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RUSSIA'S NEW NUCLEAR WEAPON DELIVERY SYSTEMS

An Open-Source Technical Review

Jill Hruby
Sam Nunn Distinguished Fellow

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FOREWORD

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In March 2018, President Vladimir Putin unexpectedly turned his annual televised address to Russia's Federal Assembly into a show-and-tell about the development of five new nuclear weapon delivery systems. "Listen to us now," he said, challenging the West. Less than a year later, Putin offered an update on the systems, which are designed to evade U.S. missile defense, and previewed a sixth that—while declared to be a conventional system—may become nuclear-capable in the future.

Jill Hruby's paper, written during her tenure as the Sam Nunn Distinguished Fellow at the Nuclear Threat Initiative (NTI), focuses on the technical aspects of these complex systems. Using publicly available information, Hruby explores a set of Russian capabilities that are noteworthy in terms of both technological breadth and variety: a new heavy intercontinental ballistic missile, strategic- and shorter-range hypersonic weapons, and development efforts toward novel strategic-range systems such as a nuclear-powered torpedo and cruise missile. Though her paper concludes that the Russians are behind on most of their announced development and deployment schedules, Putin's public disclosure of these systems suggests that he intends to demonstrate nuclear strength and innovation to his people and to the rest of the world.

The technical and safety issues that may delay ... development and deployment of some of the Russian systems may offer some additional time for U.S. and Russian leaders to re-engage and renew crucial dialogue and cooperation.

Regardless, Putin's nuclear initiatives are risky and complicate a diplomatic relationship already strained by alleged Russian violations of—and U.S. withdrawal from—the Intermediate-Range Nuclear Forces Treaty and uncertainties regarding whether the two countries will agree to extend the duration of the New Strategic Arms Reduction Treaty (New START). The Russian systems seem more likely to exacerbate strategic instability than convince the United States to revisit its intent to develop new nuclear capabilities, as announced in the 2018 Nuclear Posture Review. That instability also may have consequences beyond the bilateral U.S.–Russia relationship, as a persistent lack of dialogue and cooperation between the world's two largest nuclear powers, combined with the breakdown of Cold War arms control, will accelerate a broader nuclear arms race and erode the international consensus on the goals of the Nuclear Nonproliferation Treaty.

That's why the development of these weapons systems at this particular time, as well as some of the nuclear policies the United States is pursuing, should be a wake-up call for action on renewing dialogue and cooperation with Russia to prevent nuclear catastrophe. If a new arms race is joined with ever-more lethal weapons on both sides, we will be living in a far more dangerous world.

Jill Hruby's paper is not only a testament to her abilities as a national security leader and scholar, but also to NTI's commitment to providing the scientific and technical basis for policy experts to conduct further analysis of the impact these and other complex systems may have. The technical and safety issues that may delay the development and deployment of some of the Russian systems may offer some additional time for U.S. and Russian leaders to re-engage and renew crucial dialogue and cooperation. They should do so now—before it's too late.

NOTE FROM THE AUTHOR

In late 2018, when I joined NTI as the Sam Nunn Distinguished Fellow with an objective to help bridge nuclear nonproliferation technical and policy issues, open-source information on Russia's nuclear weapon delivery capabilities was becoming increasingly available and plentiful through Russian official statements, Russian media, international reporting, and defense-oriented blogs. President Vladimir Putin's decision to publicly release details about the development of these new systems in March of 2018 opened the door to this new public information flow. The information gives nuclear policy analysts the opportunity to work with more detailed unclassified information. At the same time, it presents a new challenge for analysts to keep up with news releases on various systems and verify that sources are either credible and/or corroborated by other sources. The combination of this new opportunity and challenge prompted me to undertake a comprehensive review and evaluation of the open-source information now available in the hopes it will be useful to nuclear policy analysts today and going forward.

To develop this report, I scoured the news media and blogs on the new Russian delivery systems and documented the information I found, along with the sources. If I found only a single reference to something, I did not include it, with rare exception. If I found many references, I included the information. If I found conflicting information, I presented the range of information and indicated the predominant data. Whenever possible, I compared reported plans with actual evidence of development, such as openly reported observed system tests.

In addition, I have provided relevant technical background and descriptions to provide context for the information. This is especially true with regard to hypersonic technology because it is a new development in the nuclear field. At the request of my NTI colleagues, I also included some information on the status of U.S. and Chinese activity in hypersonic technology to provide context for the Russian developments.

This report is current to September 2019. While undoubtedly some of the information gathered is not fully accurate and the information will change with time, new development activities, and additional observation, I hope the information in this report provides a foundation and resource for the nuclear non-proliferation community.

EXECUTIVE SUMMARY

After years of secret development of new nuclear weapon delivery systems designed to evade missile defense, Russia began openly reporting its nuclear activities in March 2018 with President Vladimir Putin's Address to the Federal Assembly. Although it is hard to be certain why these developments were revealed, it is widely speculated that Putin intended to demonstrate strength to the Russian people just before a Russian presidential election while simultaneously displaying Russian scientific and technological innovation to the United States and NATO. Putin's clear message was that Russian innovation to evade U.S. missile defenses will preserve a formidable Russian nuclear deterrent force.

The number of innovative Russian nuclear weapon delivery systems under development is impressive—six in all. For ease of discussion, these six systems are grouped into three categories: Intercontinental Ballistic Missile (ICBM), Hypersonic Delivery Systems, and New Advanced Strategic Weapon Delivery Capabilities.

It is widely speculated that Putin intended to demonstrate strength to the Russian people just before a Russian presidential election while simultaneously displaying Russian scientific and technological innovation to the United States and NATO.

This report uses exclusively open-source information to analyze the six new delivery systems, providing the technical characteristics, deployment schedule, and military objectives of each. The descriptions include details of the design and test results to the extent that information is available and credible. In many cases, there are conflicting reports of capabilities and deployment schedules, and those are included with an assessment of the most probable.

The full report provides an overview of hypersonic missile technology and includes short summaries of U.S. and Chinese hypersonic programs for background and comparison. However, this report is primarily focused on the new Russian delivery systems summarized below.

ICBM: Sarmat

The Sarmat is a liquid-fueled, multiple-warhead heavy ICBM being developed to replace the aging Voevoda (SS-18) ICBM. The Sarmat is expected to have a range of 16,000 km (9900 mi), which would allow a southern approach to U.S. targets, thereby avoiding current missile-defense installations in Alaska and California. The new capabilities reportedly under development for the Sarmat include a short-boost-phase engine to complicate launch detection and verification, and a new composite-material body to improve throw-weight and range while using the same silo. The number of warheads on the Sarmat varies in reporting from 3 to 24, and advanced countermeasures are expected. The Voevoda carries 10 warheads, and the Sarmat will likely carry 10 to 16 warheads with an expected total yield of about 8 Mt. Additionally, the Sarmat is expected to carry different types of warheads on the same ICBM, one type being the new Avangard hypersonic system. In order to replace the Voevodas before their end of life, deployment of the Sarmat must begin in 2022, with the expected deployment of 46 completed by 2027. To date, only the ejection mechanism and possibly the first phase of the Sarmat have been tested, and full-scale system testing is still needed. The Sarmat is at least four years behind the originally announced schedule. While some down-selection of advanced capabilities will likely occur before production and deployment, the Sarmat is anticipated to have a longer range, increased throw-weight, and some characteristics to make missile interception more difficult than for the Voevoda.

Hypersonic Delivery Systems: Kinzhal, Avangard, and Tsirkon

The Kinzhal is believed to be a modified Iskander-M short-range, ground-launched, solid-propelled missile that is delivered to high altitude by a modified MiG-31 interceptor jet. Once dropped from the jet, the solid-propelled rocket is ignited and the missile obtains a speed of Mach 5 to Mach 10. The Kinzhal has fins to provide maneuverability, but its trajectory is largely aeroballistic. Russia has declared the Kinzhal as dual-capable, qualified to carry either a conventional or nuclear warhead. When the one-way aircraft flight range is taken into account, the Kinzhal can hit targets up to 2000 km (1240 mi) away, a medium-range capability. The Kinzhal has been tested tens to hundreds of times and is reported to have begun trial deployment. Ten jets are said to have been modified to carry one Kinzhal at a time. Some reports claim as many as 50 jets might eventually be modified to carry the Kinzhal, and Tu-22M3 jets with longer range and more capacity might be modified to carry four Kinzhals at a time in the future. The military objectives of the Kinzhal include standoff strike on high-value targets such as missile-defense installations and carrier groups.

The Avangard is a hypersonic boost-glide vehicle that has been under development since Soviet times, with design and testing accelerated in 2014. The Avangard has been successfully tested three times since 2014, with a test in December 2018 launched on an SS-19 ICBM reportedly achieving speeds over Mach 20 and flying 6000 km (3700 mi). The Avangard is reported to be made of composite materials to withstand the high temperatures of hypersonic flight, but little is reported about its communication system or accuracy. The nuclear version of the Avangard is expected to carry a warhead of 150 kt or possibly larger. The Russians originally stated that the Avangard would be deployed on SS-19s by the end of 2019, although this planned date has since been updated to 2020. Even the 2020 goal is ambitious and unlikely to be met. Tests and/or deployment of a few Avangard missiles in the early 2020s is possible with continued significant investment and technical success. No information regarding nuclear deployment is known, but more successful full-scale flight tests before nuclear-warhead mating would be responsible. The military objective of the

Avangard is to evade missile defense and strike high-value infrastructure at strategic range.

The Tsirkon is a hypersonic cruise missile announced as having a conventional capability, but speculation abounds that it could carry a nuclear warhead in the future. The Tsirkon has a solid-fueled first phase, followed by a scramjet second phase. In development since 2011, the Tsirkon is thought to be made of a new metal alloy capable of withstanding the high temperature of hypersonic flight. Significant maneuverability during flight and terminal phases is anticipated. The primary challenge for hypersonic cruise missiles is the reliability and lifetime of the scramjet engine. Expected to be sea-launched, the Tsirkon will likely obtain a speed of Mach 5 to Mach 6 and a range of about 500 km (300 mi). Successful tests from a ground-based launcher were conducted in April 2017 and December 2018. The Tsirkon is expected to be deployed on Russia's two Kirov-class battle cruisers after modifications. The first battle cruiser is expected to be ready to carry the Tsirkon in 2022. Given the relative immaturity of scramjet engines and the new metal alloy production, Tsirkon deployment before the mid- to late-2020s would be surprising. When deployed, the Tsirkon is expected to target missile-defense installations, decision centers, and high-value assets from a safe distance without risk of interception, because of its speed and maneuverability over short ranges.

New Advanced Strategic Weapon Delivery Capabilities: Poseidon and Burevestnik

The Poseidon is a nuclear-powered, nuclear-tipped torpedo designed to be released from a submarine in safe waters and then travel at depths of 1000 m (3300 ft) and speeds of 111 kph (70 mph) for distances of 5000 km (3100 mi) or more. First revealed in a suspected intentional leak in 2015, the Poseidon is being designed to be difficult to detect and intercept. The Poseidon is expected to be powered by a compact nuclear power plant to achieve its long travel distances and high speeds. A nuclear warhead of 2 Mt, possibly surrounded by cobalt, would be carried by the Poseidon and exploded to destroy targets through blast, radiation contamination, and/or tsunami effects. The *Belgorod*, a special purpose submarine is being modified to carry six Poseidons and Khabarovsk-class submarines are reportedly also undergoing modification to carry eight Poseidons each. Testing of the nuclear reactor to the propulsion system is believed to be underway. Even if the submarines meet the planned modification date, deployment with the Poseidon is not expected until the mid- to late-2020s at the earliest, given the present rate of development and testing of the torpedo. The Poseidon is a second-strike, strategic-range weapon targeted at coastal infrastructure or carrier groups using a delivery approach entirely distinct from ballistic missiles.

