-range Pershing-II missile to achieve higher accuracies that would allow the use of a lower-yield warhead. A MaRV capability was developed in the mid-2000s for the Conventional Trident Modification, to achieve the high accuracies necessary for the delivery of non-nuclear payloads against fixed targets; this was abandoned due to concerns that a Trident armed with conventional warheads might be mistaken for a nuclear attack. Regardless of whether maneuver is achieved with a BGV or MaRV, it requires receiving updated information on the position of the BGV or MaRV relative to the target. This could be done by equipping the BGV or MaRV with inertial or GPS navigation or an optical or radar sensor that can detect the target. A recent analysis by the Congressional Budget Office notes that hypersonic weapons could cost one-third more than maneuverable warheads of the same range deployed by ballistic missiles.[9]

Although MaRVs can execute maneuvers that change course by hundreds of kilometers, they do so only in the last minute of flight, after the RV has reentered the atmosphere. Because BGVs reenter the atmosphere much earlier, they can execute earlier and larger maneuvers. Whereas a ballistic missile RV or MaRV launched from the continental United States against North Korea would necessarily overfly Russia and China, a BGV might avoid such overflight. Overflight could also be avoided by using aircraft or through the positioning of the launch platform (e.g., SSBN), and the dangers of overflight could be managed through notifications, so it is not clear that the large maneuvers made possible by BGVs would provide an important advantage.

Attack warning

An important difference between BGVs and traditional RVs is in detection and tracking. Both involve the launch of a ballistic missile, and the very bright infrared signal from the hot missile exhaust can be detected and tracked by early warning satellites. RVs are released on predictable ballistic trajectories at high altitudes in space, where they can be detected and tracked at long distances by ground-based radars. By contrast, BGVs reenter the atmosphere soon after the boost phase and use lift forces to glide through the atmosphere to their targets. Although the much lower altitude path delays detection of BGVs by ground-based radar, friction with air heats the BGV to temperatures that are readily detectable by space-based infrared sensors.[10] BGVs would not avoid attack warning and tracking and therefore would not raise concerns about surprise attack or reduced warning time.

There is an important caveat. The United States maintains the option of launching its silo-based ICBMs on confirmed warning of an attack, before the ICBMs are destroyed by incoming warheads. This prevents an adversary from being confident that they could preemptively destroy U.S. ICBMs. Confirmation of attack is provided by radar detection of the incoming warheads, which confirms the warning provided earlier by satellites that detect the infrared signal from the missile launches. The requirement that an attack be confirmed by independent systems using different physical principles is known as "dual phenomenology." Under current U.S. doctrine, the launch-under-attack option for ICBMs can be exercised only if the attack is detected with both early-warning satellites and early-warning radars. It is assumed that Russia also maintains the option to launch its missiles on warning of an attack, but it is not known whether radar confirmation of satellite warning is required.[11]

As noted above, a BGV attack will be detected not only by the launch of the missile, but also by the infrared emissions of the BGV as it travels through the atmosphere towards its target. In both cases, detection and tracking are provided by satellites with infrared detectors. But radar detection of the BGV will occur much later. Even in the most favorable case for radar detection—a missile launched from the Russian ICBM base at Dombarovsky against the U.S. ICBM base at Minot, which almost directly overflies the U.S. early-warning radar at Thule—radar detection of the BGV will occur 9 minutes later than an RV on a minimum-energy trajectory.[***] Because the BGV will arrive on the target 3 minutes earlier than the RV, the time available for a decision to launch U.S. ICBMs is reduced by a total of 12 minutes. In order to ensure that all ICBMs can be launched before they are destroyed, the President must issue a decision to launch at least 9 minutes before the attacking warhead arrives. As shown in Table 1, this leaves little time available for a decision after radar confirmation: only 2 minutes for a BGV attack compared to 14 minutes for a ballistic RV on a minimum-energy trajectory.[12] This is the most favorable case for radar confirmation of a BGV attack; other trajectories would result in later radar detection, with less time remaining before the BGV arrives on target.