The Burevestnik is a nuclear-powered, nuclear-tipped subsonic cruise missile designed to have a range of about 23,000 km (14,000 mi). A compact nuclear power plant would heat the air in a ramjet engine to allow long flights. Compact nuclear power sources for Burevestnik are being designed and tested, but no long-range test has been successful. Although they are potentially feasible, there are risks associated with flying nuclear power sources because they could fissure or lose isolation. Earlier attempts by the United States to develop nuclear-powered cruise missiles were cancelled because of radioactive debris issues; however, significant advances in closed-loop compact nuclear power sources in the 1 MW–to–20 MW range have been achieved since the U.S. efforts. The Burevestnik is the least mature of the six new delivery capabilities, and only recently a deployment date of 2025 was announced. Realistically, it seems that deployment could be at least a decade away, if ever. The Burevestnik is a second-strike, strategic-range weapon of a type that has not been deployed by any other nation.

All six of these nuclear delivery systems have ongoing development and test programs; none are limited to computer-graphic depiction alone. Only the Kinzhal seems to have completed testing and begun trial deployment. More testing is needed before the Sarmat and Avangard are deployed. These tests will be internationally observed because they involve ICBM launches. The Sarmat and the Avangard will likely be deployed beginning sometime between 2022 and 2025 unless continued difficulties with safety or material availability are encountered. The other systems—Tsirkon, Poseidon, and Burevestnik—are less mature and unlikely to be deployment-ready before the mid- to late-2020s because of significant technical hurdles. Only two successful system-level tests of the Tsirkon have taken place, and both have had limited range due to short lifetimes of scramjet engines. The Poseidon and Burevestnik are not yet ready for system-level testing, and the subsystem tests, which have been conducted about once a year, have focused on the nuclear-powered propulsion systems.

Whether or when any nuclear options would be deployed on these systems is uncertain and missing from open reporting. Little is known regarding the accuracy of the delivery systems; however, it may be that the lower the accuracy of these systems, the higher the probability that a nuclear warhead is needed to achieve the military objective.

Generally, Russian government sources and associated open reporting overstate the capabilities of all the systems and forecast unrealistically rapid schedules. The resources required to complete the design, testing, production, and deployment of each of these systems are very significant. A fatal accident in August 2019 involving radioactive material, believed to be from a compact nuclear reactor, occurred on a sea platform at the Nyonoksa missile test range. Although the reporting is quite speculative, this accident likely involved testing of one of the new delivery systems. The Nyonoksa accident and an earlier fire at the Sarmat production plant, in April 2019, may indicate that Russia's program for new nuclear delivery vehicles is too aggressive, behind schedule, and bypassing safety precautions.

Understanding and following the development of the new Russian nuclear-weapon delivery systems is important for future arms-control agreements and strategic-stability policy decisions. This report is intended to provide unclassified, open-source background information to inform policy analysis of how such systems might affect strategic stability and future arms-control options.

INTRODUCTION

Since the United States withdrew from the Antiballistic Missile (ABM) Treaty in 2002, Russia has been working on advanced nuclear-weapon delivery systems that could evade evolving U.S. missile defenses. For years, the Russian efforts were kept largely under wraps, but in his 2018 Presidential Address to the Federal Assembly,[1] Russian President Vladimir Putin began openly discussing the development of five new nuclear-weapon delivery systems. In his March 1 address that year, Putin spent about 45 minutes—a full 40 percent of the time—announcing the new nuclear-weapon delivery systems (and one additional laser system), complete with videos and graphics to emphasize that these new systems were state-of-the-art and near deployment-ready. In his 2019 address the following February,[2] Putin announced another new weapon-delivery capability[3] and provided an update on the status of the systems announced in 2018. In his addresses, Putin repeatedly stressed that these systems were designed to evade U.S. missile defenses being deployed globally at fixed sites and on mobile sea-based platforms.

Putin's clear message was that Russian innovation to evade U.S. missile defenses will preserve a formidable Russian nuclear deterrent force.

Although it is hard to be certain why these developments were revealed, it is widely speculated that Putin intended to demonstrate strength to the Russian people just before a Russian presidential election, while simultaneously displaying Russian scientific and technological innovation to the United States and NATO. Putin's clear message was that Russian innovation to evade U.S. missile defenses will preserve a formidable Russian nuclear deterrent force.

The six nuclear-weapon delivery systems that President Putin announced in 2018 and 2019, in order,[4] are: (1) Sarmat—a multiple-warhead heavy intercontinental ballistic missile (ICBM), (2) Burevestnik—a nuclear-powered cruise missile, (3) Poseidon—a nuclear-powered torpedo, (4) Kinzhal—an air-launched hypersonic ballistic missile, (5) Avangard—a boost-glide hypersonic vehicle, and (6) Tsirkon—a sea-launched hypersonic missile.[5] Of the six new delivery systems, only one, the Sarmat, is a predictable development effort; it replaces an aging ICBM, with added evasive features. The other five new nuclear-weapon delivery vehicles utilize new technologies to evade U.S. missile defenses. Three are strategic range—Avangard, Poseidon, and Burevestnik—despite long-standing U.S. statements that missile defense is neither aimed at nor effective against Russian strategic capabilities. The program underway is ambitious in its scope, given the sheer number of systems as well as the technological variety and sophistication.

In this paper, these weapons will be discussed in three categories, and in order of maturity within each category, as follows:

- ICBM: Sarmat
- Hypersonic delivery systems: Kinzhal, Avangard, Tsirkon
- New advanced strategic weapon delivery systems: Poseidon, Burevestnik

There is no specific open-source information about the nuclear warheads that would be used on these systems. For some systems, the yield of the nuclear weapon is reported, but the news reporting is often inconsistent. There is also no discussion of whether the warheads contain new or reused nuclear materials or physics packages. Because Russia has not conducted a full-scale nuclear test since 1990, it is reasonable to assume that the planned nuclear warheads will use physics packages already designed and tested but potentially repackaged for the new systems, or new physics packages designed with subscale testing and computer simulations.

Russia's pursuit of these capabilities is likely motivated by a combination of factors, including the belief that its deterrent is being, or could in the future be, eroded by U.S. missile defenses; the desire to negotiate new agreements with the United States to limit missile defenses and other threatening capabilities; the goal to force the U.S. to spend more money on missile defense; the aspiration to out-innovate the United States in nuclear-weapon delivery options; and the need to support the powerful defense-industrial sector.

Given the degraded state of communication between the United States and Russia, and the potential for these new weapon systems to affect strategic stability, it is important to understand the Russian delivery systems, their capabilities, and their likely deployment schedules. This paper summarizes the new Russian nuclear-weapon delivery systems using available open-source information, including a summary of each system's technical characteristics, announced and/or likely deployment date, and reported military objectives. It is meant to inform future work in the policy community on the arms-control and strategic stability implications of these systems. Other technological advances being made simultaneously may also impact arms control and strategic stability, but the Russian developments reported here are best understood from open-source reporting.

INTERCONTINENTAL BALLISTIC MISSILE

Sarmat Multiple-Warhead Heavy ICBM

The first system announced by Putin in his March 2018 address was a new ICBM called the Sarmat,[6] a replacement for the R-36M2 Voevoda ICBM (called the SS-18 by NATO) deployed currently.[7] Putin announced the Sarmat as more capable than the Voevoda. "Weighing over 200 tons, it has a short boost phase, which makes it more difficult to intercept for missile-defense systems," he said. "The range of the new heavy missile, the number and power of its combat blocs is bigger than Voevoda's. Sarmat will be equipped with a broad range of powerful nuclear warheads, including hypersonic, and the most modern means of evading missile defense…. Voevoda's range is 11,000 km while Sarmat has practically no range restrictions…. It can attack targets both via the North and South poles." The video accompanying his speech showed ICBM tracks from Russia to the United States through both a northern and a southern route.

The RS-28 Sarmat is a liquid-fueled, multiple-warhead ICBM under contract to the Makeyev State Rocket Design Center since 2011[8] and being manufactured at the Krasnoyarsk Machine-Building Plant (Krasmash).[9] NATO refers to the new Sarmat as the SS-30 Satan 2. The Voevoda was designed and manufactured during Soviet times in Ukraine; its service life has been extended, and it is projected to go out of service as early as 2022, with the oldest units needing to be replaced as early as 2022 and all the units needing to to replaced by 2027,[10] imposing a time constraint on the Sarmat development and deployment schedule.

Test footage of the Sarmat strategic missile system

Source: Ministry of Defense, Russia

Technical characteristics

The development of the Sarmat was reported previously in open sources; however, some of the claims in Putin's 2018 address were new. The new capabilities, if realized, would make the Sarmat ICBM a more advanced capability than the Voevoda, with new military characteristics and advanced evasive technologies.

Below is an assessment of reported information that adds detail to the capabilities referred to in the 2018 speech:

- **Short boost phase:** The short-boost-phase claim is somewhat puzzling, because the Sarmat, like the Voevoda, uses liquid fuel.[11] Liquid fuels tend to produce longer boost phases than solid fuels.[12] It is hard to be definitive about what is behind the short-boost-phase claim, but there is substantial reporting suggesting the new first-stage engine for the Sarmat, the PDU-99,[13] is being designed to lower the signature and/or increase the thrust and boost speed of the Sarmat. Reporting consistently names Energomash as the engine design agency; however, whereas many report the PDU-99 is a variant of the engine used on the current Voevoda,[14] others claim it is a more advanced pulsed-detonation engine.[15] Some reports assert the new engine will hyperaccelerate the Sarmat into orbit, reducing the infrared signature of the launch as well as the time available for early-warning satellites to detect such a launch.[16] Since infrared signature is closely related to engine type, fuel composition, burn time, rocket geometry, chamber parameters, and flight conditions,[17] it is possible that a new engine and/or new fuel could cause the boost phase to be harder to detect and characterize. It is widely reported the PDU-99 was tested in August 2016, although no detail is given about the engine.[18] Later that same month, it was also reported, a full-scale pulse detonation engine was tested by the Russian Advanced Research Foundation[19] supported by Energomash. The Advanced Research Foundation engine was said to employ clean fuel and obtain high thermodynamic efficiency while providing lower cost and increasing the payload weight for space missions.

  If the pulse-detonation engine test is accurately reported, it represents a scientific breakthrough. However, deploying a pulse-detonation engine on the Sarmat would be quite ambitious and likely would require significantly more testing.

- **Range:** The Sarmat ICBM will be placed into existing SS-18 missile silos with minimum modifications to launch-area infrastructure.[20] The missile is expected to be about 36.3 m (109 ft) long and 3 m (9 ft) in diameter.[21] Whereas Putin claimed "practically no range restrictions" for the Sarmat, most reporting suggests the range will be about 16,000 km (about 9900 mi), to support a South Pole route to the United States. Without getting larger, the Sarmat is said to have increased its range and throw-weight[22] by reducing its missile airframe weight by nearly 50 percent through the use of advanced composite materials.[23] Although there were two range options developed and originally deployed for Voevoda—11,000 km (about 6800 mi) for a North Pole attack and 16,000 km (about 9900 mi) for a South Pole attack—the only currently deployed version of the Voevoda has a range of 11,000 km (about 6800 mi).[24] If the Sarmat range is 16,000 km (9900 mi), it will provide Russia with an ICBM range beyond what is currently deployed but equivalent to formerly deployed ICBM ranges.

- **Number, power, and types of nuclear warheads:** The Voevoda carries up to 10 warheads of about 750 kt each as well as decoys and penetration aids. The number of warheads expected to be carried on the Sarmat is most frequently reported as 10 to 16,[25] but reports can be found referencing as few as three[26] and as many as 24[27] hypersonic Avangard warheads. All reports suggest the Sarmat is being designed to carry a combination of countermeasures and warheads that can target different locations.[28] References to throw-weight and yield include up to 10 750-kt warheads (7.5

Mt), 16 hypersonic glide vehicles yielding 500 kt each (8 Mt), 24 hypersonic glide vehicles each yielding 150 kt (3.6 Mt), or combinations thereof. The total yield the missile can carry has been consistently reported to be about 8 Mt.[29] If the number of warheads is 10, and the total yield is 8 Mt, the Sarmat will be very similar to the Voevoda deployed today.[30] Given what is reported about the size and weight of the Avangard, it is reasonable to assume the Sarmat will not carry 24 warheads without significant re-engineering of the hypersonic system.

- **Modern means to evade missile defense:** The implication in Putin's speech is that the Sarmat has modern evasive measures in addition to a short boost phase. Some of these measures likely include the use of improved decoys, making it hard for radars to adequately track the correct target. (Decoys are already employed on the Voevoda.) The original Voevoda missile is sometimes said to have deployed fractional orbital bombardment re-entry vehicles capable of dynamically maneuvering outside of the ballistic track to make the warhead's flight path and intended target harder to predict.[31] The Sarmat is expected to carry the Avangard hypersonic missile, which will likely have more non-ballistic maneuverability.

The claims of potential capabilities for the Sarmat are extensive, and it is reasonable to assume that trade-offs will be made between realizing the advancements and the cost and schedule associated with deployment. An open-ended development schedule for the Sarmat is not a realistic option, since the Voevoda lifetime is limited.

Deployment schedule

During his 2018 and 2019 addresses, Putin mentioned that the Sarmat was in active testing. There have been two tests (late December 2017 and March 30, 2018) of the ejection mechanism from the silo, and the second may have also validated performance of the initial flight phase. A third ejection test may have been conducted in May 2018,[32] and it is shown along with component manufacturing on a video released on July 28, 2018.[33] Although it was expected, no complete flight testing of the Sarmat was conducted in 2018, and full-scale tests were initially reported to be delayed to 2019.[34] Given that preparation for such tests has not yet been observed, it is reasonable to assume it could be 2020 before a full-scale flight test is conducted. Recent reporting described a fire at the Sarmat production facility in April 2019, and Russian government officials now say the tests will be completed by the end of 2020.[35]

The development of Sarmat is behind the originally announced deployment date of 2016–2018.[36] Current Russian plans indicate serial production in 2020 and operational deployment in 2021.[37] These dates are optimistic relative to expected final testing timelines, which continue to be pushed out. In early 2017, there were 46 Voevoda missiles fielded,[38] and it is generally believed that all will be gradually replaced by the new Sarmat ICBMs. It seems likely that Russia will be able to replace the Voevoda with some version of the Sarmat at or before the end of life of most or all Voevoda missiles, but significant work and expenditure will be required.

Military objective

Historically, Russia has deployed a higher proportion of its strategic nuclear forces on land rather than at sea, in contrast to the United States, which relies more heavily on sea-based weapons. Silo-based ICBMs are viewed as the fastest response leg of a nuclear triad but vulnerable to a first strike. Because of the number and types of warheads and likely decoys intended for the Sarmat, Russia seems to be seeking to increase its ability to overwhelm any U.S. missile defenses and ensure that its strategic-range ICBM-based nuclear missiles can penetrate existing or new missile-defense capabilities.

HYPERSONIC DELIVERY SYSTEMS

Three of the six new Russian capabilities are hypersonic weapon systems: Kinzhal, Avangard, and Tsirkon. Since hypersonic systems dominate Russia's new weapon-delivery systems development, a brief introduction to hypersonic weapon systems is included here before the description of the Russian development activities.

Hypersonic vehicles travel at speeds of Mach 5 or higher—that is, over 6100 kph (3800 mph) at sea level.[39] While the name implies that speed is the distinguishing factor of hypersonic vehicles, for weapon systems it is only one of the characteristics that provide advantage. Compared with today's cruise missiles, hypersonic vehicles do offer significant speed advantages. However, compared with long-range ballistic missile systems, hypersonic vehicles do not have such an advantage, because such ballistic missiles already travel at hypersonic speeds during a large portion of their flight.[40] Other characteristics of hypersonic systems, however, are potentially advantageous compared with ballistic missiles. Of particular interest are the ability to fly at low altitude, making detection by earth-based sensors difficult; the ability to maneuver during flight to avoid detection and interception; and the unpredictability of targets, since hypersonic vehicles don't follow a ballistic trajectory. For these reasons, hypersonic weapons—combining the speed of ballistic weapons with the low-altitude flight and maneuvering capabilities of cruise missiles—are considered militarily advantageous, especially to evade missile-defense systems.

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Traditionally, hypersonic systems have been considered in two broad categories: glide vehicles and cruise missiles.[41]

A hypersonic glide vehicle is typically boosted to hypersonic speed in the upper atmosphere by a missile, then released from the boost vehicle to glide unpowered at high speeds at the edge of the atmosphere before descending through the atmosphere to a target. Because glide vehicles need to be delivered to altitude and speed by a lift vehicle, these hypersonic systems are often referred to as boost-glide vehicles. Research begun in the late 1930s has continued on both hypersonic glide missiles and spacecraft.[42]

Characteristics of hypersonic glide vehicles include:

- high lift-to-drag ratio
- maneuverability during flight and on descent
- a shape that determines performance characteristics such as glide distance, speed, and maneuverability, which is usually a conical body with fins or a delta-shaped body, somewhat like a space shuttle but with sharper edges

Recently, the attributes of hypersonic glide vehicles, including speed, maneuverability, and low-altitude flight, have made them particularly attractive as weapons to evade missile defenses. Although hypersonic glide vehicles are not usually powered, a propulsion system to increase speed or maneuvering capability (especially in the supersonic portions of the flights) can be integrated.

Like other types of cruise missiles, hypersonic cruise missiles are powered throughout flight and offer maneuverability combined with high speed. Their range is determined by the type of engine and fuel used. Hypersonic missiles typically operate using air-breathing supersonic combustion ramjet (scramjet) engines to accelerate and maintain missile speed. A scramjet usually begins operating at Mach 4 or Mach 5. Therefore, a hypersonic cruise missile must first be accelerated to Mach 4 or Mach 5 by other means, such as rocket engines. The study of scramjet engines has been underway since the 1950s,[43] with the first successful flight tests in the 1990s[44] and some breakthroughs since then.[45] While elegant in theory, since they have no moving parts and use air as the oxidant, scramjet engines that operate more than a few hundred seconds have not yet been designed and tested; their range is significantly limited.[46] Because of the challenge of developing long-life scramjet engines or an alternative, development of hypersonic cruise missiles technically lags behind that of hypersonic glide vehicles.

In addition to the technical challenges already mentioned, there are some overarching issues for any type of hypersonic weapon system. The most challenging is considered to be heat management, because hypersonic travel in the atmosphere results in surface temperatures of about 2000°C.[47] These temperatures require the development of new materials and/or heat-removal methods to ensure survivability of the delivery vehicle (especially the nose cone, sharp edges, and fins) and interior guidance systems. The other significant technical challenge involves communication to and from the vehicle through the surrounding plasma sheath[48] that forms when vehicles travel at speeds above about Mach 8 or Mach 10 in the atmosphere.[49]

Hypersonic weapons are under development not only in Russia but also in the United States and China, and to a lesser extent in the United Kingdom, India, France, Australia, Japan, Germany, and likely elsewhere.[50] The U.S. and Chinese hypersonic weapon programs will be briefly described later in this section, after the Russian system descriptions. Importantly, Russia and Chine are the only nations to declare intent to develop dual-capable hypersonic missiles, which could carry either conventional or nuclear warheads. The Russian motivation for hypersonic weapons is repeatedly stated to be missile-defense evasion.[51]

As described in the following sections, the Russians are developing both a hypersonic glide vehicle and a hypersonic cruise missile. In addition, Russia has developed an air-launched hypersonic ballistic missile that it claims is in trial deployment. The hypersonic ballistic missile is a modified existing solid-propelled missile delivered by a high-speed interceptor aircraft. If successful in its efforts on these three programs, Russia could deploy dual-capable air- and ground-launched hypersonic weapons, and a conventional sea-launched hypersonic weapon that could be modified to be nuclear-capable.

Kinzhal Air-Launched Hypersonic Ballistic Missile

Kinzhal, meaning "dagger," is a hypersonic short-range ballistic missile launched from a high-speed aircraft. The Kinzhal weapon-delivery system mates a short-range solid-fuel aeroballistic missile to a modified MiG-31 interceptor jet, to provide hypersonic medium-range standoff strike. Putin claimed, "The missile flying at a hypersonic speed, 10 times faster than the speed of sound, can also maneuver at all phases of its flight trajectory, which also allows it to overcome all existing and, I think, prospective anti-aircraft and anti-missile defense systems, delivering nuclear and conventional warheads in a range of over 2,000 kilometers."[52] Of all the systems announced by Putin in 2018, the Kinzhal is believed to be the one either in trial deployment or closest to operational deployment.[53]

The Kinzhal is reported to be a substantially modified Iskander-M short-range (400 km to 500 km, 250 mi to 310 mi),[54] ground-launched, nuclear-capable ballistic missile using a solid-propellant rocket with small fins for maneuverability.[55] The Russian designation for the Kinzhal is Kh-47M2. The MiG-31 interceptor jet is called the Foxhound by NATO, and the version modified to carry the Kinzhal is referred to as the MiG-31K.