	RV	BGV
ICBM launch from Dombarovsky	H	H
Satellite IR detection	H + 1 min	H + 1 min
Rade detection at Thule	H + 9 min	H + 18 min
Last opportunity for LUA order	H + 23 min	H + 20 min
Impact at Minot	H + 32 min	H+ 29 min
Decision time available for LUA order	14 min	2 min

Table 1. Time from launch to radar detection and LUA decision for BGV and RV on a ballistic minimum-energy trajectory, launched at time "H" from Russian ICBM base at Dombarovsky against U.S. ICBM base at Minot.

The importance of the delayed radar confirmation is unclear. Russia (or perhaps China) would have to deploy hundreds of BGVs in order to threaten most or all of the 400 U.S. ICBM silos. If this occurs, the United States might respond by relaxing the requirement for radar confirmation to exercise the launch-under-attack option. It might instead require detection of both the missile launch and the BGV trajectories through the atmosphere. Although both would be based on detection by infrared sensors on satellites, the infrared signals would be very different and could be detected by different satellite systems, which might be considered adequate to confirm an attack with sufficient confidence to permit launch-under-attack. Ongoing U.S. development efforts for new detection and tracking systems aim to enhance the reliability and accuracy of these infra-red signals. This includes the new Hypersonic and Ballistic Tracking Space Sensor (HBTSS) and other satellites of the "Proliferated Warfighter Space Architecture."

Missile defense

Perhaps the most significant difference between BGVs and RVs is their vulnerability to interception by missile defenses, which may be the primary motivation for the development of long-range nuclear BGVs by Russia and China. RVs on ballistic trajectories travel for most of their flight at high altitudes in space, where they can be engaged by midcourse missile defense interceptors that use infrared sensors to locate and home on the RV. But the national

[***] Note that the RS-28 Sarmat could launch either RVs or BGVs against the United States via the Southern hemisphere, avoiding detection by north-facing early-warning radars.

and regional midcourse missile defense systems that have been deployed by the United States to defend large areas cannot engage targets below 100 kilometers, because the heat generated at lower altitudes would blind the infrared sensors used to locate and home on the target warhead. Because BGVs have glide altitudes of 40 to 50 kilometers, they cannot be engaged by the interceptors deployed as part of the U.S. Ground-based Midcourse Defense or the Aegis Sea-based Midcourse Defense systems.[13]

BGVs might be vulnerable to terminal-phase interceptors that are designed to operate at lower altitudes, such as the Patriot Advanced Capability-3 system, particularly after the BGV has slowed to speeds that are lower than the interceptor. For example, Ukrainian forces used such a terminal-phase missile defense system to intercept Russian Kinzhal missiles. But the areas that could be defended by a terminal-phase system are relatively small. Although that might be adequate for the defense of high-value point targets, such as an airfield or aircraft carrier, it would not provide a basis for a regional or national missile defense against BGVs.

Because BGVs are launched by ballistic missiles, they would be vulnerable to defensive systems that destroy missiles in their boost phase. Boost-phase defense is extremely challenging because the boost-phase is short (3-5 minutes) and takes place deep within an adversary's territory (for an ICBM) or over the open ocean (for an SLBM). This makes it difficult to position interceptors close enough to engage the missile during the boost phase. Although it might be possible to mount an effective boost-phase defense against missiles launched by a small country, such as North Korea, no workable concept has been proposed that would permit a boost-phase defense against missiles launched from deep within Russia or China.[14] Other types of missile defense that leverage higher interceptor speeds and rely on space-based infrared sensors for detection and tracking are still in the research and development stages.

In summary, the deployment of hypersonic weapons should not negatively affect the survivability of nuclear forces. On the contrary, to the extent that BGVs can penetrate national missile defenses more effectively and reliably than traditional RVs and their associated countermeasures, they should strengthen deterrence and improve stability by providing additional confidence in second-strike retaliatory capabilities. This should, in turn, reduce the potential for arms racing and build-ups of offensive forces to offset missile defenses.

Escalation risks

Certain characteristics specific to BGVs may raise new risks of inadvertent escalation in a conflict between NATO and Russia. From the defender's perspective, BGVs are unique and different from ballistic and cruise missiles. A country under attack can detect an incoming BGV without being able to predict the intended target. This differentiates BGVs from ballistic missiles, whose point of impact can be calculated and whose maneuverability is limited to the relatively short reentry phase, and from cruise missiles, which are more difficult to detect from a distance but take longer to reach their target. Military forces under attack by a BGV may expect the missile to strike a target deemed much more important than its actual aim point.