Technical characteristics

The Kinzhal hypersonic system involves the MiG-31K jet carrying the Kinzhal missile to altitudes of about 18 km (59,000 ft) at supersonic speeds. The missile is released and falls probably tens of meters (about 100 ft), ejects a rocket cap that is used to protect the rocket motor during the jet flight, then uses its solid rocket motors to accelerate to hypersonic velocity. A video released on March 11, 2018 shows a flight test of this system.[56] The MiG-31K interceptor jets can carry and launch one Kinzhal at a time.[57] The MiG-31K aircraft is maneuverable, and because the Iskander-M can maneuver during the terminal phases of flight[58] it is likely the Kinzhal can as well. Additionally, because the Iskander-M has a thermonuclear option with a 10–50 kt warhead,[59] it is reasonable to assume that the Kinzhal would have a similar yield. Some Russian literature has indicated that the upgraded Tu-22M3 bomber also may carry and launch up to four Kinzhals, although there is some skepticism about whether the bomber is fast enough or flies high enough for this purpose.[60] The range of Kinzhal if carried on the MiG-31K is 2000 km (about 1240 mi), and 3000 km (about 1900 mi) if carried on a Tu-22M3. (The range cited includes the one-way aircraft flight distance

Kinzhal mounted on MiG-31K, 2018 Moscow Victory Day Parade
Source: www.kremlin.ru

Russian Aerospace Forces launch the Kinzhal missile
Source: Ministry of Defense, Russia

and the missile range combined.) This a medium- or intermediate-range system (never covered by the Intermediate-Range Nuclear Forces Treaty, because it is not land based) even though Putin calls this and the other new systems "strategic."[61] There are some reports of air refueling the MiG-31K while carrying the Kinzhal, suggesting the desire to increase the overall range of the delivery system.[62] The Su-57 stealth fighter is a prospective carrier if that jet is ever developed and deployed.[63]

Deployment schedule

Putin claims the Kinzhal began trial deployment in December 2017 in the Southern Military District, and Russian news media variously claim either more than 250 or 380 flights have occurred.[64] Reports in U.S. literature tend to corroborate significant testing and trial deployment, although not necessarily the number of flight tests. It is reported that 10[65] to 50[66] MiG-31Ks will be modified to carry the Kinzhal, with at least six operational in March 2018.[67] There is no specific reporting about the deployed Kinzhal missiles carrying a nuclear warhead. A nuclear-tipped Kinzhal would allow more military effectiveness with less accuracy than a conventionally tipped Kinzhal but would risk nuclear escalation. The Iskander-M has a 5–7 m (16–23 ft) circular error probable (CEP)[68] when coupled with optical homing, a 30–70 m (98–230 ft) CEP when operating autonomously.

Military objective

The Kinzhal provides standoff air-launched hypersonic strike capability with limited maneuverability. The Russian press states that the military purpose of Kinzhal is to strike U.S. or NATO ship-based anti-missile systems or land-based anti-missile systems in Romania (and Poland in the future). The declared Russian purpose to destroy missile defenses is consistent with the technical characteristics and the number of modified jets, although this system could be used for other high-value targets such as carrier groups.

The Kinzhal provides evidence that the Russian military, like the U.S. military, views air-launched standoff, speed, and maneuverability as critical assets for future warfare and deterrence. The United States has plans for a nuclear-tipped long-range standoff (LRSO) air-launched weapon, but the U.S. version is to be a strategic weapon deployed on heavy bombers and is not intended to be hypersonic.

Avangard Boost-Glide Hypersonic Missile

The Avangard is a "traditional" boost-glide vehicle.[69] The hypersonic glide vehicle is lifted into space using a multi-phase ballistic missile and then released in low-earth orbit, descending to the edge of the atmosphere and gliding at hypersonic speeds.[70]

Other than acknowledging Avangard's development by the industrial sector and stating that Russia is "one step ahead … in most essential areas" of hypersonic technology, Putin did not elaborate on the Avangard in his 2018 speech. In 2019, Putin said, "We have launched serial production of the Avangard system ... As planned, this year, the first regiment of the Strategic Missile Troops will be equipped with Avangard."

Technical characteristics

The Avangard boost-glide hypersonic missile is believed to have been under development since the 1980s, first in the Soviet Union and then in Russia. There have been a few different development campaigns, with the most recent beginning in 2014. In total, there were about 14 reported flight tests between 1990 and 2018, many of which were failures or only partially successful.[71] In the latest campaign, there have been four confirmed tests, one reportedly unsuccessful and three reportedly successful. The latest successful test was conducted in late December 2018 with the launch of an Avangard on an SS-19 ICBM from the Dombarovsky ICBM base in the southern Ural Mountains to Komchatka 6000 km (about 3700 mi) away. The test was declared by Putin an "excellent New Year's gift to the nation."[72]

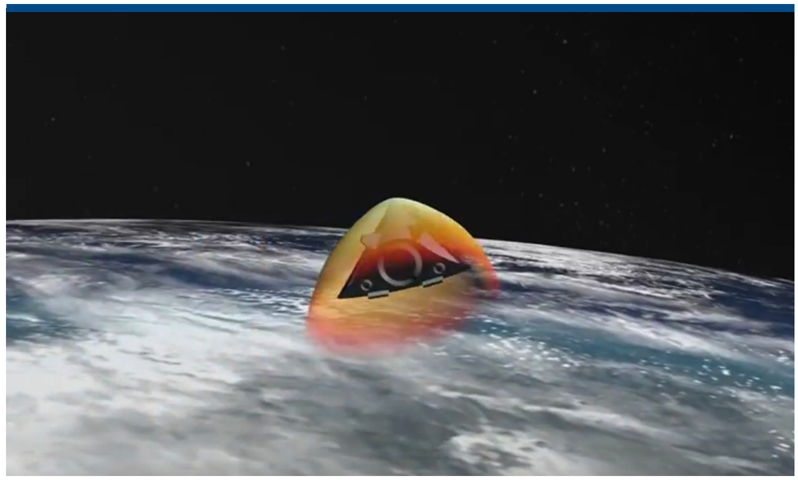
The December 2018 Avangard test reportedly reached speeds of Mach 20 or as high as Mach 27.[73] The boost-glide vehicle was shown by Putin as a computer graphic,[74] but the actual geometry is undisclosed. The Avangard is typically depicted as a delta-shaped vehicle, surrounded by a plasma sheath. The Avangard is a large vehicle, reported to be 5.4 m (almost 18 ft) long.

To date, SS-19 ballistic missiles (produced in Ukraine during Soviet times) have provided the ICBM boost for the Avangard tests.[75] An SS-18 missile silo was converted for use because the SS-19 with the Avangard is too long for the SS-19 silo. It is expected that initial deployment of Avangard will be with SS-19 ballistic missiles, and longer-term deployment will be on the new Sarmat missile[76] described earlier in this report.

The Avangard was announced as dual-capable, with a warhead that could be either conventional or nuclear. There are inconsistencies in the expected nuclear yield, ranging from 150 kt to 2 Mt.[77] A 150-kt warhead[78] on the Avangard seems more likely for the intended targets, assuming successful development of a navigation system.

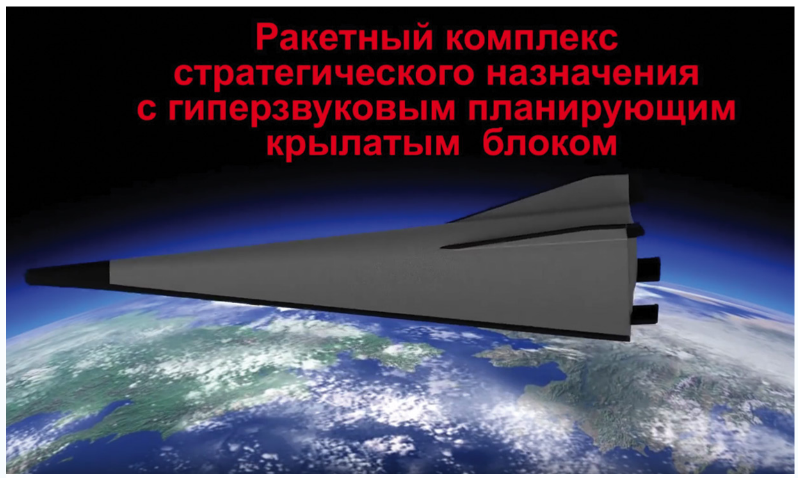
The successful testing of the Avangard represents a significant materials-science and heat-management achievement. In order to achieve success, Russia is said to have developed a special composite material that withstood the 2000°C temperatures for the tens of minutes of intercontinental hypersonic flight. The vehicle may also be equipped with a thermoregulation system,[79] but this is not widely reported.

It is unclear how the Avangard communicates and what accuracy the vehicle achieved during its testing.[80] Technologies have been maturing to enable communication through plasma, including use of high or low frequencies, vehicle design, antenna placement, particle injection, and magnetic plasma shaping, among others.[81] Without communication through plasma or another sophisticated guidance method, the accuracy of the Avangard could be low, increasing the likelihood of a nuclear capability.



Avangard computer graphic

Source: Ministry of Defense, Russia



Avangard depiction

Source: Ministry of Defense, Russia

Deployment schedule

It is probable that the Avangard development and the Sarmat development were aligned for initial deployment but the Sarmat fell behind schedule. The Kremlin seems to be using a stopgap measure by testing and planning initial deployment of the Avangard on SS-19s. Each SS-19 will carry one Avangard.[82] The number of Avangard systems that can be deployed on the Sarmat is uncertain. Russian reporting claims the Sarmat can carry 16 Yu-71s (conventionally tipped Avangard systems) and up to 24 Yu-74s (nuclear-tipped Avangard systems).[83] However, some sources suggest that these numbers are overstated and that the Sarmat could in fact carry only up to three Avangard systems, and only if lower-yield and lighter glide vehicles are designed.[84] The Avangard length (5.4 m or 18 ft) suggests a heavy system, and the large numbers (16 to 24) on a single ICBM seem unrealistic unless a lighter version of the Avangard is being developed.

It was announced that serial production of the Avangard has begun and two SS-19 missiles deployed with Avangards are planned at Dombarovsky by the end of 2019.[85] By the end of 2027, that regiment and one other are to have six Avangard systems each, for a total of 12 systems. Given that only three successful flight tests of this design have occurred, the 2019 deployment seems ambitious and probably unrealistic. However, the overall number of 12 by 2027 seems credible given the existence of the SS-19 missiles and the maturity of the Avangard, although it is confusing relative to potential Sarmat deployment. In July 2019, there were U.S. media reports that Russia was struggling to manufacture the Avangard due to a lack of critical carbon-fiber components. In response to the U.S. reporting, Russian officials issued a statement that the production and delivery of the Avangard were proceeding on schedule and that it was still slated to achieve initial operating capability by 2020.[86]

By today's standards in either the United States or Russia, more testing would be prudent before deployment of a nuclear warhead on these advanced systems. Perhaps the three successful tests are considered adequate for the initial deployment of two conventionally armed missiles, but an increased rate of testing would be a strong signal of potential deployment of the full slate of 12 missiles or the deployment of nuclear-tipped Avangard systems.

In the next decade, there does not seem to be a reasonable path for Russia to replace all, or even most, of its ICBM-based warheads with Avangard systems. The limited number of 60 Avangard systems sometimes reported seems more likely.[87]

Military objective

The Russians have said the purpose of the Avangard hypersonic boost-glide weapon is to destroy missile-defense installations and high-value targets. In the case of the Avangard hypersonic boost-glide weapon on the SS-19 or Sarmat ICBM, high-value targets could include hardened targets such as missile silos or command centers in the United States. It is conceivable that a conventionally armed Avangard boost-glide system with modern guidance and high speeds could be engineered to damage or penetrate hardened structures, and a nuclear-armed Avangard would be expected to be effective against these targets.

In addition to defense installations or high-value targets in the United States, the Avangard could provide a limited first-strike or retaliatory nuclear capability that could not be challenged by missile defense.[88] Essentially, the Avangard can be viewed as an ICBM warhead replacement that can satisfy the same military objectives while evading missile detection or defense, and may be capable of destroying high-value or hardened targets.

Tsirkon Hypersonic Cruise Missile

While addressing the Russian Federal Assembly on February 20, 2019, Putin described the Tsirkon as "a hypersonic missile that can reach speeds of approximately Mach 9 and strike a target more than 1,000 km (620 mi) away… It can be launched from water, from surface vessels and from submarines…"[89] In that same speech, Putin announced, "Russia will be forced to create and deploy weapons that can be used … in areas that contain decision-making centers for the missile systems threatening us."

The Tsirkon is a hypersonic cruise missile with two stages. The first stage uses a solid-fuel rocket to lift and accelerate the missile, and the second phase uses a scramjet motor to move the missile at hypersonic speeds over a range likely limited by the lifetime of the scramjet engine. If the Tsirkon were tested (or deployed) on aircraft in a way similar to the deployment scheme for the Kinzhal, the solid-fuel first stage could be eliminated.

To date, the Tsirkon has not been officially described as a nuclear-capable missile; however, the reference in Putin's address to Tsirkon deployment to attack decision-making centers suggests it might be deployed with a nuclear payload (like the U.S. Tomahawk sea-launched cruise missile when it was initially deployed), and news reporting occasionally mentions a nuclear-tipped option.[90] The 2018 U.S. Nuclear Posture Review indicates that the United States will study and potentially pursue in the coming years a nuclear-armed sea-launched cruise missile, perhaps increasing the possibility that the Tsirkon will be given a nuclear-tipped option in turn. For these reasons, the Tsirkon is covered in this report of new nuclear-weapon systems.

The Russian designation for the Tsirkon[91] is 3M-22 or 3K-22, and the NATO designation is SS-N-33.[92]

Technical characteristics

Open-source reporting on the Tsirkon is quite scarce, although the Tsirkon is reported to have been in development since at least 2011,[93] with a period of active testing beginning in 2015. The body length is estimated at 8 to 11 m (24 to 33 ft),[94] warhead weight is 300 kg to 400 kg (660 lb to 880 lb), and peak altitude along the trajectory at 30 km to 40 km (100,000 ft to 130,000 ft).[95] The production agency is the Scientific Production Organization for Machinery-building, or NPO Mashinostroyeniya.[96] The Tsirkon is said to be designed to use the 3S-14 Russia Universal Vertical Launching System, the same seaborne launcher as the Onyx and Kalibr missiles, in order to make it easy and affordable to deploy on ships and submarines.[97]

The Tsirkon is reported to have some sophisticated features potentially including:

- A new fuel for the scramjet, called Decilin-M, to extend the range of the missile. Decilin-M is reported to be a high-calorie synthetic aviation fuel rumored to be like the U.S. synthetic fuel JP-10. [98]
- A new metal alloy to withstand the temperatures obtained during hypersonic flight. The composition of this new material is reported to be highly classified and likely the result of a long development effort.[99]
- Pyrotechnic release of the scramjet engine from the missile before final approach to target for more stability. There is a Russian patent that describes this concept.[100]
- Maneuverable during the terminal target approach, allowing for extra protection from any defensive system.[101]

In reporting about the Tsirkon, the plasma sheath is largely described as a positive feature that allows the missile to go undetected by radar, since the plasma absorbs radar frequencies.[102] As with the Avangard, however, the communication through the plasma sheath for guidance is not mentioned.

Early tests of the Tsirkon are believed to have been completed with the Tu-22M3 bomber as the "first stage," followed by at least five tests from a coastal platform using both the rocket and scramjet.[103] There are reports that tests conducted from the coastal platform in Nyonoksa in late 2015, in March 2016, and in February 2017 may not have been completely successful. Tests in April 2017 and December 2018 were reportedly successful, with the missile obtaining a maximum speed of Mach 8.[104, 105] The priority for the Tsirkon is sea-based deployment, and tests from sea-based platforms are said to be scheduled for late 2019. Some believe the Tsirkon will have a light version that will be air-deployed, likely from a Tupolev Tu-160/M/M2 jet, although this seems to be quite speculative.[106]

The range and speed mentioned in Putin's 2019 speech (1000 km and Mach 9) are higher than previously reported. The difference between the prior reporting and Putin's speech could come from technical improvements (such as a new fuel or longer-lasting scramjet), misstatements about Tsirkon's performance, or different versions of the Tsirkon being developed simultaneously; or it could be a matter of various flight altitude and trajectory options for the Tsirkon. Since previously designed and tested scramjets have lasted about six minutes, the range provided by the scramjet at Mach 5 would be around 500 km (310 mi). Therefore, the highly reported Mach 5 to Mach 6 and 500 km (310 mi) range seems to be a realistic estimate. However, a semiballistic trajectory could potentially reach Mach 9 and 750 km (466 mi).[107] If the speculated air-launched version were to be developed, then a range of over 1000 km (620 mi) could be possible, because the aircraft would provide some of the range.[108] The lower-altitude version has the advantage of being more difficult to observe than the semiballistic version. It is unclear whether the Tsirkon has high-g evasive-maneuvering capability.

Deployment schedule

There are many discrepancies in the reported deployment schedule. Tsirkon is expected to be deployed on Russia's two heavy nuclear-powered battle cruisers currently undergoing maintenance and modernization,[109] the first expected to be complete 2021 or 2022.[110] During modernization, the battle cruisers will be equipped with 10 universal vertical launchers to allow Tsirkons or other missiles to be used interchangeably.[111] The launchers are said to hold up to eight missiles each for a total of 40 to 80 missiles depending on the type.[112]

The Tsirkon deployment date has been variously reported as 2018, 2022, and 2025[113] and is likely planned to coincide with the refurbishment schedule of the battle cruisers. However, given the significant technical challenges of developing and producing a reliable scramjet and a specialized metal-alloy cruise missile body, deployment before the mid- to late 2020s seems highly unlikely without an increased pace of development and testing.

In addition to deployment on the battle cruisers, it is reported, the Tsirkon will be carried by the Yasen-class (also called Husky-class) submarine[114] and perhaps the Steregushchiy-class corvettes,[115] although neither carrier appears to be in near-term plans. As mentioned earlier, there is also speculation that a lighter version of the Tsirkon could be air-carried, and a version could be created for export to India or elsewhere.[116]

Military objective

The claimed military objective of the Tsirkon is to destroy carrier groups before it can be intercepted. Given the hypersonic speeds and the relatively short travel distances if it were launched either from either shore or sea, the total time to detect and intercept would likely be less than five minutes. Today's U.S. and U.K. ship-based defenses are not designed to work at those speeds, and even if the missile were destroyed it would be close enough that fragments could cause significant damage.

Secondary missions of the Tsirkon are said to be land-based targets such as command and control centers or missile-defense installations. Tsirkons carried by submarines that move close to shore could target command and control centers within a few hundred kilometers (about 100 mi) from the coast. The missiles would travel quickly and might be able to penetrate underground bunkers due to the momentum imparted by their high speed.[117] Tsirkon missiles deployed in Kaliningrad could potentially reach the missile-defense installation in Poland.

Russian state TV channel Russia-1 has presented a list of five U.S. decision-making centers, some of which are not currently operating, that would be likely targets for Russia's Tsirkon hypersonic missiles deployed on submarines:[118]

- the Pentagon
- Camp David
- Fort Ritchie
- McClellan Air Force Base
- Jim Creek Naval Radio Station

This list of targets seems to indicate that the Tsirkon's target list of decision-making centers has not yet been fully developed.

Russian Hypersonic Technology Investment

The long-term success of Russian hypersonic efforts may depend on both near-term investments in hypersonic vehicles and delivery systems and long-term investments in infrastructure and research. While this is not the focus of this paper, it has been reported that Russia has three test ranges that have been used for the hypersonic program, and two wind tunnels.[119] Little is available in open sources about advanced research programs underway in Russia beyond the three systems discussed. As measured by papers presented at the AIAA International Space Planes and Hypersonic Systems and Technologies Conference over nine years ending in 2017, Russia's research publications lag significantly behind those of China, the United States, and others.[120]

Russian Hypersonic Delivery System Summary

Open-source reporting and observed testing of Russian hypersonic missile efforts provide evidence that Russia is developing three types of hypersonic vehicles. Jet aircraft, ICBMs, and battle cruisers are being modified or developed in parallel with hypersonic vehicle development. Each hypersonic vehicle type has a unique delivery platform, and together they provide air-delivered, ground-delivered, and sea-delivered capabilities. It is credible that any of these systems could carry nuclear warheads, and the air- and ground-delivered systems have been announced as dual-capable.

Although Putin refers to these weapon systems as strategic, only one, the Avangard, has strategic-range strike capability. As initially deployed, the Kinzhal air-delivered weapon is expected to have medium-range capability, and the Tsirkon sea-delivered weapon is expected to have short-range capability.

The Russian efforts and successes to date suggest that the Kinzhal hypersonic ballistic missile is likely already in trial deployment. With continued and significant investment and technical accomplishments, Russia could have the Avangard hypersonic boost-glide vehicle deployed in the early to mid-2020s, and the Tsirkon sea-launched cruise missile in the mid- to late 2020s.

However, due to the failures and delays already experienced, coupled with the significant investment required to continue testing, producing, and deploying these weapons, the deployments are not expected to be as fast as Russian officials or open-source reporting suggests. Which systems are fully developed, the number produced, and when and how they are deployed will depend on the magnitude and pace of Russian investment and accomplishments, and perhaps U.S. or China advancements, or arms control agreements. Official government statements and open-source reporting provide insight into the most aggressive Russian deployment plan.

Some have argued that the dual-capable aspect of these weapons is quite troubling and destabilizing.[121] The Russians seem intentionally ambiguous about which and how many of the new hypersonic systems will carry nuclear weapons, and secretive about what types of warheads will be deployed on these new systems.

U.S. and Chinese Hypersonic Delivery System Summary

As mentioned earlier, the development of new hypersonic systems is proceeding not only in Russia but also in the United States and China, and to a lesser extent elsewhere. A brief summary of U.S. and Chinese developments is included here to provide a context for evaluation of the Russian program.

United States

Although the United States had early and intermittent forays into hypersonic weapon and aircraft development, the latest weapon-development efforts began in the early 2000s as part of the conventional prompt global strike (CPGS) program.[122] The primary motivations for CPGS were to better execute the war on terror by quickly reaching time-urgent targets across the globe and to penetrate anti-aerial/anti-access denial systems. CPGS efforts resulted in two successful flight tests, in 2011 and 2017, of a hypersonic boost-glide vehicle, and a failed flight test in 2014. The 2011 test was launched from Hawaii and landed in the Marshall Islands, approximately 3700 km (2300 mi) away. The 2017 test was also launched from Hawaii.

With the intense development activities in Russia and China, hypersonic-weapons development was identified in 2019 by the U.S. Department of Defense as a priority research-and-development area, and development was accelerated by the John S. McCain National Defense Authorization Act for Fiscal Year 2019. The nature of the hypersonic-weapon development program changed from CPGS to conventional prompt strike, with emphasis on short-, medium-, and intermediate-range missiles.