There are three ways in which target ambiguity might lead to inadvertent escalation. First, after detecting an incoming BGV, the targeted nation could fear that the attack is directed against missile launchers or associated command-and-control posts. Given the high stakes in a military conflict and the impossibility to predict the BGV's point of impact, it might launch its own missiles before the incoming BGV can reach and destroy them rather than wait and risk losing its forces. Second, the nation under attack may fear an attack on critical components of its early-warning infrastructure that would destroy its capability to detect follow-on salvos. In an effort to preempt or limit the expected damage from such a wider attack, the nation might respond to the detected incoming BGV with a counterattack aimed at disrupting or destroying adversary aircraft, missiles, launch platforms, and supporting structures. It might also try to deter its adversary from what it deems a looming wider attack by launching missile strikes against high-value targets or even threatening the use of nuclear weapons.[15] Any of these reactions taken under target ambiguity and worst-case assumptions could trigger further escalatory responses.

The risk of such miscalculations due to target ambiguity is compounded through declaratory ambiguity and the high per-unit costs of BGVs. Declaratory ambiguity arises when the military purpose of a weapons system is not specified or otherwise apparent to a potential adversary. The United States seeks hypersonic weapons to "help maintain tactical advantage,"[16] but also as a capability to preemptively attack enemy missiles.[17] A similar ambiguity is arguably characteristic for Russian theater-range BGVs as traditionally all Russian/Soviet missiles are potentially dual-capable. While states may employ such ambiguity to bolster the deterrent effect of a given capability, this may lead adversaries to believe BGVs are a bigger threat than intended, increasing risks of misperception and inadvertent escalation.

If a state that touted its BGVs as a strategic capability launches a BGV against a tactical asset, the attacked country may instead perceive it as an incoming threat to a target of much higher value and respond accordingly even before the point of impact is confirmed. The high per-unit costs of BGVs can further reinforce impressions that any incoming BGV poses an immediate strategic threat. Estimates put the costs of BGV variants currently under development in the United States at often several times those of similar alternatives.[18] With this in mind, a potential adversary might conclude that commanders would be hesitant to use this capability against anything but the most high-value targets.

Risk-reduction measures

Fortunately, measures to reduce risks of inadvertent escalation related to BGVs are available. Risk-reduction measures should aim at decreasing declaratory ambiguity and diffusing worst-case assumptions. Although it might seem attractive to maintain a high degree of ambiguity around the capability and envisaged purpose of BGVs, commanders may avoid using BGVs against a tactical target if it could prompt an escalatory response due to the adversary's misperception of an incoming BGV.

To diffuse worst-case assumptions, both Russia and the United States and its allies could clarify internally what mission sets their BGVs should fulfill. Subsequently, both sides could brief each other about their envisioned purposes for BGVs, similar to the dialog on nuclear doctrines in the P5 format. Existing risk-reduction measures can help, too. Despite distrust, the United States and Russia should keep a hotline open between military commanders. Finally, both sides should ensure that the commanders who can order the deployment or launch of BGVs have adequate situational awareness and can gauge potential escalation risks. For those weapons systems that can threaten an adversary's strategic nuclear forces, the launch authority should be with the President and/or the Secretary/Minister of Defense.

Arms control

Prospects for formal arms control agreements to limit BGVs are dim given the state of NATO-Russia relations. Should political conditions in the future change, however, several proposals would be conceivable. For example, restrictions on BGVs could either take the form of unilateral testing and deployment moratoria, negotiated limits, agreed upon geographical zones of basing or an outright ban for specified delivery vehicles, launchers or BGVs.

BGVs are deployed on land-, air-, and sea-based platforms. Those deployed on silo-based ICBMs, such as Russia's Avangard system, already fall under the limits of New START. This U.S.-Russian treaty limiting the two nations' strategic offensive forces is set to expire in February 2026. If and when Washington and Moscow resume arms control talks in the future, a follow-on agreement to limit strategic offensive forces, including BGVs deployed on ICBMs, should be near the top of the agenda. The verification methods that were included in New START to confirm the number of reentry vehicles deployed on ballistic missiles can be adapted for BGVs. Nevertheless, it is still premature to prognosticate what quantitative limitations, territorial restraints or quantitative ceilings on deployment could be applicable, even with the resumption of U.S.-Russian strategic dialogue.