Today's U.S. hypersonic-weapons program focuses exclusively on research and development for conventional-warhead delivery. Limiting the development of U.S. systems to conventional warheads requires that a high degree of accuracy be achieved for militarily effectiveness, and some have claimed this puts greater technical demands on U.S. development activities than those on Russia's.[123] The United States has no planned strategy for hypersonic systems acquisition and is unlikely to field a hypersonic-weapon system before 2022. It is expected that the Department of Defense will request an acquisition program if development programs succeed in the next few years.

The U.S. program comprises a common glide vehicle called the Advanced Hypersonic Weapon (AHW) along with Navy, Army, and Air Force delivery vehicles. In the original boost-glide mode, AHW was designed to provide a range of 6000 km (3700 mi), a 35-minute time of flight, and accuracy of 10 m (33 ft).[124] In addition, the Defense Advanced Research Projects Agency (DARPA) continues research activities on more advanced glide vehicle and cruise missile concepts, along with new delivery systems.[125]

The common hypersonic glide vehicle development is led by the Navy and is an adaptation of the prototype designed by Sandia National Laboratories and successfully tested in 2011 and 2017. The booster systems are being developed by the services separately. The Navy is developing an intermediate-range conventional prompt-strike weapon as a submarine-launched system, with flight tests and prototyping expected through 2024, and the Army is developing a medium-range (2250-km, 1400-mi) ground-based hypersonic two-phase booster system.[126] The Air Force is developing a short-range hypersonic conventional-strike weapon that is a solid-rocket-powered hypersonic system, to launch from the B-52, and a air-launched rapid response weapon with an range of 575 mi (925 km).[127] Notably, the United States is not developing an ICBM-boosted conventional hypersonic missile weapon at this time. The Pentagon abandoned the ICBM-boosted approach out of concern that such systems could be confused with nuclear-armed missiles and could unintentionally cause a nuclear exchange.[128]

The United States is also investing in research infrastructure such as wind tunnels and test ranges for hypersonic technology at universities and government facilities. Today, the United States has 48 declared critical facilities for hypersonic development, more than 10 test ranges, and two hypersonic wind tunnels, with another in development. In testimony in March 2019, Michael Griffin, the Department of Defense's Under Secretary for Research and Engineering, said, "We have significantly increased flight testing, as we intend to conduct approximately 40 flight tests over the next few years, to accelerate the delivery of capability to our warfighters years earlier than previously planned."

In addition to developing conventional hypersonic weapons, the United States is also investing in new missile-defense technologies that can defeat adversarial hypersonic weapons.[129]

China

China appears to have been working on modern hypersonic weapon systems since the early 2000s in academic, industrial, and military research institutes.[130] The most significant weapon development in China has been the hypersonic glide vehicle originally referred to as the WU-14 and more recently called the DF-ZF HGV. The DF-ZF HGV has been tested at least nine times since 2014—the first seven tests aimed at the development of the DF-ZF HGV and the last two tests aimed at mating the DF-ZF HGV to a DF-17 medium-range ballistic missile. Only one of the tests was a failure.[131] Images of the DF-ZF HGV have not been released, and both conical-shaped renderings and delta-winged renderings have been posted.

Chinese Hypersonic Glide Vehicle

Source: AP Photo/Ng Han Guan

The DF-17 medium-range ballistic missile was reportedly specifically designed to deliver the DF-ZF HGV. Two tests of the mated hypersonic system conducted in November 2017 were successful; the missile was reported to have flown at Mach 5 to Mach 10 over 1400 km (870 mi) at an altitude of about 60 km (37 mi) and to have struck "within meters" of the intended target.[132] This system is reported to have extreme maneuverability.[133]

In addition to the DF-17 medium-range ballistic missile specifically designed for the DF-ZF HGV and used for testing to date, analysts speculate that other Chinese ballistic missiles could be used to boost the hypersonic glide vehicle. Some believe the DF-21 medium-range missile or DF-26 intermediate-range missile could support an anti-access/aerial denial strategy. Many believe the DF-41 ICBM under development, expected to carry multiple warheads and be capable of a 12,000-km (7456-mi) range, could carry the DF-ZF HGV. The DF-41 is capable of reaching the U.S. mainland.[134]

Some report the DF-17 hypersonic system will be ready for operation as early as 2020,[135] and given the number of tests, it is reasonable to assume that deployment in the early 2020s is possible. China recently announced its hypersonic vehicle system would be capable of carrying a nuclear warhead.

In addition to the DF-ZF HGV, China tested a delta-shaped hypersonic plane called the Starry Sky-2 in August 2018,[136] dropped three different scaled-down hypersonic aerodynamic shapes from a balloon in September 2018,[137] released images of potential hypersonic cruise missile the Jai Geng No 1 in April 2019,[138] and is doing research on scramjet engines.[139] In the Starry Sky-2 test, a hypersonic glide plane was ground-launched, reached a top speed of Mach 6, conducted extreme maneuvers, maintained velocities above Mach 5.5 for 400 seconds, and landed fully intact.[140]

China has invested heavily in research capabilities for hypersonic technology and operates two test ranges and three wind tunnels, with a fourth in development.

Comparison of Russian, Chinese, and U.S. Capabilities

Russia, China, and the United States are using different approaches to the pursuit of hypersonic weapons, in part because different military objectives and gaps are being filled. Therefore, it is not straightforward to declare who is ahead or behind in development. In addition, significant investments are being made in hypersonic weapon development in all countries, and advances are rapid.

For weapon efforts, China and the United States are each focusing on the maturation of one hypersonic glide body that will be carried by one or more boosters. In the case of China, the focus is on a ground-based rocket booster with significant success. The United States adopted this focused approach later than China and is now developing multiple booster systems for air, ground, and sea launches. Russia has developed three types of hypersonic vehicles and has been developing air-, ground-, and sea-launched systems that use different boosters.

Each country can claim successes: China has completed the largest number of successful tests to date of a rocket-boosted glide vehicle. Russia was the first to trial deploy a hypersonic system, the Kinzhal air-launched ballistic missile. The United States was the first to have a successful test of a hypersonic glide vehicle with significant range and accuracy.

This technology race is playing out in real time, and all three countries are significant players. If the development and investments continue, it is likely that each country will deploy one or more hypersonic weapon systems. Whether or not any or all countries will deploy nuclear-tipped hypersonic weapons remains to be seen. Over the longer term, it is very likely that without any new arms-control agreements, additional countries will also eventually deploy hypersonic weapon systems.

NEW ADVANCED STRATEGIC WEAPON DELIVERY SYSTEMS

Two advanced new strategic-range systems were announced by Putin. The two systems (named by the Russian public after the announcement) are the Poseidon—a nuclear-powered, nuclear-tipped torpedo—and the Burevestnik—a nuclear-powered, nuclear-tipped cruise missile. These two systems are quite different in their design features, development maturity, and even targeted military function. Nonetheless, they are grouped together in this section because they have a common strategic objective of providing long-range delivery of nuclear weapons by means not used by other nations, and the common technical characteristic that they depend on the use of a compact nuclear power source.

Because these systems have not been fully developed by others [141] and because they are additions to the current strategic-range nuclear delivery means of heavy bombers, submarine-launched ballistic missiles, and ICBMs, some U.S. nuclear experts refer to them as "exotic." The primary characteristic of both systems is their ability to avoid interception.

Two advanced new strategic-range systems were announced by Putin. The two systems are the Poseidon—a nuclear-powered, nuclear-tipped torpedo—and the Burevestnik—a nuclear-powered, nuclear-tipped cruise missile.

The two advanced strategic weapons rely on compact nuclear reactors for power that are believed to be in development at Afrikantov Experimental Design Bureau for Mechanical Engineering, a subsidiary of Rosatom affiliated with the All-Russian Research Institute of Experimental Physics (VNIIEF) in Sarov. Because the propulsion system and power requirements for the cruise missile and underwater drone are so different, it is likely the compact nuclear reactors are a somewhat different design. Small-reactor technology has been advancing rapidly over the past decade, with Russia concentrating on small reactors that can be placed on floating platforms,[142] undersea power sources for Arctic oil recovery,[143] and new weapons such as the Poseidon, Burevestnik, and high-energy laser announced in Putin's 2018 speech. The United States is concentrating on small reactors for commercial purposes[144] as well as to power high-energy weapons and bases overseas.[145]

On August 8, 2019, a blast and fire involving a radioactive substance occurred on a sea platform at the Nyonoksa (also written Nenoksa) missile test site in the White Sea. Initially Russian officials said the testing involved a "liquid propellant rocket engine";[146] later statements included "isotope power source on a liquid fuel engine"[147] or "isotope power source in a liquid propulsion system,"[148] depending on the news source. The accident caused a fourfold to 16-fold increased radiation level for about two hours in the nearby town of Severodvinsk shortly after the explosion.[149] Five scientists from VNIIEF were confirmed dead, two or more additional people may have been killed, and others were injured in the accident.[150] Russian reports have not provided the purpose of the testing, although Putin acknowledged it was a promising weapon system. Initially the U.S. press largely speculated the accident occurred while testing the Burevestnik cruise missile.[151] Other reports claimed that the nuclear reactor could be for Poseidon.[152] Later, some suggested that the radiation came from a radioisotope thermoelectric generator used to keep the Tsirkon warm before launch,[153] although this theory has been proven unlikely due to the radioisotopes identified in the hospital where patients were treated and from later meteorological station reporting of isotopes. Finally, the accident was attributed in some reporting to the recovery of a Burevestnik missile from a previous test as opposed to a new test.[154] In any case, the activity in the White Sea, with or without an accident, confirms that work is being done on novel compact nuclear power reactors involving Rosatom. The accident is likely to slow progress of the development activity.

Poseidon Nuclear-Powered, Nuclear-Tipped Torpedo

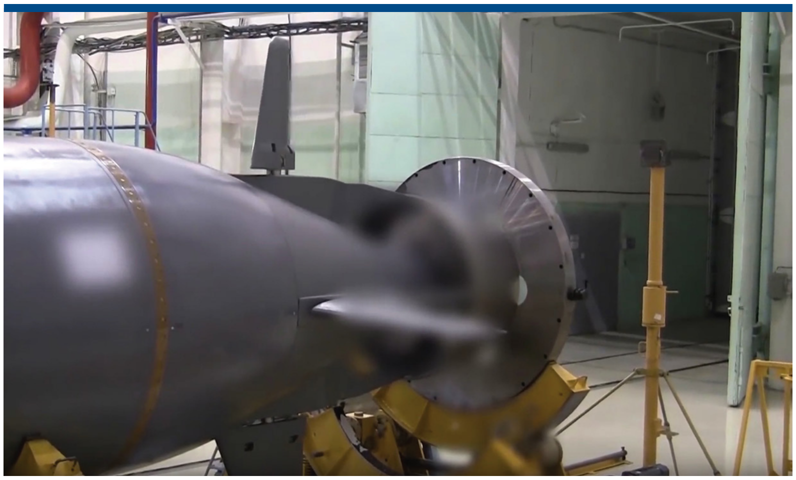
According to Putin in March 2018, Russia is developing "unmanned submersible vehicles that can move at great depths (I would say extreme depths) intercontinentally, at a speed multiple times higher than the speed of submarines, cutting-edge torpedoes and all kinds of surface vessels … They are quiet, highly maneuverable and have hardly any vulnerabilities for the enemy to exploit. ... Unmanned underwater vehicles can carry either conventional or nuclear warheads, which enables them to engage various targets, including aircraft groups, coastal fortifications and infrastructure."[155] Putin also said such capability was possible because of an innovative nuclear-power unit tested in December 2017 that was unique for its small size and amazing power-to-weight ratio, was 100 times smaller than units powering modern submarines, and could also reach maximum capacity 200 times faster.

The Poseidon, frequently referred to as an unmanned underwater vehicle, underwater drone, or torpedo, was previously called Ocean Multipurpose System Status 6 by the Russians and Kanyon by NATO. While most reporting about Poseidon refers exclusively to the torpedo, there are numerous reports that claim several delivery means for the Poseidon—including a submarine-launched torpedo and another, called the Skif,[156] that would consist of the torpedo in a container placed on the ocean floor either by submarine or surface boat and activated on demand at a later time.[157] Because the torpedo design for both delivery options is expected to be the same and reporting on the Skif is rare and not fully corroborated, this section focuses exclusively on the sub-launched torpedo and its delivery platforms. If the Skif is being developed, it has the potential to have significant military and strategic stability implications.

Technical characteristics

The design of Poseidon was first revealed in open-source reporting in September 2015 by *The Washington Free Beacon*. It was further exposed on Russian television in November 2015 when a meeting of Putin with his top military officers looking at charts that were plainly visible to the camera was aired.[158]

The revealed image provided detailed design specifications for a torpedo that could travel a 10,000-km (about 6200-mi) range, obtain speeds of 100 knots (about 115 mph, 185 kph), and achieve a maximum depth of 1000 m (3300 ft). The torpedo itself would have a 1.6-m (5-ft) diameter and be 24 m (79 ft) long. This is about twice the size of a submarine-launched ballistic missile and about 30 times the size of regular torpedo.[159] The area set aside for warhead placement was shown as a cylindrical tube 1.5 m (about 5 ft) in diameter and 4 m (about 13 ft) in length. The torpedo would be carried from and released by a Khabarovsk-class submarine and/or the new special mission submarine called the *Belgorod*.[160]



Aft end of Poseidon

Source: Ministry of Defense, Russia

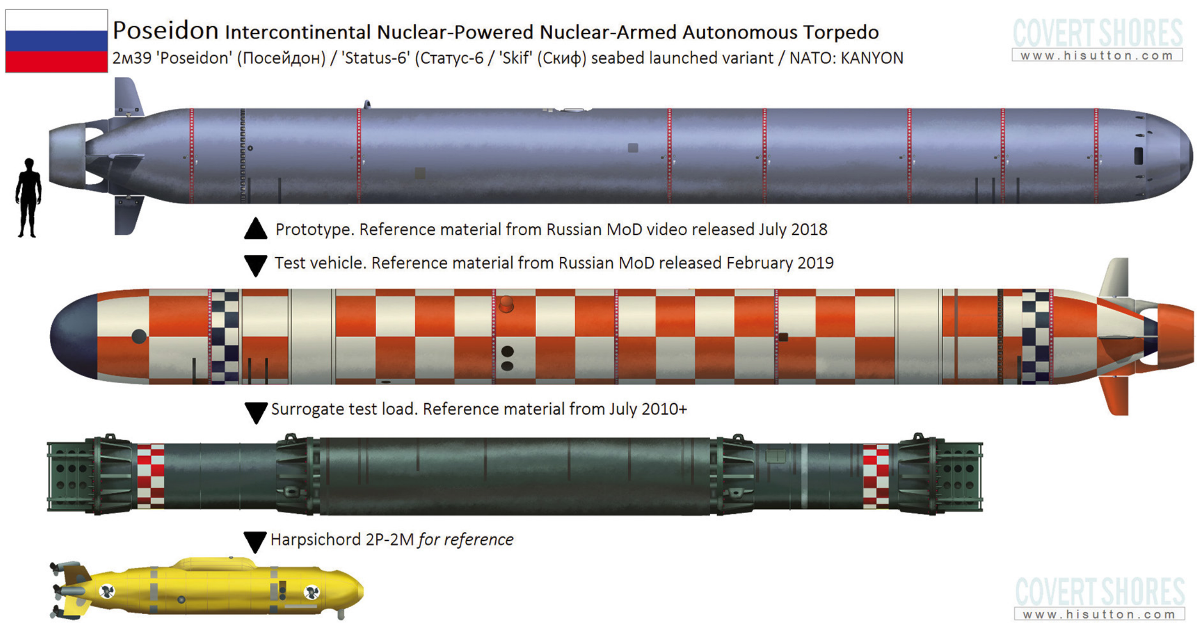
Assuming the torpedo is carried by a submarine and launched in safe waters, at the speeds reported the torpedo could travel for 40 hours or more to reach a U.S. coast. Due to the high speed and long travel time, the Poseidon would likely be noisy and detectable even if the new technologies to make it quiet are realized. However, it would be hard to defeat with available U.S. resources because of its speed and depth.[161]

As originally reported, the Poseidon would carry a very large nuclear warhead, 50 Mt to 100 Mt,[162] that could destroy and contaminate coastal cities, or destroy carrier battle groups from a distance. Additionally, it was frequently reported the warhead could be enveloped in a cobalt case, so that when it exploded underwater cobalt particles would be dispersed with entrained water and radioactive fallout would contaminate large areas (a concept called “salting”).[163] It was further suggested that a tsunami would be generated by the very large nuclear explosion, causing additional harm to large coastal areas and/or infrastructure.[164]

A few years later, in 2018, Russian media sources began reporting Poseidon speeds of 60 to 70 knots (70 mph to 80 mph, 110 kph to 130 kph), and a 2-Mt warhead, [165] both lesser capabilities than originally reported and likely a result of design maturation. An estimate of a nuclear warhead that would fit into the cylinder, with 1.5-m (5-ft) diameter and 4-m (13-ft) length suggest that a 2-Mt is more probable than a 50-Mt to 100-Mt warhead.[166] For comparison, the largest warhead ever deployed was the Soviet 50-Mt Tsar Bomba. The Tsar Bomba was 2.1 m (about 7 ft) in diameter and 8 m (26 ft) long. It is worth noting that the 1000-m (3300-ft) depth claim has not changed; it is seen as the most credible of the original assertions.

In July 2018, President Putin announced the completion of lab testing and readiness for sea trials of Poseidon, and videos were published in the Russian media.[167] The videos showed hardware on a factory floor and computer-generated graphics of the Poseidon underwater. Analysis of the video images indicates that the Poseidon is 2 m (about 7 ft) in diameter and 20 m to 24 m (66 ft to 80 ft) long, with room for a nuclear reactor in the center and a nuclear warhead toward the front.[168] The dimensions from the video analysis coincide well with the original drawings.

Little detail is reported about the nuclear reactor for the Poseidon. Some report it is a gas-cooled reactor.[169] Others have speculated that it is a modern fast-neutron reactor with a liquid metal coolant, likely a lead-bismuth mixture to reduce the noise.[170] Liquid-metal-cooled reactors do not need an electromagnetic



Source: H.I. Sutton, "Poseidon Intercontinental Nuclear-Powered Nuclear-Armed Autonomous Torpedo," Covert Shores (website), February 22, 2019, www.hisutton.com/Poseidon_Torpedo.html.

circulation pump and provide gearless operation with a turbine.

In December 2018, Russia media announced that the nuclear propulsion system of the Poseidon was being tested in a sea area protected from surveillance. The reactor was said to be installed in the hull of an operating drone, and the tests being conducted were as part of experimental design work rather than full-fledged sea trials.[171] The suspected test submarine, the *Sarov*, was located on the White Sea near Severodvinsk.

Additional detailed open-source analysis published in Feb 2019[172] contains satellite images of the *Sarov* being modified to carry Poseidon as far back as 2007 and being loaded with Poseidon surrogates as early as 2012.

Deployment schedule

From reporting and images, it seems clear that Russia has designed and built prototype nuclear engines and torpedo bodies. Lab testing of the engines is reported to have been completed, and sea testing has started.

Alongside these accomplishments, needed modifications are said to have been made to the *Belgorod* submarine to allow it to carry the Poseidon. The Khabarovsk-class submarines are also expected to be modified to be Poseidon carriers. Best estimates suggest a potential for the Poseidon to be deployed in 2027 or later.

On February 20, 2019, in his national address, Putin announced, "[A]s soon as this spring the first nuclear-powered submarine carrying this unmanned vehicle will be launched."[173] Later that day, video was released showing a Poseidon seemingly prepared for testing with some obscured underwater footage.

In March 2019, TASS reported that the *Belgorod* would complete dockside trials throughout 2019 and assume combat duty in 2020. The *Belgorod* is a one-of-a-kind submarine said to be capable of carrying six Poseidon drones. It was also released that the Khabarovsk-class submarines will be made operational in 2022.[174] The Russian state armament program calls for the Russian navy to deploy 32 Poseidons from 2018 to 2027.[175]

The expectation is that two Khabarovsk-class submarines in the Northern Sea and two in the Pacific will each carry eight Poseidons[176] (With six Poseidons each, a fifth submarine each would be needed.)

From photos, videos, and reporting of the Poseidon, coupled with satellite images of submarine modifications, it seems clear that Russia is doing more than just talking about the Poseidon. However, a substantial amount of development and testing would be required to realize the claims that have been published.

Military objective

The Poseidon was first discussed primarily as a retaliatory second-strike weapon to destroy and/or contaminate U.S. coastal cities and infrastructure without being intercepted. However, in Putin's address, aircraft carrier groups were added as Poseidon targets. Some reporting suggests that the Poseidon has a sonar in its nose for the carrier-group scenario. The declared military objectives are not unique among Russian systems, including the newly announced Kinzhal (for targeting aircraft carrier groups) and Avangard (for targeting infrastructure and coastal cities). Thus, it is possible that Russian intends the primary purpose of Poseidon to be to target and hold at risk coastal cities, while Avangard would strike the interior of the United States, particularly the U.S. ICBM fields.