Figure 2. A nuclear-capable B-52H Stratofortress equipped with fins as FRODs.[22]

BGVs on delivery systems with ranges below 5,500 km are not limited under New START. Should the United States and Russia agree to limit such theater-range systems, they could verify compliance through established measures, including data exchanges about the maximum number of warheads different launch platforms can carry as well as the location of these platforms. Under past arms control agreements, the parties conduct on-site inspections at military bases hosting the platforms to verify the data.

Short of on-site inspections, functionally related observable differences (FRODs) provide another option to monitor BGV deployments on road-mobile missile launchers, aircraft, and surface ships. Such FRODs have been an established practice in past U.S.-Russian arms control agreements to make platforms capable of carrying restricted weapons distinguishable to an external observer.[19] For example, U.S. nuclear-capable B-52 bombers were equipped with lateral "fins" observable through satellite imagery to distinguish them from exclusively conventionally capable bombers (see Figure 2). Surface ships and road-mobile launchers could feature similar FRODs. After establishing the maximum number of hypersonic BGVs a platform can carry and equipping the relevant platform with FRODs, the parties can deduce the maximum number of BGVs deployed on these platforms through satellite imagery. Notably, the proposed verification measures are not specific to hypersonic BGVs and could also be applied to verify limits on other types of weapons such as ballistic and cruise missiles.

The prospects for Russia and the United States to adopt these measures in the near future are dim. In 2021, the two states agreed to extend the New START Treaty limiting their strategic nuclear arsenals until 2026 and entered bilateral consultations on a future arms control framework. The United States suspended the dialogue following Russia's invasion of Ukraine in 2022; when Washington proposed to resume dialogue in 2023, Moscow rejected the offer, demanding the United States cease its "hostile policies" toward Russia.[20] Even if talks on strategic nuclear arms control resume, limiting conventional or dual-capable theater-range systems may prove more controversial domestically and especially among NATO allies. Nonetheless, if political conditions change and a window of opportunity opens, the proposed measures may serve as a blueprint to address the escalation risks and arms control challenges specific to BGVs.

Against this background, NATO allies would do well to prioritize among possible arms control and risk reduction measures and try to form a consensus around the items they deem most important and feasible once Moscow agrees to consultations. While quantitative limits may be a long shot, a dialog on the capabilities and envisaged purposes of BGVs could be starting point. Likewise, both the United States and Russia can independently take unilateral risk-reduction measures, such as an internal review of the possible escalation risks related to BGV use and, if necessary, adjustments to their launch authority.

Nonetheless, much of the alarm around BGVs is unwarranted. Considering their prospective impact on delivery times, attack warning and maneuverability, BGVs should not negatively affect the survivability of nuclear forces. Instead, to the extent that BGVs can penetrate national missile defenses more effectively and reliably than traditional RVs and their associated countermeasures, as delivery vehicles for strategic nuclear weapons they could strengthen deterrence and improve stability by providing additional confidence in second-strike retaliatory capabilities.

The escalation risks that can arise from the use of conventional and dual-capable theater-range BGVs due to target ambiguity and attack warning could be addressed given political will. If the United States and Russia resume consultations on a future arms control framework, discussions on their purpose and capabilities and military-to-military communications links should feature on the agenda. In the meantime and as new BGVs come into service, NATO allies should engage in consultations to ensure that the United States can act with their support should a window of opportunity for arms control negotiations with Russia open.

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About Deep Cuts

For years, more and more arms control treaties have been eroding and nuclear disarmament is in a deep crisis. The goal of this research and transfer project is to analyze obstacles to U.S.-Russian nuclear and conventional disarmament, to strengthen European security and to develop concrete risk-reduction measures that limit the potential for military escalation in the short term and aim to cut nuclear stockpiles in the long term.
The Deep Cuts Commission was established in 2013 and is coordinated by IFSH. The project partner is the independent Arms Control Association in Washington, D.C.

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Impress

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