Burevestnik Nuclear-Powered Cruise Missile

Of the systems announced in March 2018, the one that was the most surprising and considered the furthest from deployment was the 9M730 Burevestnik ("Announcer of the Storm" in English) subsonic nuclear-powered cruise missile, called the SSC-X-9 Skyfall by NATO. Putin chose to discuss this system immediately after the most well-known system, the Sarmat ICBM, near the beginning of his rollout of new weapons. Regarding Burevestnik, Putin said, "It is a low-flying stealth missile carrying a nuclear warhead, with almost unlimited range, unpredictable trajectory and ability to bypass interception boundaries." He went on to claim, "In late 2017, Russia successfully launched its latest nuclear-powered missile at the central training ground. During its flight the nuclear-powered engine reached its design capacity and provided the necessary propulsion. Now that the missile launches and ground tests were successful, we can begin developing a completely new type of weapon, a strategic nuclear system with a nuclear-powered missile." In the video that accompanied his announcement, a missile was seen launching into the sky, and computer-generated graphics showed it maneuvering at a low altitude through mountainous terrain, weaving

Burevestnik Cruise Missile

Source: Ministry of Defense, Russia

through missile defenses in the Atlantic, and then flying around South America to the U.S. West Coast.[177]

Technical characteristics

The Burevestnik is based on a concept that has been explored since early in the atomic age: a nuclear-powered propulsion system that could allow a missile or aircraft to travel great distances due to the high power-to-weight ratio of nuclear fuel compared to other fuels. No such nuclear-power propulsion system has been successfully deployed by any nation to date, although many have been conceived and some tested.[178]

In the case of the Burevestnik missile, the concept is to use a miniature nuclear power plant carried in the missile to heat air in a ramjet engine and provide propulsion during flight. The Burevestnik range is often described as "unlimited," but most press reports say the missile could stay aloft for a day or two. Since it is anticipated to be a subsonic cruise missile, this range could be 23,000 km (15,000 mi) or more. In operation, the Burevestnik would carry a nuclear warhead (or warheads); circle the globe at low altitude, avoid missile defenses, and dodge terrain; and drop the warhead(s) at a difficult-to-predict location (or locations). For reasons that seem more political than technical, Putin sometimes refers to this weapon as an unlimited-range Tomahawk.

The Burevestnik concept is often compared to Project Pluto, an idea pursued by the United States in the late 1950s and early 1960s. Project Pluto was led by what is now Lawrence Livermore National Laboratory and had an eventual goal to prototype a nuclear-powered ramjet engine for a supersonic low-altitude missile (SLAM). Conceptually, a SLAM missile would be launched with a rocket booster and then fly on nuclear power for months at speeds of Mach 3 to Mach 5, carrying multiple nuclear warheads that could be released over the Soviet Bloc at any time.[179] The SLAM would continue flying to conduct damage assessment. This comparison is flawed, however, because the Burevestnik aims to be a subsonic, not a supersonic, missile, and the length of time in flight is envisioned to be days, not months. However, the similarities cannot be missed: they are both nuclear-powered, nuclear-tipped cruise missile concepts that reportedly would use terrain mapping for very long flight routes and ramjet engines for propulsion. But there are other differences, as well. In Project Pluto, the reactor was unshielded and the release of gamma radiation was considered an added benefit. Today, much more is known about radiation effects, making it unlikely that Russia intends to spew radioactivity in the atmosphere around the globe as Pluto would have done. The eventual cancellation of the highly provocative Project Pluto should not be used to dismiss Burevestnik. Nuclear reactor fuels and concepts have advanced, and it is more plausible that a high-energy-density, closed-cycle, small-volume nuclear reactor could be used to power a cruise missile. Nonetheless, the deployment of a nuclear-powered cruise missile poses safety risks, including the dispersion of radiation if it were to be intercepted.

In principle, even without interception, nuclear-powered missiles pose two significant risks if something goes wrong: the possibility of a fissure occurring in flight, and that of the reactor's losing its isolation. Clearly the Russians are considering these risks; during the test flights the cruise missile was accompanied by two cargo planes (Il-76) put up by Rosatom and converted into laboratories equipped with material to detect radiation and equipment to track the trajectory of the missile.[180] Additionally, the cruise missile needs to "land" in a manner to avoid radioactive contamination.

Despite the potential dangers, the development of the Burevestnik is reported to have begun in 2011,[181] with tests beginning by June 2016. There is a consensus in the press, with purported agreement from U.S. intelligence services, that the Burevestnik has been tested 13 times, with two partial successes.[182] It is believed that a test in September 2017 resulted in a cloud of Ru-106 radioactivity with a source between the Urals and the Volga River.[183] The partially successful test conducted in November 2017, and referred to by Putin in his 2018 address, consisted of a launch from a mobile platform in Novaya Zemlya followed by about two minutes of flight and then a descent into the Barents Sea.[184] A recovery effort consisting of three Russian boats, including one with the equipment to handle the recovered nuclear reactor, was seen in the area of the suspected crash. British and U.S. efforts to recover pieces of Burevestnik are also suspected.[185] A nuclear reactor test that ended by crashing into the sea could have been by design; a sea crash is generally safer and less noticeable by the international community than a land crash if the nuclear reactor is damaged and emits radiation. The latest, and second partially successful, test was conducted on January 29, 2019, at the Kapustin Yar test range.[186] This test focused on testing the engine, some say without the reactor. Videos of the Burevestnik being built were released in February 2019, just after Putin's national address.

For flight testing, the Burevestnik is launched from a ramp with a solid-fueled rocket. Its motor starts propelling during flight. In theory, the nuclear motor is simple: it does not include any moving parts and does not need massive reserves of fuels. The air penetrates the inlet of the cruise missile, reaches the nuclear reactor, and is heated to a temperature of about 1400°C to 1600°C. The air is then released to propel the vehicle.[187] The power rating of the nuclear reactor for Burevestnik is unknown, but for comparison the Tomahawk needs about 800 kW of power.[188] Modern nuclear reactors from 1 MW to 20 MW thermal, called microreactors, can be made quite small. The U.S. Department of Energy has a microreactor program exploring gas-, liquid-metal-, molten-salt-, and heat-piped-cooled concepts that could be transported by truck or commercial aircraft.[189]

There is some limited speculation that the Burevestnik could also be carried and released from a MiG-31 BM, and images of what could be the Burevestnik on a MiG-31BM have been published.[190]

No information about the yield or number of nuclear missiles a Burevestnik would carry has appeared in the open sources.

Deployment schedule

The first reporting of Burevestnik deployment, in September 2019, suggested it would be ready to deploy in 2025.[191] Given the history of nuclear propulsion, deployment of an actual system within a decade seems highly unlikely.

Military objective

The military objective of the Burevestnik is to evade missile defense, follow untraditional flight paths, and be able to strike any target with little warning. Russian military expert Alexei Leonkov called the Burevestnik a weapon of retaliation, which Russia would use after ICBMs to finish the rout of all the military and civilian infrastructure and not leave a chance of survival.[192]

CONCLUSION

The large number and new types of nuclear-weapon delivery systems represent significant efforts by Russia's military designers and its industrial complex. One of the new hypersonic systems, the Kinzhal, is in trial deployment, at least as a conventionally tipped aeroballistic missile. Although advances are being made in replacing an older multiple-warhead ICBM with a more modern and capable version, the system is not yet fully tested, and deployment is behind schedule. The development of a nuclear-capable strategic-range hypersonic boost-glide vehicle and a potentially nuclear-tipped hypersonic cruise missile remains active but not mature, with the deployment dates likely after the early and mid-2020s, respectively. Russia's efforts to create nuclear-powered torpedoes and cruise missiles, entirely new kinds of strategic nuclear-weapon delivery concepts, are further behind, and their ultimate success remains uncertain. The primary military parameters and the technological challenges for the six systems are summarized in an abbreviated form on the following page.

The projections collected from official Russian government statements and open-source reporting for this summary document have been found to be generally optimistic and ambitious. Most announced test dates and deployment dates have not been met, for reasons including, for example, a shortage of critical carbon-fiber material, a fire at the ICBM production factory, and a fatal explosion during testing involving a nuclear reactor. The number of issues being experienced in the development and deployment of these new systems may indicate an overzealousness by Russia to show progress now that the systems have been openly publicized. The announced deployment dates are therefore seen as the earliest possible dates; more realistic dates are likely farther in the future.

The risks and rationale for pursuing such systems, as well as the implications of new technologies as hypersonics, should be a priority agenda item for the United States and Russia in their discussions of strategic stability and nuclear-risk reduction.

Summary of the Primary Military Parameters and Technological Challenges of Russia's New Nuclear Weapon Systems

System – Russian Common Name (NATO common designation)	Type	Reported Maximum Speed in Testing	Reported Maximum Range	Reported Warhead Type(s)	Reported Nuclear Yield	Technological Significance and Challenges	Estimated Deployment Date
RS-28 Sarmat (SS-30 Satan 2)	Liquid-fueled, multiple warhead ICBM to replace Voevoda (SS-18 Satan)	Over Mach 20	16,000 km	Nuclear, with different types of warheads and decoys including the Avangard	Total 8 Mt, likely carrying 10–16 warheads, but reports range from 3–24 warheads	Short-boost-phase, high-thrust engine, composite material body enabling more range and throw weight	2022–2027
Kinzhal	Hypersonic aeroballistic, modified Iskander-M ground-launched missile	Mach 5–10	2000 km (including one-way aircraft flight distance)	Conventional or nuclear	10–50 kt	Modified intermediate-range missile delivered to upper atmosphere by MiG-31K interceptor jet	Trial deployment in 2019 and continuing. 10 or more modified jets, each capable of carrying one missile.
Avangard	Hypersonic boost-glide system	Over Mach 20	6000 km	Conventional or nuclear	150 kt most likely but reports up to 2 Mt	New composite material to withstand high temperatures for tens of minutes	Likely after 2022 but probably within 5 years. More testing anticipated before nuclear deployment.
Tsirkon	Hypersonic cruise	Mach 5–6	500 km	Conventional	No nuclear capability announced but speculation it may come later	High-temperature metal alloy, new high-energy fuel, scramjet flight for about 5 minutes	2025–2030 or later
Poseidon (Kanyon)	Nuclear-powered torpedo	100–200 kph	10,000 km	Nuclear	Most likely 2 Mt (some say up to 100 Mt)	Small nuclear-power plant for propulsion	After 2027
Burevestnik (Skyfall)	Nuclear-powered cruise missile	Subsonic	Over 25,000 km	Nuclear	Unknown	Small nuclear-power plant coupled to ramjet engine	After 2030 (if ever)

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Jill Hruby was named the inaugural Sam Nunn Distinguished Fellow in November 2018. She served as the director of Sandia National Laboratories from July 2015 to May 2017. Sandia is a Department of Energy/National Nuclear Security Administration national laboratory with diverse national security missions that include nuclear weapons, cyberspace, energy, non-proliferation, biological defense, and space.

During her 34 years at Sandia, she served as vice president of the Energy, Nonproliferation, and High-Consequence Security Division; leader of Sandia's International, Homeland, and Nuclear Security Program; and technical director in Materials and Engineering Sciences and in Homeland Security and Defense Systems. She also held several leadership positions in materials science, weapon components, and micro-technologies.

Hruby has authored numerous publications and holds three patents. Her awards include an R&D 100 Award, the Suzanne Jenniches Upward Mobility Award from the Society of Women Engineers, the US Department of Energy Secretary's Exceptional Service Award, the National Nuclear Security Administrator's Distinguished Service Gold Award, and the Office of the Secretary of Defense Medal for Exceptional Public Service. In 2017, *Business Insider* named Hruby the second most powerful female engineer.

Currently, Hruby is an advisor and board member on science and national security issues, a spokesperson for women in engineering, and a mentor for emerging leaders. She participates in engineering advisory councils for Purdue University and University of California at Berkeley.

Hruby holds a bachelor's degree from Purdue University and a master's degree from the University of California at Berkeley, both in mechanical engineering.

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4 It is unclear why this order was chosen; it does not appear to be associated with maturity, deployment schedule, or any other obvious measure.

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